QUADRUPOLE SHUNTING

Measurements taken during ATF2 Beam Tuning Time 21th May 2010 and 2nd June 2010.

Acknowledgments: ATF & ATF2 for giving me the possibility to carry on this study.

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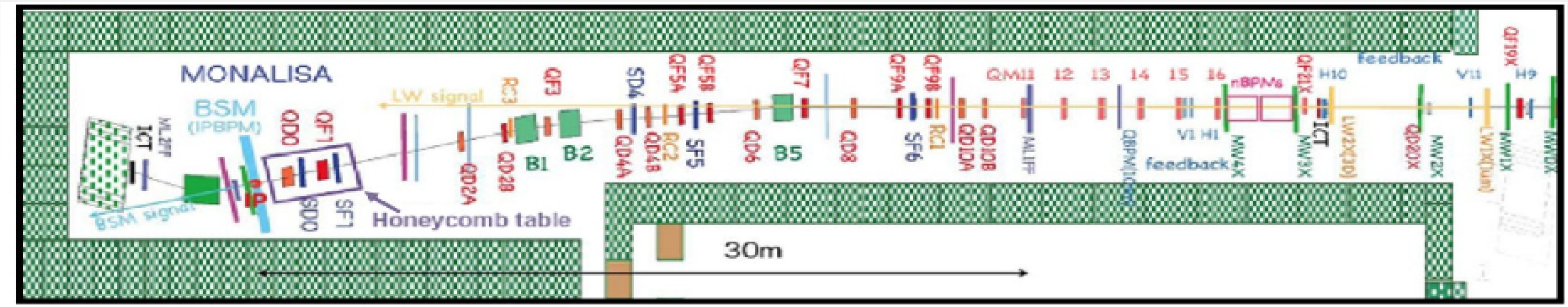
PLAN OF THE TALK

- Motivation
- Formulation
- Measurement description
- Measurements
- Analysis
- Results
- Conclusions and Future Plans

MOTIVATION

Improve the quadrupole alignment by a beam based alignment technique.



- The BPMs in the matching section of the ATF2 beamline have a resolution in the order of 20nm, they are a good candidates to carry on the study.

A BIT OF FORMULATION (I)

- General formalism:

$$M_x = \begin{bmatrix} \cosh\phi & \frac{1}{\sqrt{|k|}}\sinh\phi & 0 \\ \sqrt{|k|}\sinh\phi & \cosh\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad M_y = \begin{bmatrix} \cos\phi & \frac{1}{\sqrt{|k|}}\sin\phi & 0 \\ -\sqrt{|k|}\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad where \quad \phi = l\sqrt{|k|}$$

- Thin lens approximation:

$$M_x = \begin{bmatrix} 1 & 0 & 0 \\ |k|l & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad M_y = \begin{bmatrix} 1 & 0 & 0 \\ -|k|l & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

- II order approximation

$$M_x = \begin{bmatrix} 1+\frac{l^2|k|}{2} & l+\frac{l^3|k|}{6} & 0 \\ l|k|+\frac{l^3k^2}{6} & 1+\frac{l^2|k|}{2} & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad M_y = \begin{bmatrix} 1+\frac{l^2|k|}{2} & l-\frac{l^3|k|}{6} & 0 \\ -l|k|+\frac{l^3k^2}{6} & 1+\frac{l^2|k|}{2} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

A BIT OF FORMULATION (II)

- Since:

$$\begin{pmatrix} y_1 \\ y_1' \end{pmatrix} = M_y \begin{pmatrix} y_0 \\ y_0' \end{pmatrix} \qquad \begin{matrix} y_1 = (1 + \frac{l^2|k|}{2})\, y_0 + (l - \frac{l^3|k|}{6})\, y_0' \\ y_1' = (-l|k| + \frac{l^3 k^2}{6})\, y_0 + (1 + \frac{l^2|k|}{2})\, y_0' \end{matrix} \qquad \begin{matrix} \Delta y_1 = \frac{l^2|k|}{2} \Delta y_0 - \frac{l^3|k|}{6} \Delta y_0' \\ \Delta y_1' = (-l|k| + \frac{l^3 k^2}{6}) \Delta y_0 + \frac{l^2|k|}{2} \Delta y_0' \end{matrix}$$

