Off-momentum Optics at SuperKEKB

1. Chromatic phase-advance
2. Chromatic XY coupling

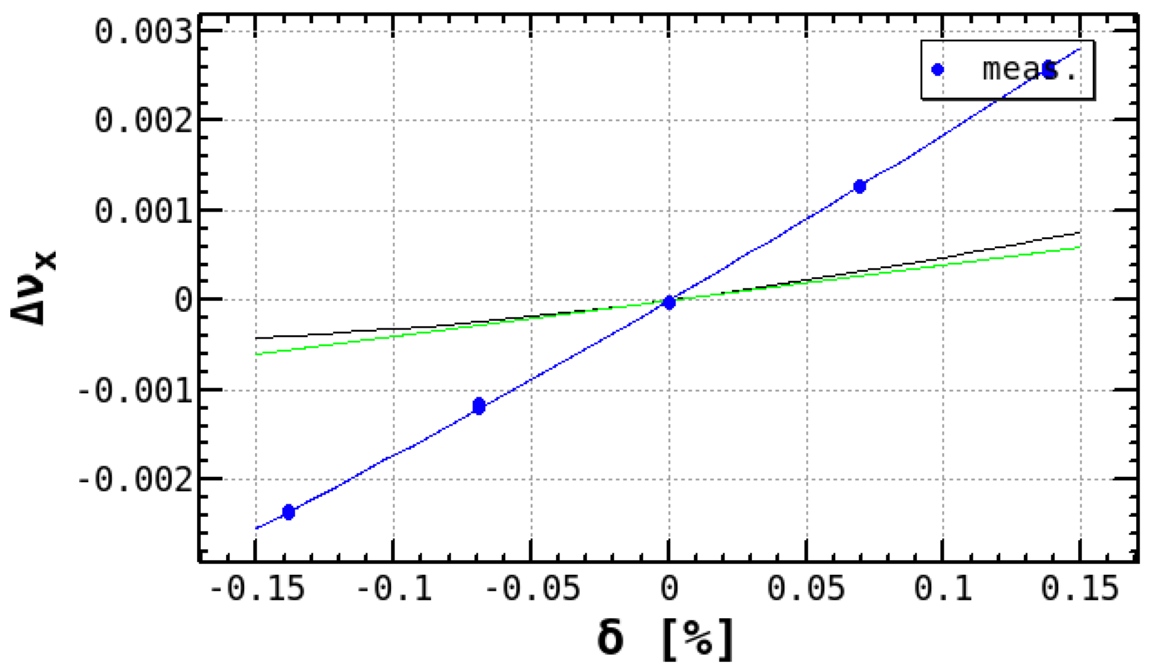
Y. Ohnishi

This work was supported by JSPS KAKENHI Grant Number 17K05475.

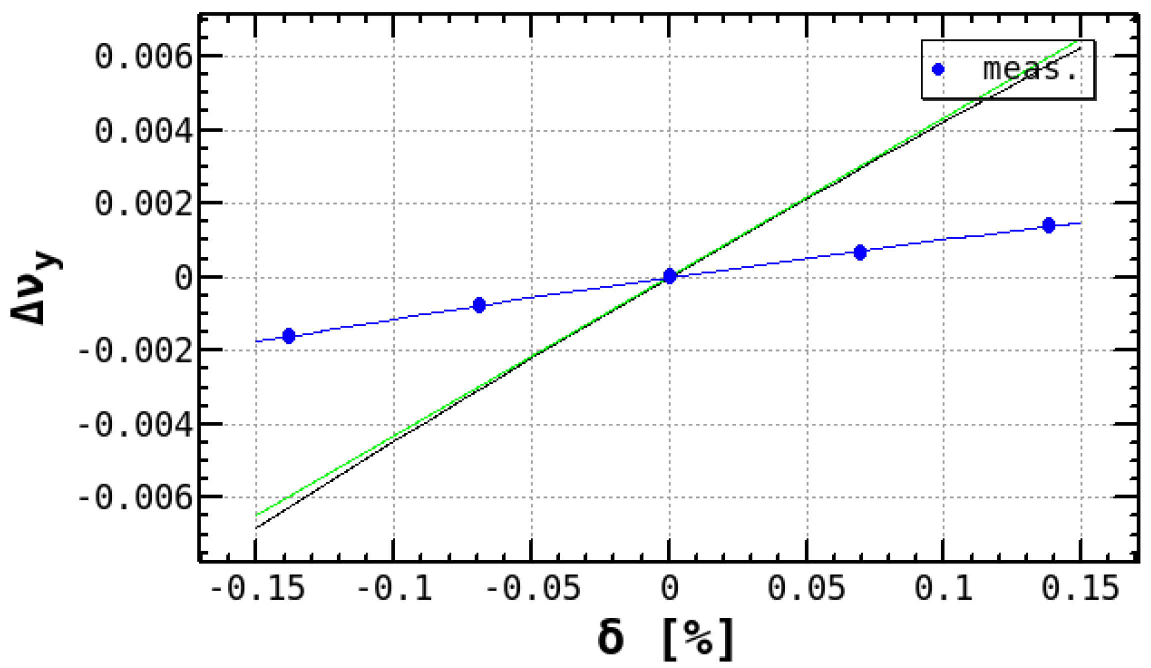
Chromaticity

LER $\beta_x^* = 100\ mm \quad \beta_y^* = 4\ mm$

ξ_x: 1.787(meas)/ 0.401(model)

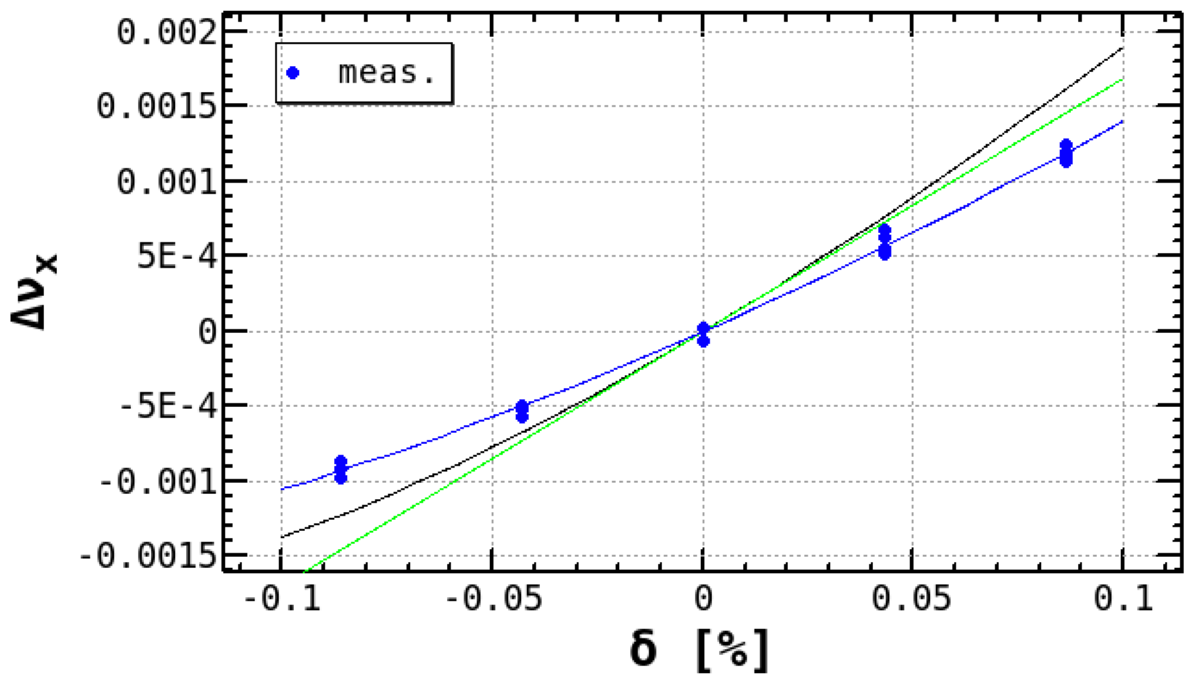


ξ_y: 1.080(meas)/ 4.327(model)