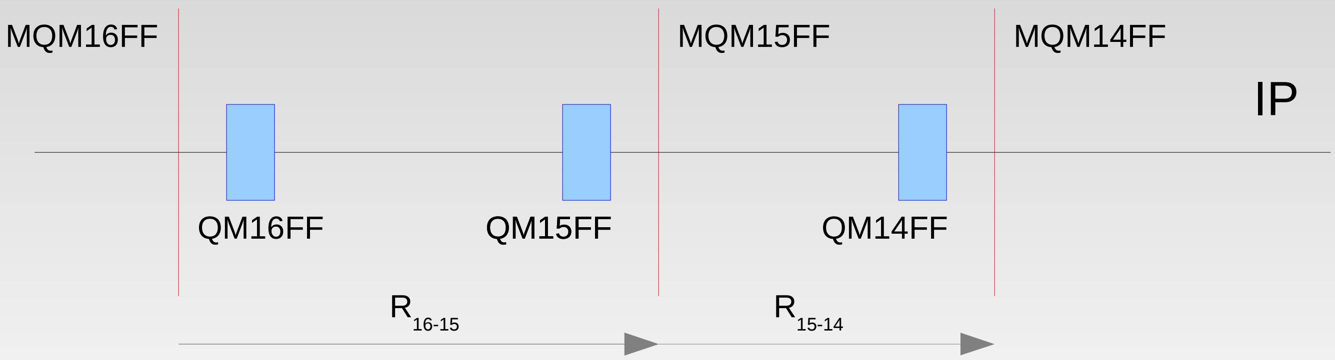
- Assuming a magnetic center movement proportional to the magnet strength (y_m ~ c'k):

$$\Delta y_1' = (-l|k| + \frac{l^3 k^2}{6})(\Delta y_0 + c' k) + \frac{l^2|k|}{2} \Delta y_0' \rightarrow \begin{pmatrix} \Delta y_1'(O^1) \approx l|k| \Delta y_0 + \frac{l^2|k|}{2} \Delta y_0' \\ \Delta y_1'(O^2) \approx \frac{l^3 k^2}{6} \Delta y_0 + c' l k^2 \end{pmatrix}$$

- The II order :

$$\Delta y_1'(O^2) \approx \frac{l^3 k^2}{6} \Delta y_0 + c' l k^2 = (kl)^2 [\frac{l}{6} \Delta y_0 + \frac{c'}{l}]$$

MEASUREMENT DESCRIPTION (I)



- QM16FF sets the orbit at QM15FF, at each orbit QM15FF is scanned. The beam position is recorded in all BPMs.
- QM15FF is displaced vertically by the mover, at each position QM15FF is scanned. The beam position is recorded in all BPMs.
- In order to avoid different hysteresis curves, the scan of all the magnets is conducted in a cycling way, by steps of dk:

KLQM16 – dk : KLQM15 – 2dk	KLQM16 : KLQM15 – 2dk	KLQM16 + dk : KLQM15 – 2dk
KLQM16 – dk : KLQM15 – dk	KLQM16 : KLQM15 – dk	KLQM16 + dk : KLQM15 – dk
KLQM16 – dk : KLQM15	KLQM16 : KLQM15	KLQM16 + dk : KLQM15
KLQM16 – dk : KLQM15 + dk	KLQM16 : KLQM15 + dk	KLQM16 + dk : KLQM15 + dk
KLQM16 – dk : KLQM15 + 2dk	KLQM16 : KLQM15 + 2dk	KLQM16 + dk : KLQM15 + 2dk

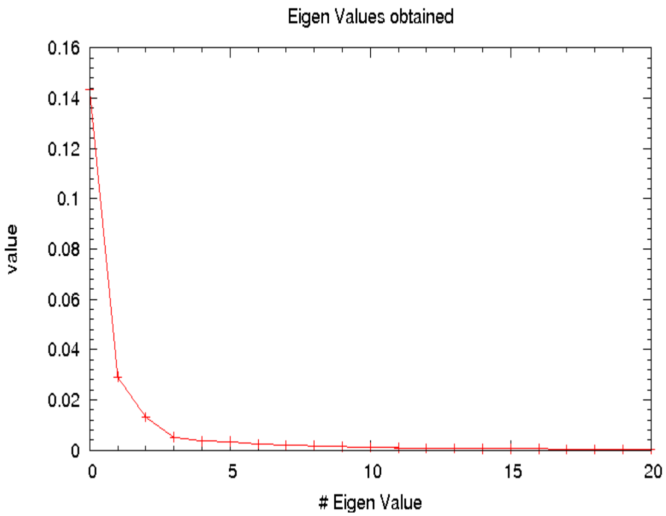
THE MEASUREMENTS

- Two sets of measurements were taken:
  - 1st SET:
    - The magnet strengths of QM16FF and QM15FF were varied within 17% in 5 steps.
    - QM15FF was displaced vertically and scanned within 17% in 5 steps.
    - QM14FF was displaced vertically and scanned within 17% in 5 steps.
  - 2nd SET:
    - The magnet strengths of (QM16FF, QM15FF), (QM14FF,QM13FF), (QM13FF,QM12FF) were varied within 27% in 3 steps. at each configuration 200 bpm readings were recorded.
- A carefully SVD analysis is applied to the data

  from the n-bpms at m-readings, in order to subtract

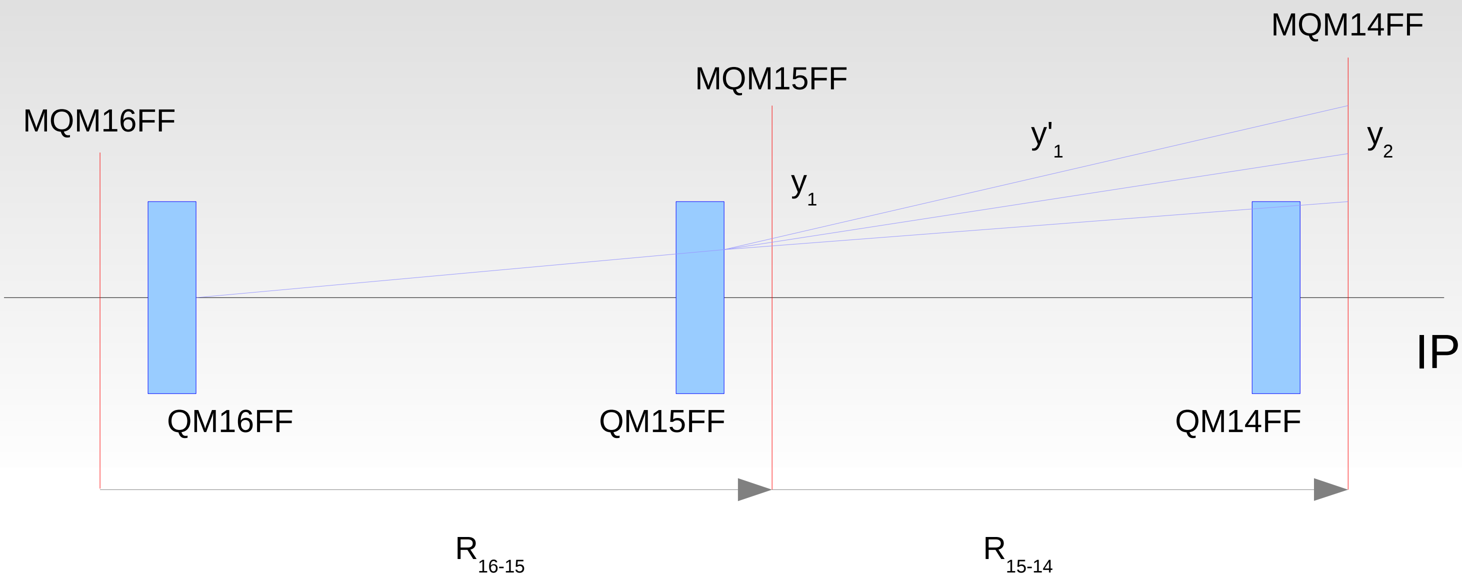
  the noise.

$$D = \begin{pmatrix} bpm_1(0) & \dots & bpm_n(0) \\ \dots & \dots & \dots \\ bpm_1(m) & \dots & bpm_n(m) \end{pmatrix}$$



ANALYSIS DESCRIPTION

- What can be measured ? **Beam position at the BPMs**



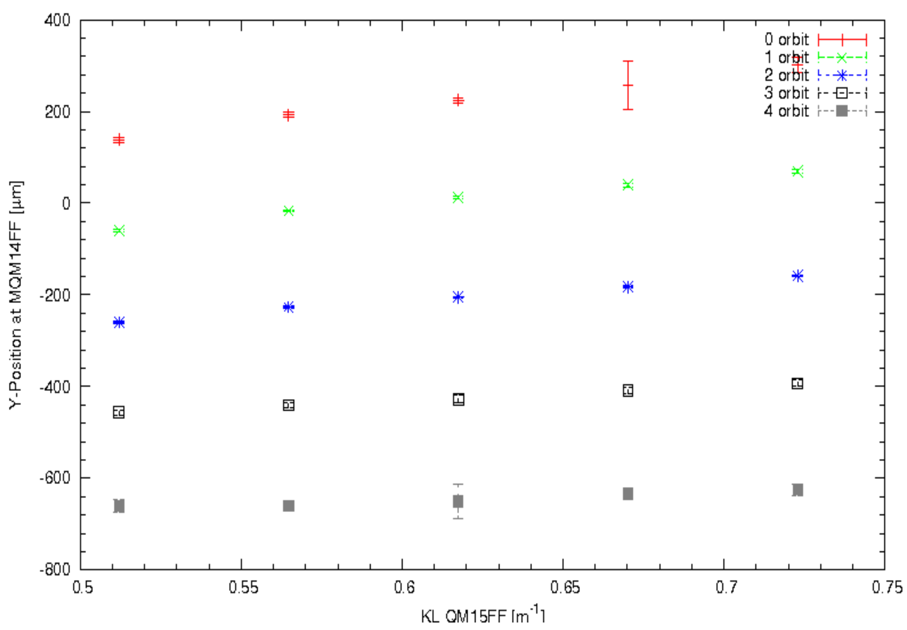
$$\Delta y_1'(O^2) \approx \frac{l^3 k^2}{6} \Delta y_0 + c' l k^2 = (kl)^2 \left[\frac{l}{6} \Delta y_0 + \frac{c'}{l} \right]$$