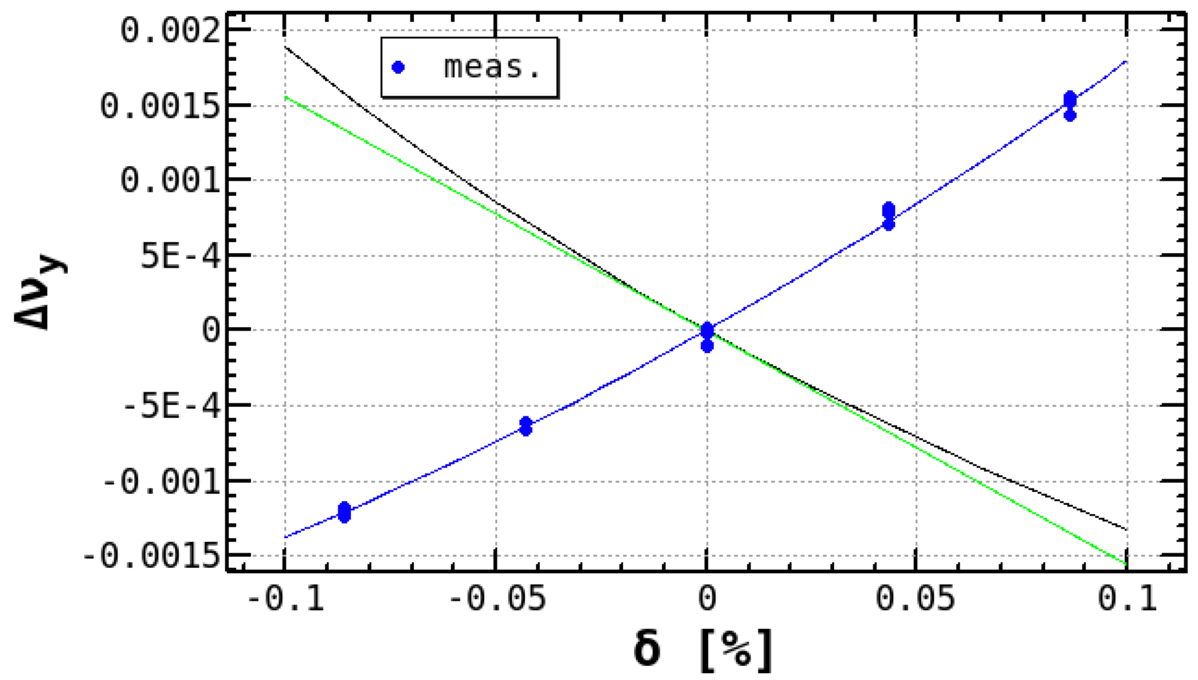


HER $\beta_x^* = 100\ mm \quad \beta_y^* = 4\ mm$

ξ_x: 1.234(meas)/ 1.691(model)



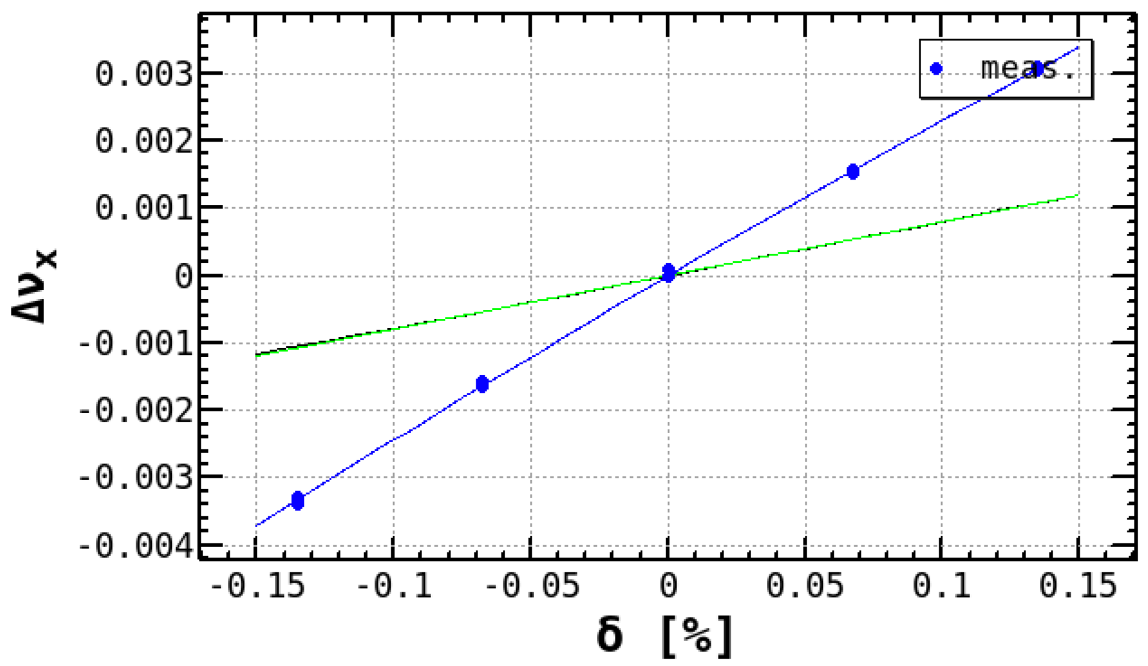
ξ_y: 1.587(meas)/ -1.560(model)



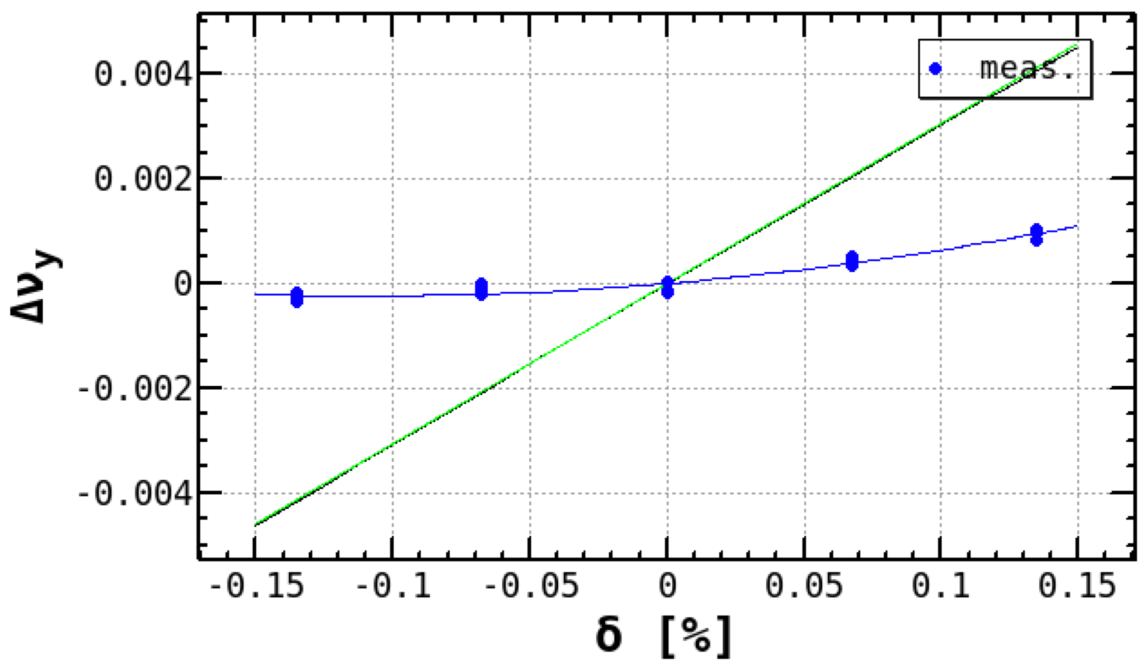
blue: measurement / black(green): model

LER $\beta_x^* = 200\ mm \quad \beta_y^* = 4\ mm$

ξ_x: 2.368(meas)/ 0.793(model)