$$\begin{pmatrix} y_2 \\ y_2' \end{pmatrix} = R \begin{pmatrix} y_1 \\ y_1' \end{pmatrix} \rightarrow \begin{matrix} y_2 = R_{33} y_1 + R_{34} y_1' \\ y_2' = R_{43} y_1 + R_{44} y_1' \end{matrix} \qquad y_1' = \frac{y_2 - R_{33} y_1}{R_{34}} \quad \rightarrow \quad \Delta y_1' = \frac{\Delta y_2 - R_{33} \Delta y_1}{R_{34}}$$

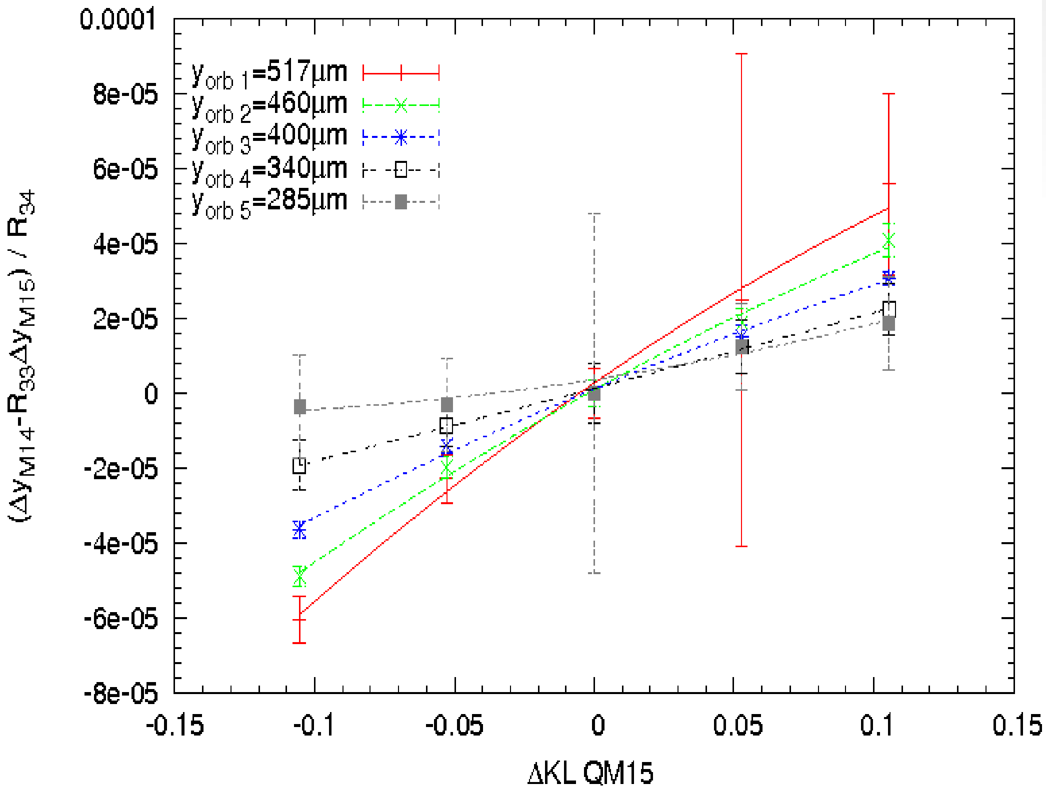
Since the BPM are not aligned, the angle is inferred from differences

R_{33} = 0.8717 , R_{34} = 1.3261 m (between MQM15FF and MQM14FF evaluated by MADX)

THE ANALYSIS (I)



$$\Delta y_1' = \frac{\Delta y_2 - R_{33}\Delta y_1}{R_{34}}$$

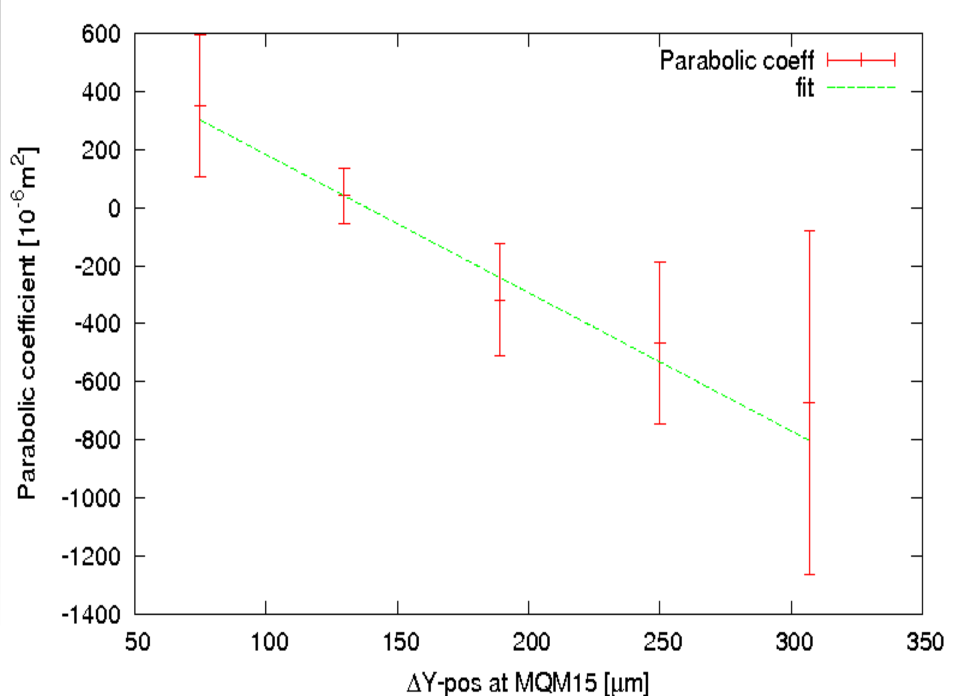


$$\Delta y_1'(O^2) = (kl)^2\left[\frac{l}{6}\Delta y_0 + \frac{c'}{l}\right] = (kl)^2\hat{C}$$

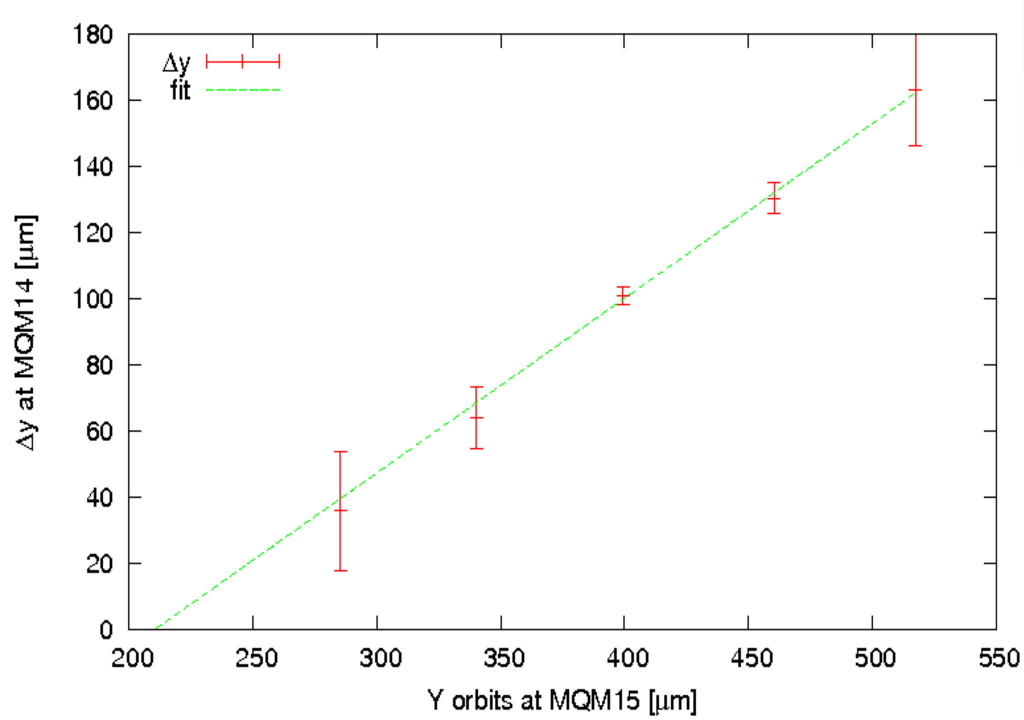
- The obtained parabolic coefficients are:

$\hat{C}$ = -6.7 10^{-4} ± 6 10^{-4} m^2
$\hat{C}$ = -4.6 10^{-4} ± 3 10^{-4} m^2
$\hat{C}$ = -3.2 10^{-4} ± 2 10^{-4} m^2
$\hat{C}$ = 4.2 10^{-5} ± 1 10^{-4} m^2
$\hat{C}$ = 3.5 10^{-4} ± 2 10^{-4} m^2