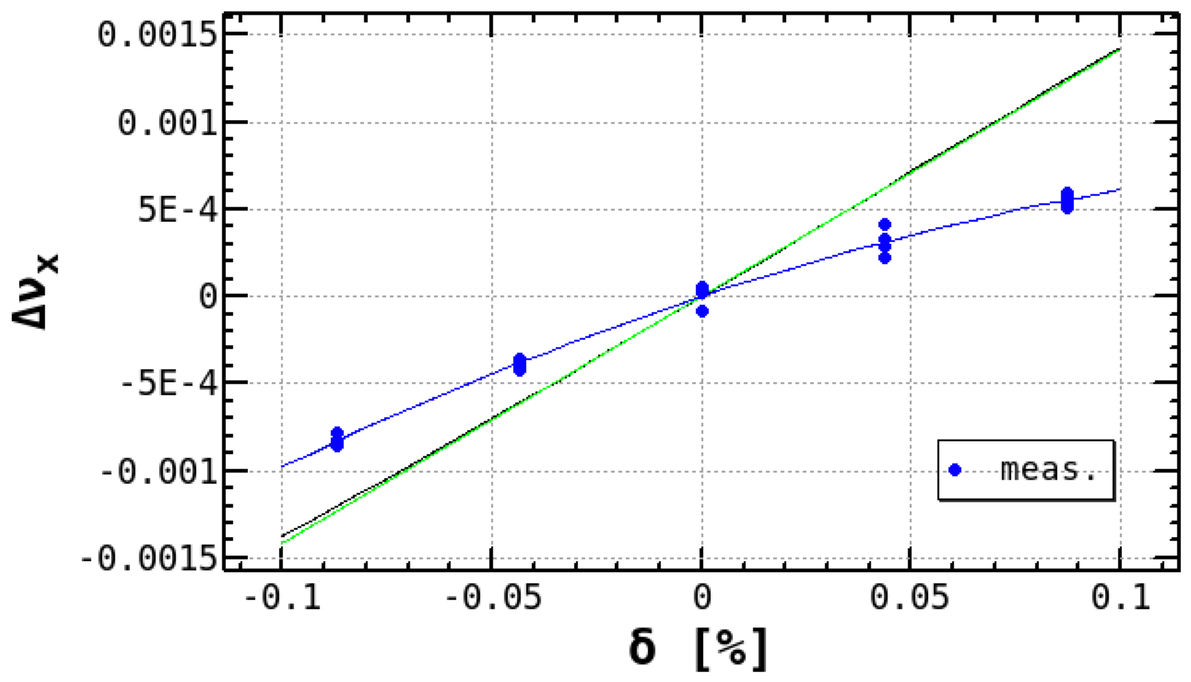


ξ_y: 0.438(meas)/ 3.071(model)

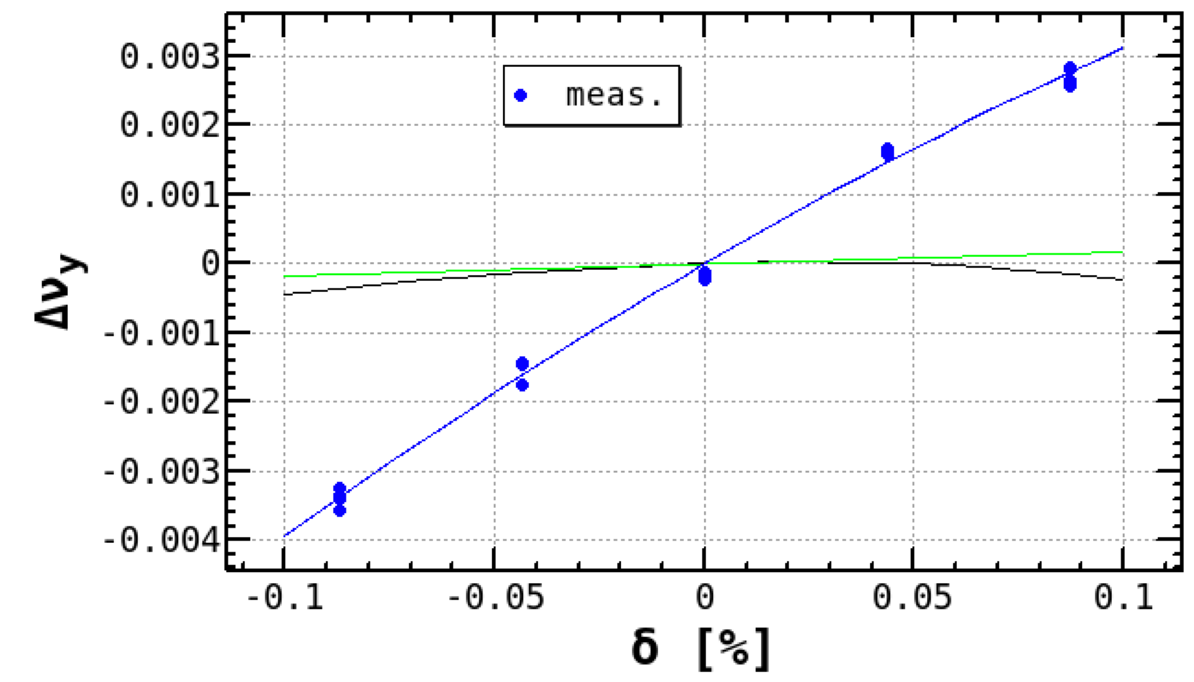


HER $\beta_x^* = 200\ mm \quad \beta_y^* = 2\ mm$

ξ_x: 0.794(meas)/ 1.421(model)



ξ_y: 3.533(meas)/ 0.171(model)



Why there is a discrepancy between model and measurement ?

Why there is a discrepancy between model and measurement ?

Natural chromaticity in Phase 2

LER : ξ_x = -69 / ξ_y = -146
HER : ξ_x = -97 / ξ_y = -168

QC2:ξ_x = -8 / QC1:ξ_y = -67
QC2:ξ_x = -25 / QC1:ξ_y = -100

LER : $\Delta\xi_x$ = 1~1.5 / $\Delta\xi_y$ = 2.5~3.3
HER : $\Delta\xi_x$ = 0.5~0.7 / $\Delta\xi_y$ = 3~3.3

between model and real machine

Why there is a discrepancy between model and measurement ?

Natural chromaticity in Phase 2

LER : ξ_x = -69 / ξ_y = -146
HER : ξ_x = -97 / ξ_y = -168

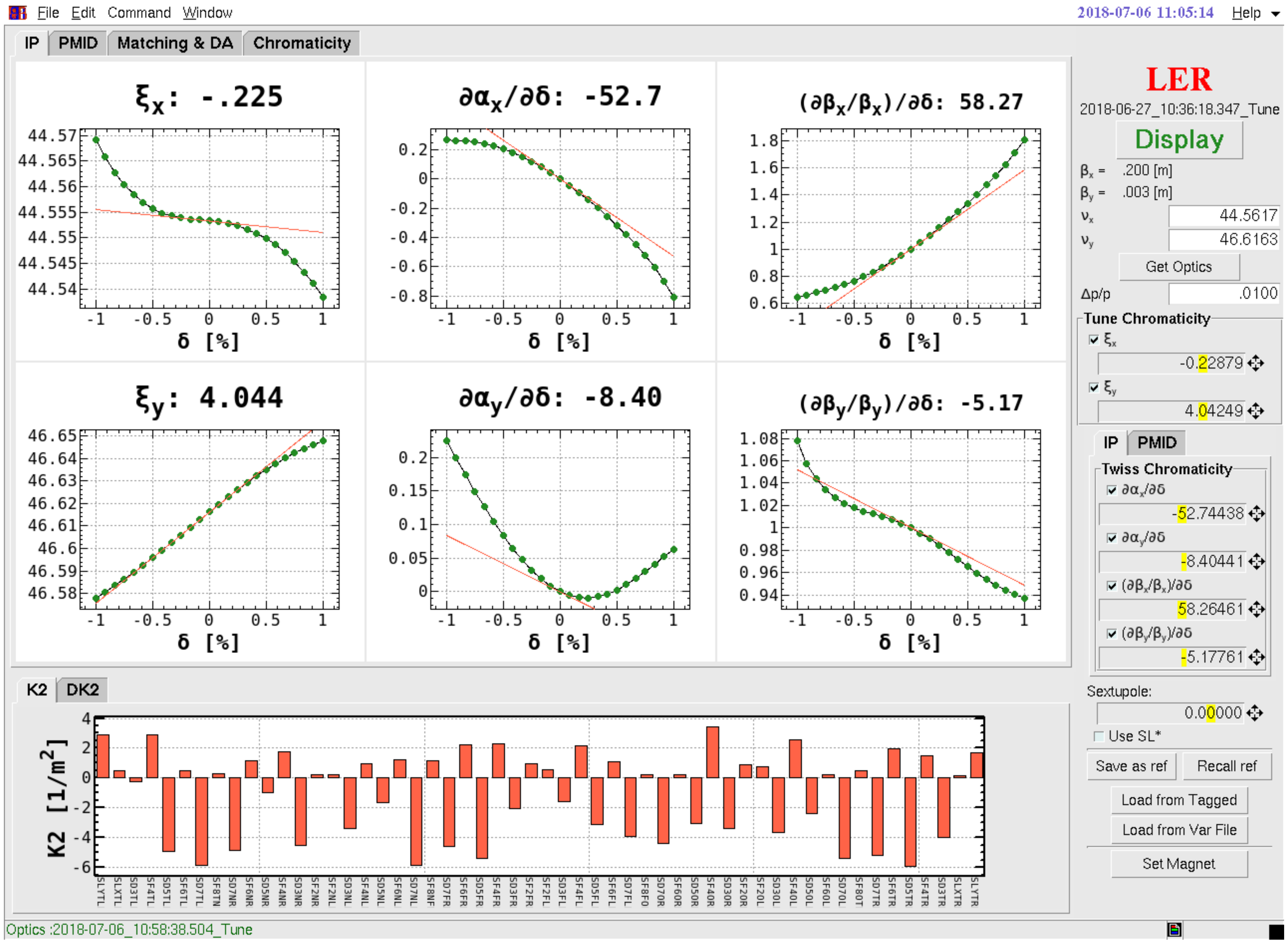
QC2:ξ_x = -8 / QC1:ξ_y = -67
QC2:ξ_x = -25 / QC1:ξ_y = -100

LER : $\Delta\xi_x$ = 1~1.5 / $\Delta\xi_y$ = 2.5~3.3
HER : $\Delta\xi_x$ = 0.5~0.7 / $\Delta\xi_y$ = 3~3.3

between model and real machine

1 ~ 2 % discrepancy is not so large ?

Sextupole Tuning



Control chromaticity and Twiss chromaticity

Relative change is OK.

Measurement of Optical Functions based on COD

$$\Delta x_i^j = \frac{\Delta\theta_j}{2\sin(\pi\nu)}\sqrt{\beta_i}\sqrt{\beta_i}\cos\left(\mid \psi_i - \psi_j \mid -\pi\nu\right) \qquad i = 1 \sim N \quad j = 1 \sim M$$

$$= A_j\left\{C_j\left(C_i\cos\pi\nu + a_{ij}S_i\sin\pi\nu\right) + S_j\left(S_i\cos\pi\nu - a_{ij}C_i\sin\pi\nu\right)\right\}$$

Fitting parameters:

$$\boxed{\begin{aligned} A_j &= \frac{\Delta\theta_j}{2\sin\pi\nu} \\ C_{i,j} &= \sqrt{\beta_{i,j}}\cos\psi_{i,j} \\ S_{i,j} &= \sqrt{\beta_{i,j}}\sin\psi_{i,j} \end{aligned}}$$

$$a_{ij} = sign(\psi_i - \psi_j)$$

$$N \times M > 2(M + N)$$

N = ~450 BPMs, M = 6 steerings

Least-square fitting: $\chi^2 = \sum_{i,j}^{N,M}\left(\Delta x_i^j - \Delta x_{i,meas}^j\right)^2$ **with** $\sum_{i=1}^{N}\frac{1}{\beta_i} = \sum_{i=1}^{N}\frac{1}{\beta_{i,design}}$

Correction of Chromatic Phase-Advance

Definition of chromatic phase-advance:

$$\Delta\psi_{x,i} = \psi_{x,i} - \psi_{x,i-1} \qquad \Delta\psi_{y,i} = \psi_{u,i} - \psi_{y,i-1} \qquad i = 2, 3, 4, \cdots, N$$

N = 440 - 460 (#BPMs)

$$\chi_i(x) = \frac{1}{2\pi}\frac{\partial \Delta\psi_{x,i}}{\partial \delta} \qquad \chi_i(y) = \frac{1}{2\pi}\frac{\partial \Delta\psi_{y,i}}{\partial \delta}$$

$$\xi_x = \frac{\partial \nu_x}{\partial \delta} \qquad \xi_y = \frac{\partial \nu_y}{\partial \delta} \longleftarrow \text{Chromaticity}$$

We solve these equations to obtain ΔK$_2$.

$$\begin{pmatrix} \chi_{1,m}(x) - \chi_{1,d}(x) \\ \chi_{2,m}(x) - \chi_{2,d}(x) \\ \vdots \\ \chi_{N,m}(x) - \chi_{N,d}(x) \\ \chi_{1,m}(y) - \chi_{1,d}(y) \\ \chi_{2,m}(y) - \chi_{2,d}(y) \\ \vdots \\ \chi_{N,m}(y) - \chi_{N,d}(y) \\ \xi_{x,m} - \xi_{x,d} \\ \xi_{y,m} - \xi_{y,d} \end{pmatrix} = M_{resp} \begin{pmatrix} \Delta K_{2,1}/K_{2,1} \\ \Delta K_{2,2}/K_{2,2} \\ \vdots \\ \Delta K_{2,M}/K_{2,M} \end{pmatrix}$$