THE RESULTS (I)



- From the different increments at each orbit the offset of the magnet can be inferred: $x_0 = 210 \pm 20\ \mu m$



- Fitting the obtained coefficients to:

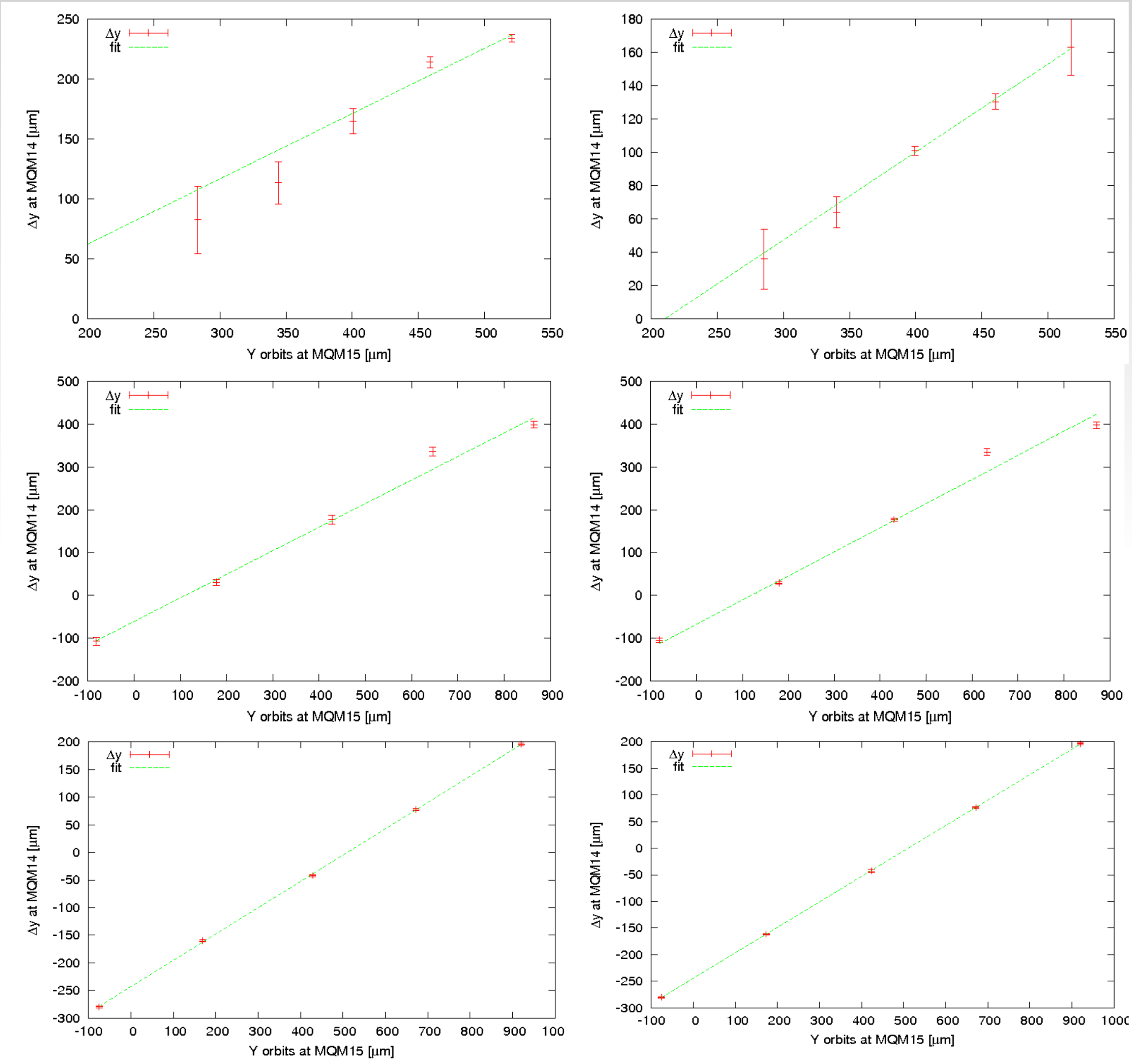
$$\hat{C} = [\frac{l}{6}\Delta y_0 + \frac{c'}{l}] \rightarrow c' = \frac{-l^2}{6}\Delta y_0 (\hat{C} = 0)$$

linear coefficient: -4.8 ± 0.5 m **≠ 0.03 = l/6**

independent coefficient: $6.6\ 10^{-4} \pm 0.8\ m^2$

$c' = 9.7 \pm 0.9\ 10^{-7}\ m^3$

RESULTS OF THE 1st SET OF MEASUREMENTS (II)



- Scanning QM16, QM15

  (100 bpm readings)