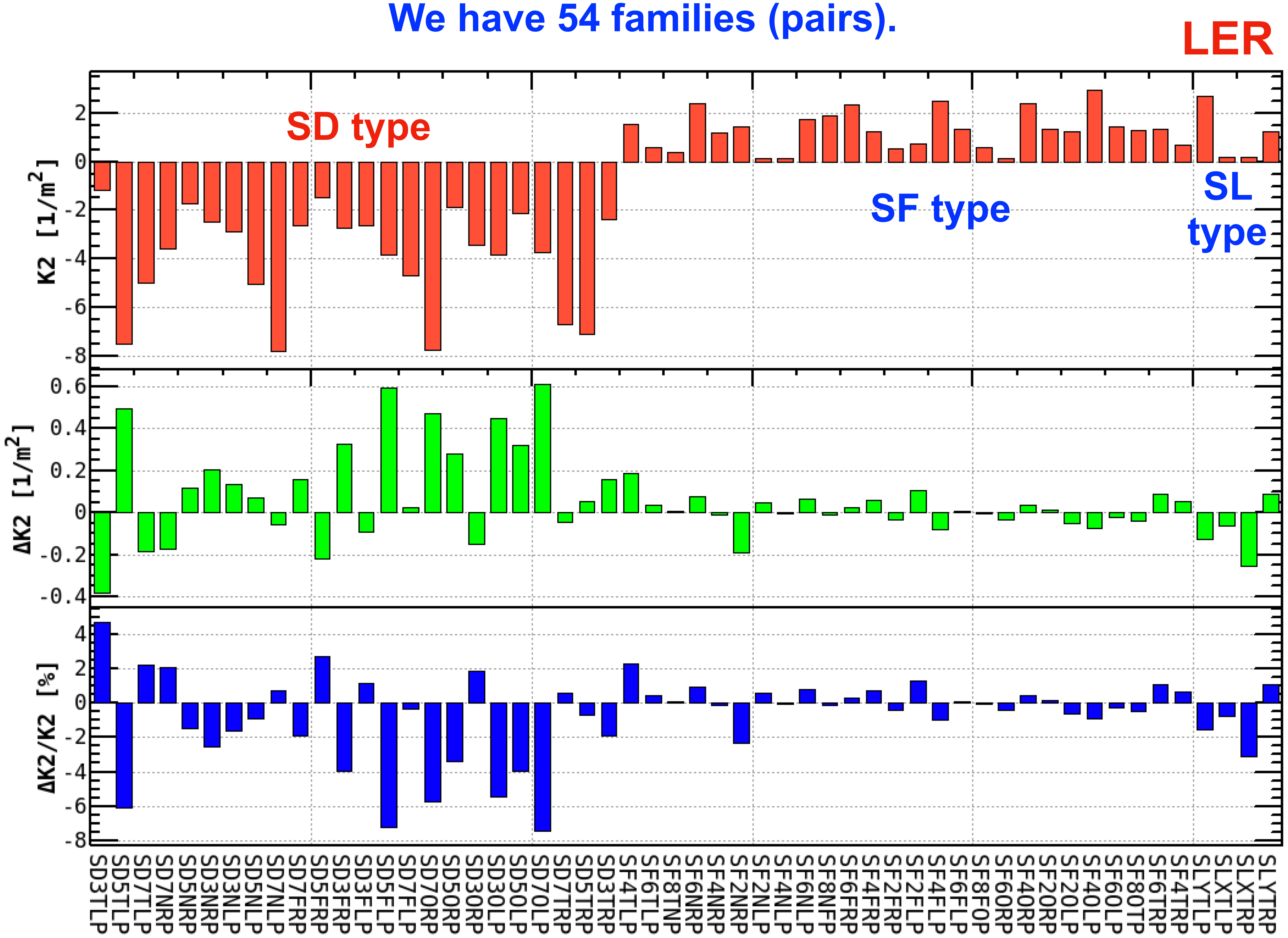
$$a_f = \frac{K_2 + \Delta K_2}{K_2}$$

SD + SF + SL : M = 54 (#families)

Sextupole Magnets in LER

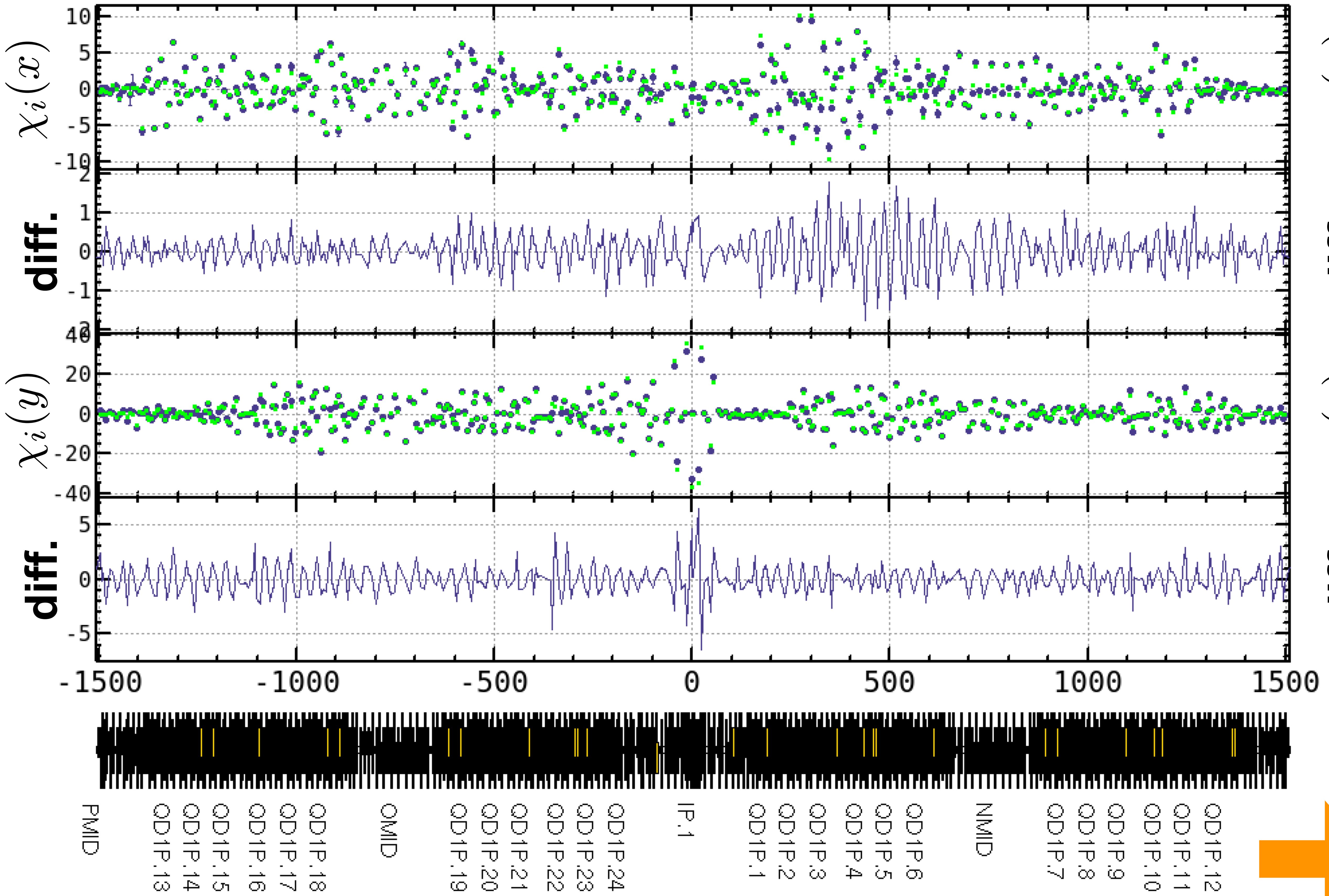
We have 54 families (pairs).

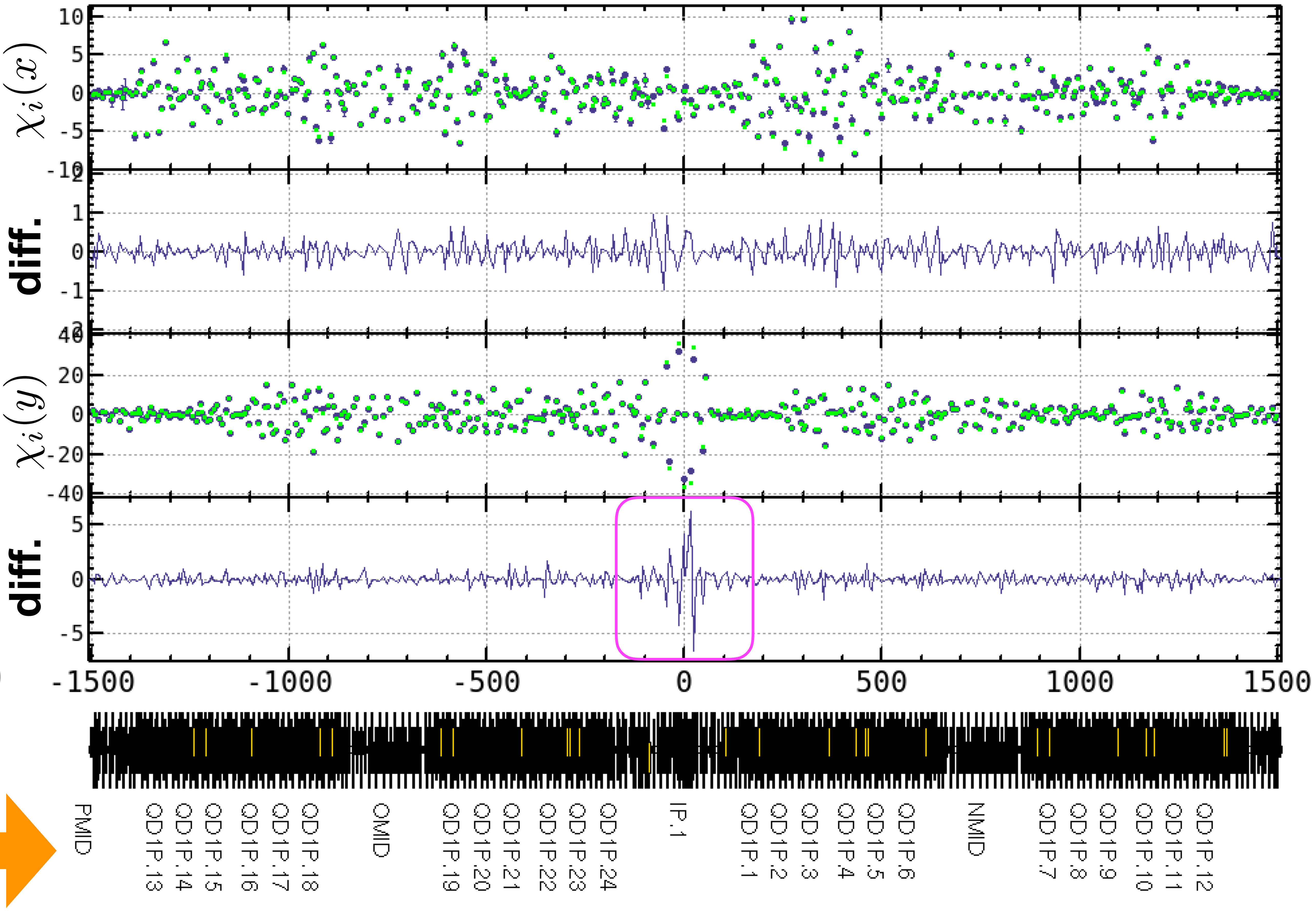
amount of correction



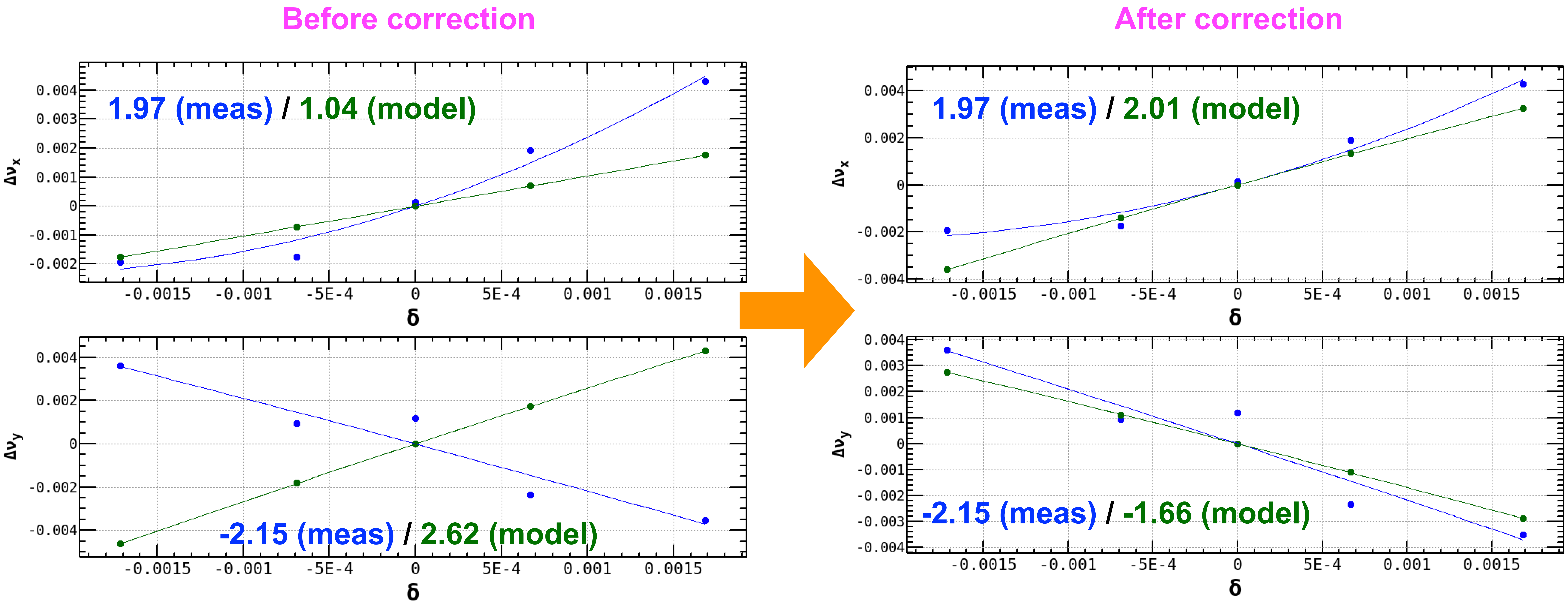
Phase 2

Model/Meas. **Before correction** $\beta_x^* = 200\ mm$ $\beta_y^* = 3\ mm$ **After correction**





The correction is successfully performed except for the IR.