- Scanning and moving QM15

  (10 bpm readings)

- Scanning and moving QM14

  (10 bpm readings)

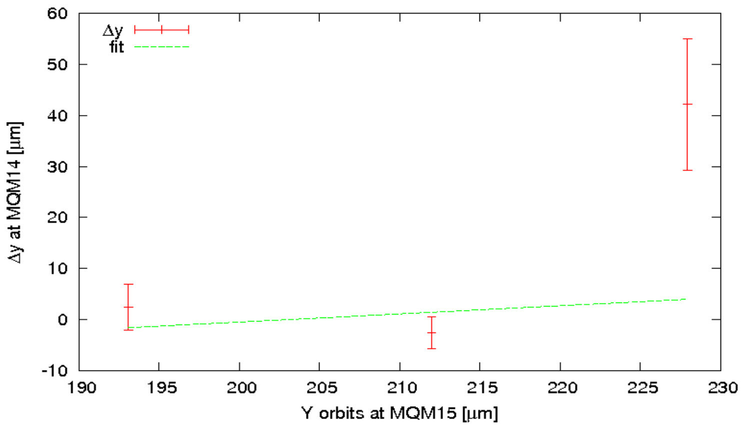
RESULTS OF THE 1st SET OF MEASUREMENTS (III)

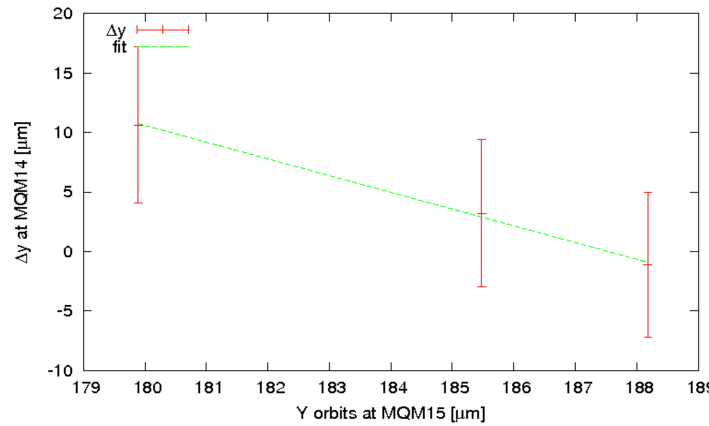
- The results from the first set of measurements are summarized in the following table:

MAGNETS	MEASUREMENT	x_0 [µm]	δx_0 [µm]	c' [m^3]	δc' [m^3]
QM16, QM15	2nd no SVD	85	89	$1.6\ 10^{-6}$	$5.1\ 10^{-7}$
QM16, QM15 *	2nd 6 eigen values	210	20	$9.2\ 10^{-7}$	$9.4\ 10^{-8}$
QM15	3rd no SVD	111	30	$1.4\ 10^{-6}$	$4.4\ 10^{-7}$
QM15	3rd 8 eigen values	120	22	$1.06\ 10^{-6}$	$2.3\ 10^{-7}$
QM14	4th no SVD	510	1	$-1.04\ 10^{-5}$	$7.8\ 10^{-6}$
QM14	4th 8 eigen values	510	3	$-4.3\ 10^{-7}$	$1.9\ 10^{-7}$

* the results corresponding to QM16, QM15 with SVD (6 eigen values) are the ones presented in the previous slides

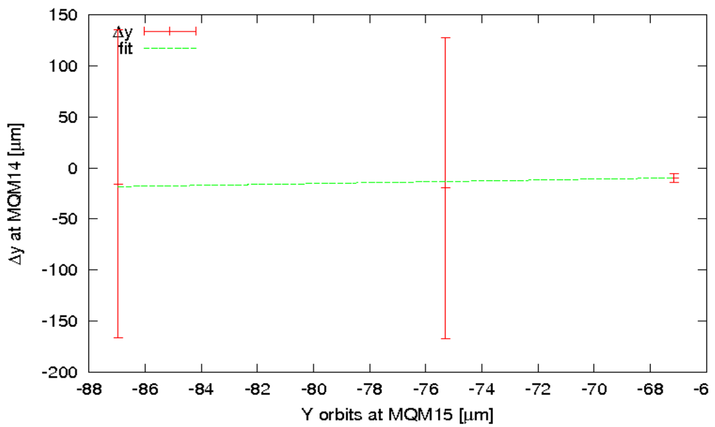
RESULTS OF THE 2nd SET OF MEASUREMENTS (IV)