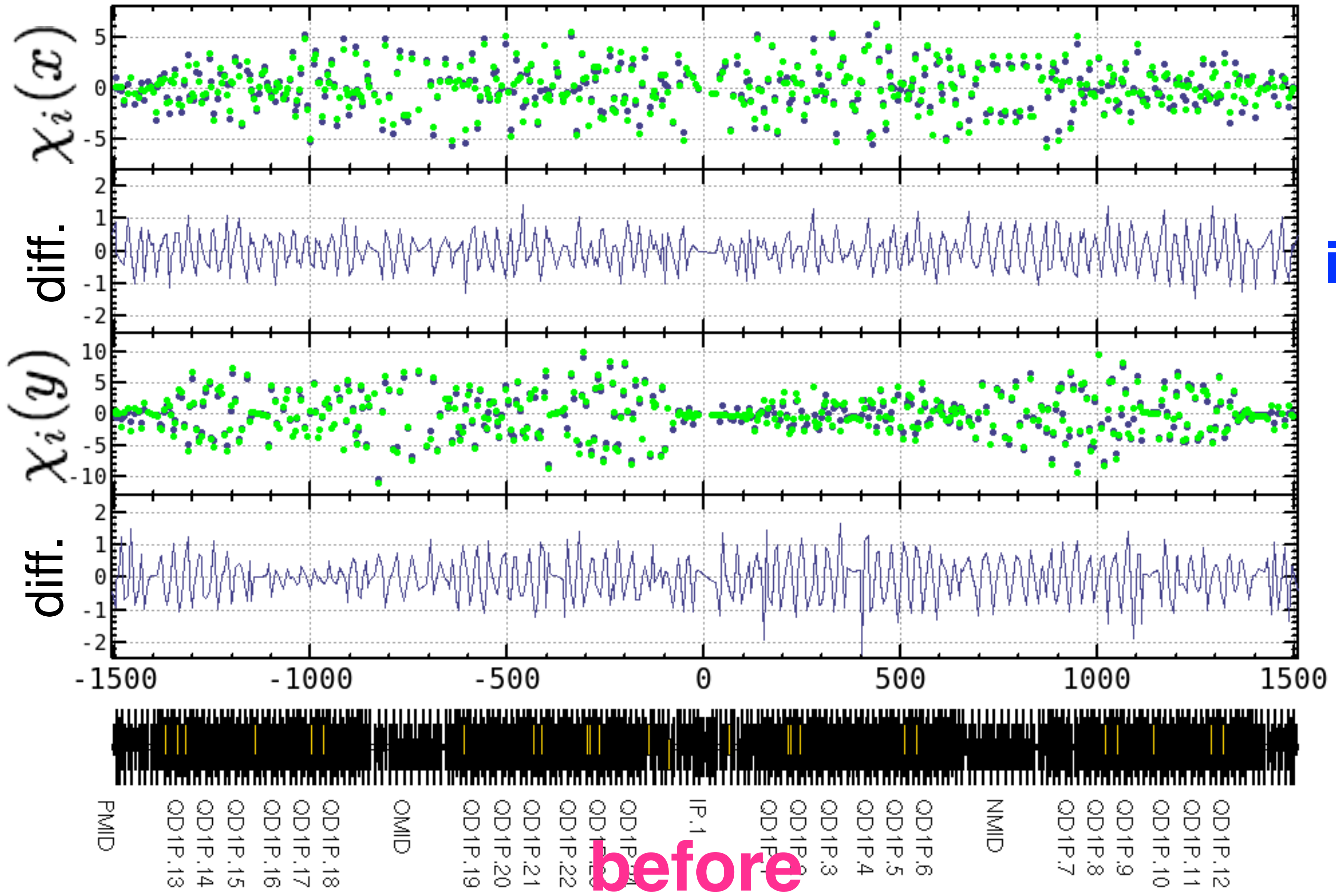


The chromaticity is well reproduced by the model after the correction.

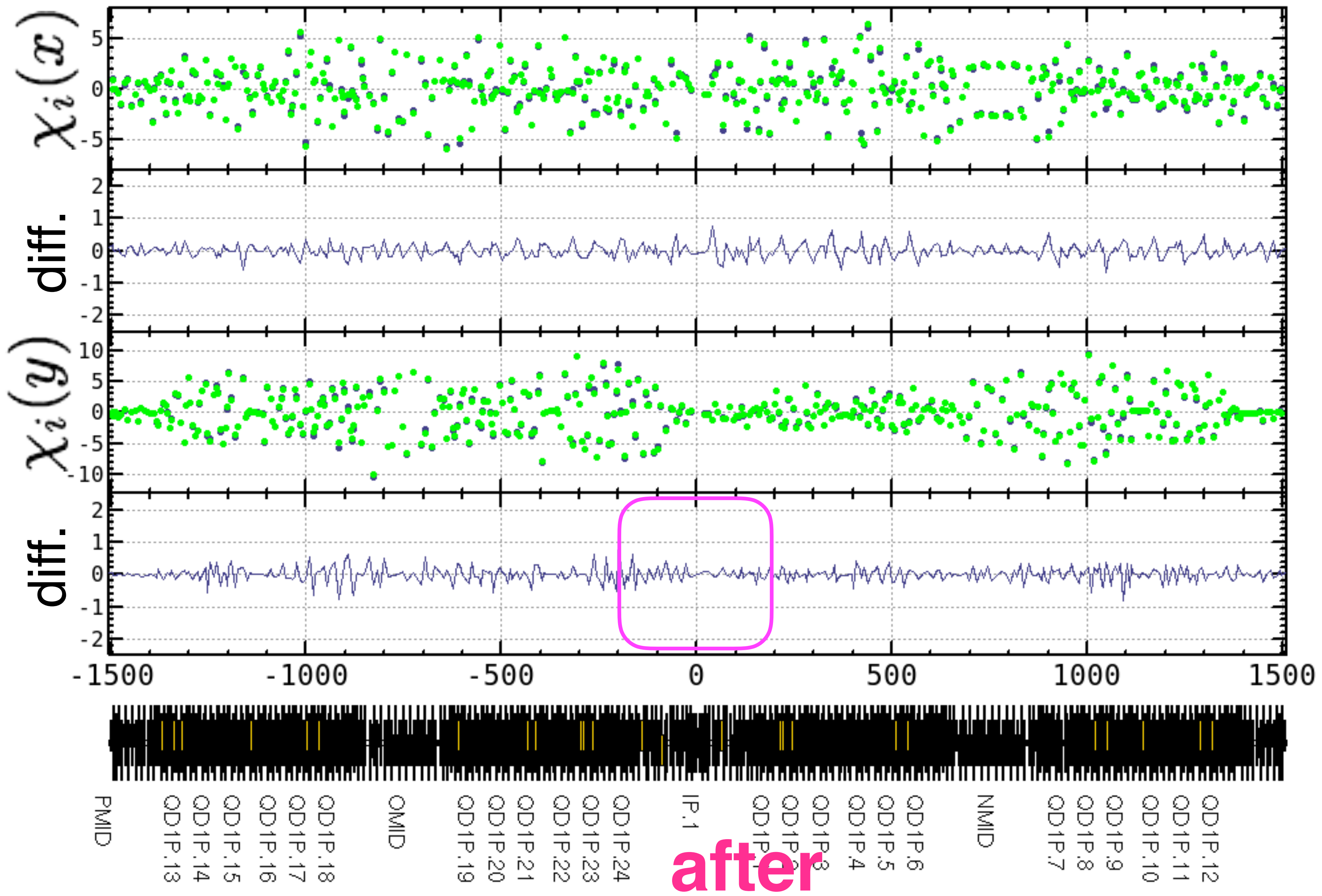
Chromatic Phase-Advance in LER (Phase I)