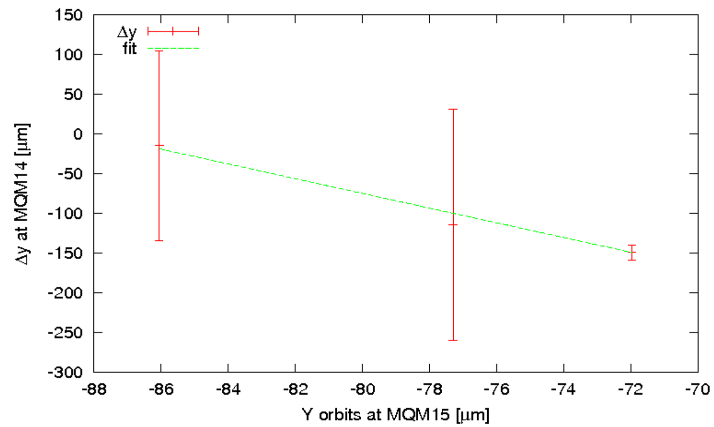




- Scanning QM16, QM15

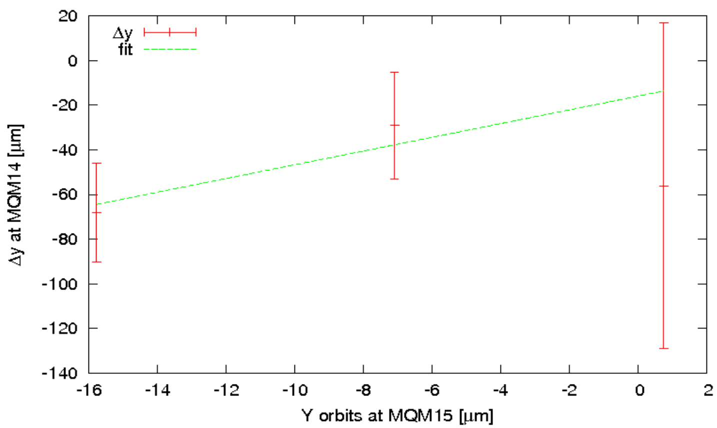
  (200 bpm readings)

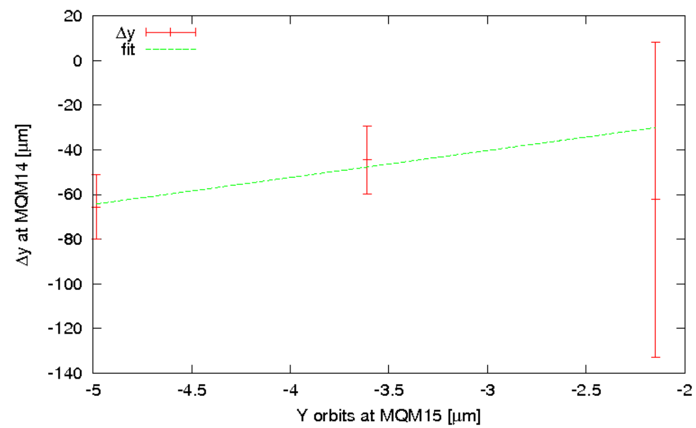




- Scanning QM14, QM13

  (200 bpm readings)





- Scanning QM13, QM12

  (200 bpm readings)

RESULTS OF THE 2^{nd} SET OF MEASUREMENTS (V)

- The results from the second set of measurements are summarized in the following table:

MAGNETS	MEASUREMENT	x_0 [µm]	δx_0 [µm]	c' [m^3]	δc' [m^3]
QM16, QM15	1^{st} no SVD	203	1141	$6.3\ 10^{-10}$	$3.3\ 10^{-10}$
QM16, QM15	1^{st} 6 eigen values	187.5	9.1	$2.7\ 10^{-8}$	$5.5\ 10^{-8}$
QM14, QM13	2^{nd} no SVD	-45	51	$2.7\ 10^{-5}$	$1.4\ 10^{-3}$
QM14, QM13	2^{nd} 6 eigen values	-88.1	6.7	$2.01\ 10^{-6}$	$1.5\ 10^{-6}$
QM13, QM12	3^{rd} no SVD	5.1	9.0	$-2.1\ 10^{-7}$	$1.6\ 10^{-7}$
QM13, QM12	3^{rd} 6 eigen values	0.3	2.5	$-5.05\ 10^{-8}$	3.410^{-8}

CONCLUSIONS AND FUTURE WORK

- From the results of the first set of measurements:
  - Moving the magnet is a preferable solution rather than changing the orbit.
- From the results of the second set of measurements:
  - Contributions from the y' term seems to be more severe.
- A complete model should be applied in order to reduce the error when determining the magnetic center.
- From the linear fit to obtain the coefficient c', there is an inconsistency when comparing the linear coefficient with the expected l/6. This may suggests :
  - Should incorporate the R-matrice between the quad and the BPM.
  - Should consider a quadratic contribution from the y' term.
  - Should take into account fringe fields.