eeFACT 2016

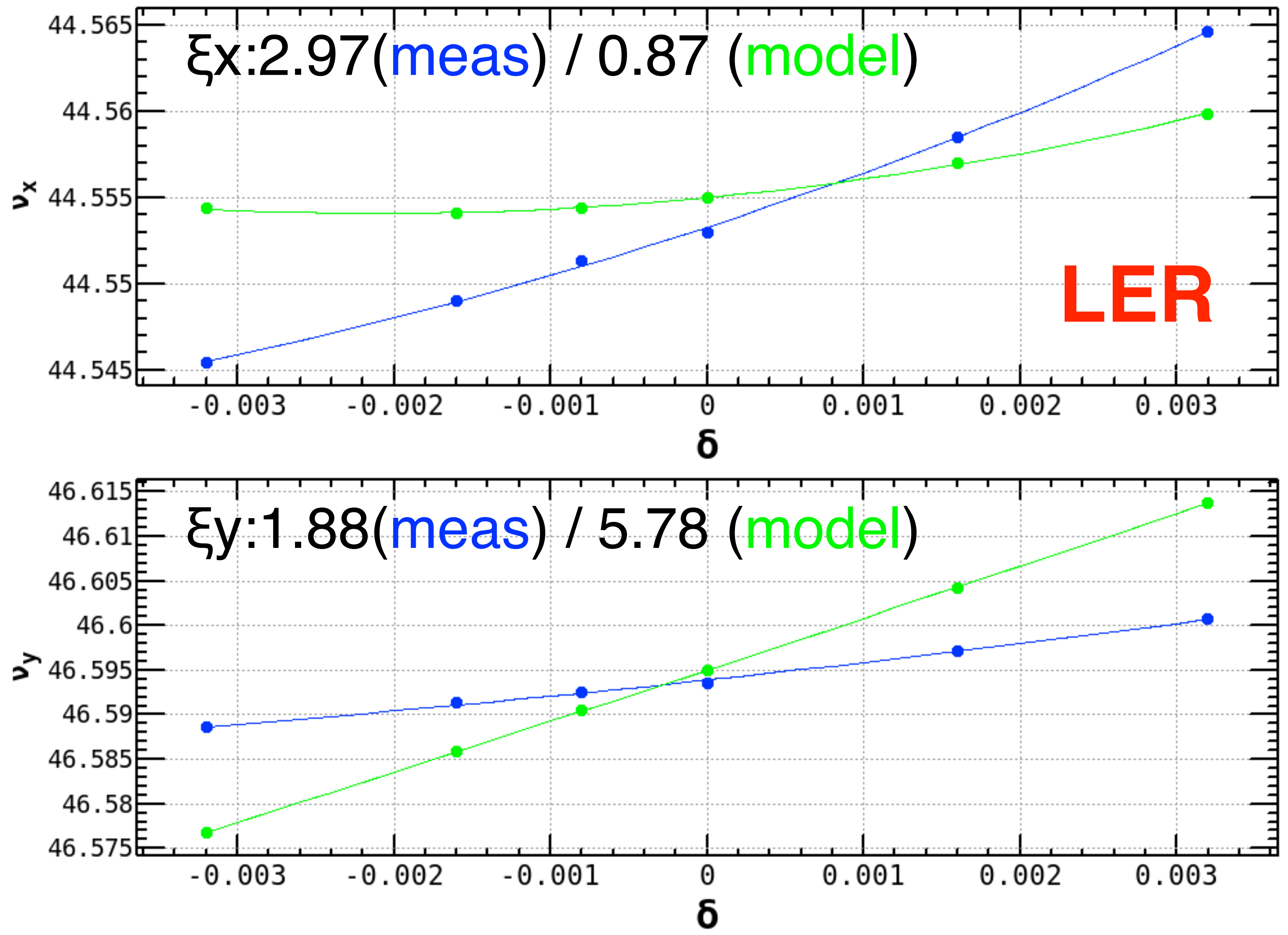
No QCS in Phase 1

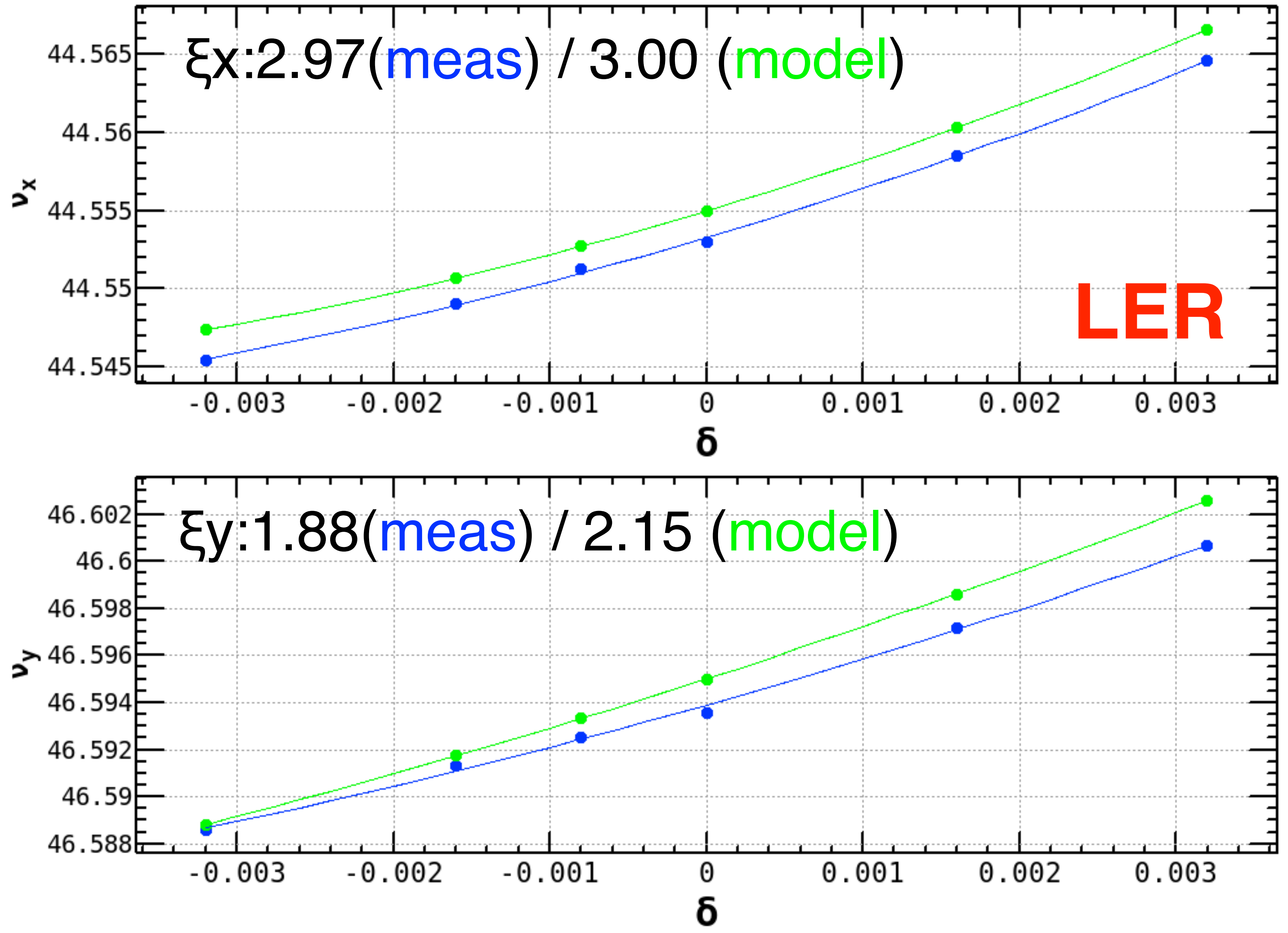


before



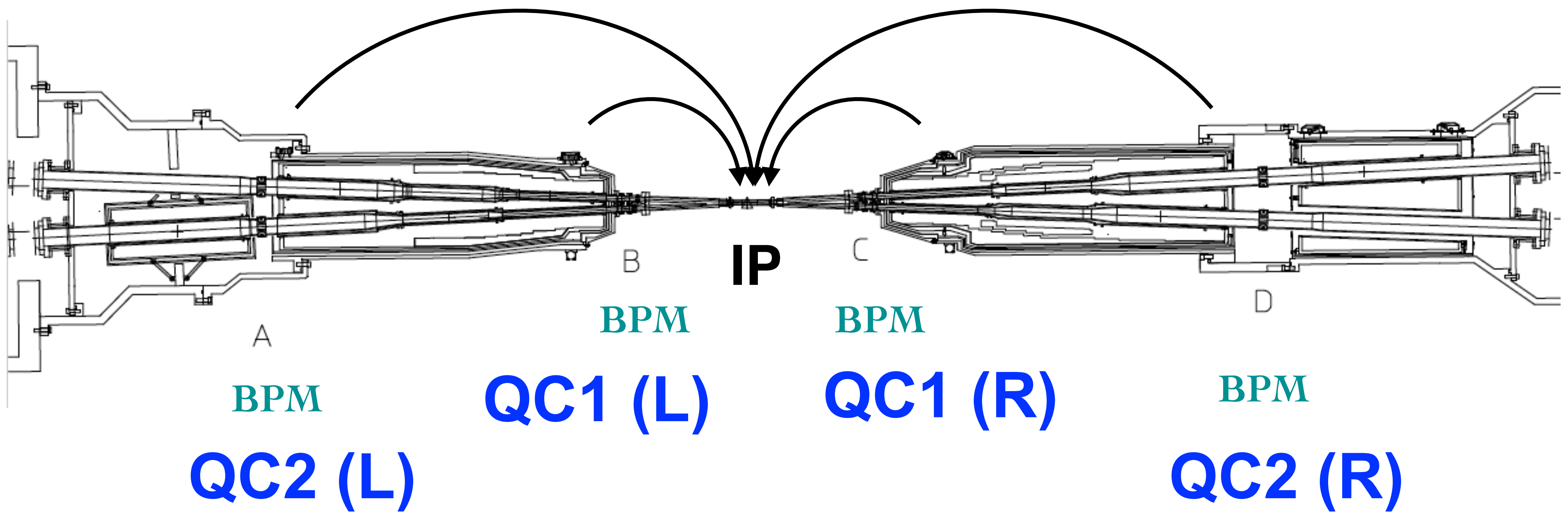
after

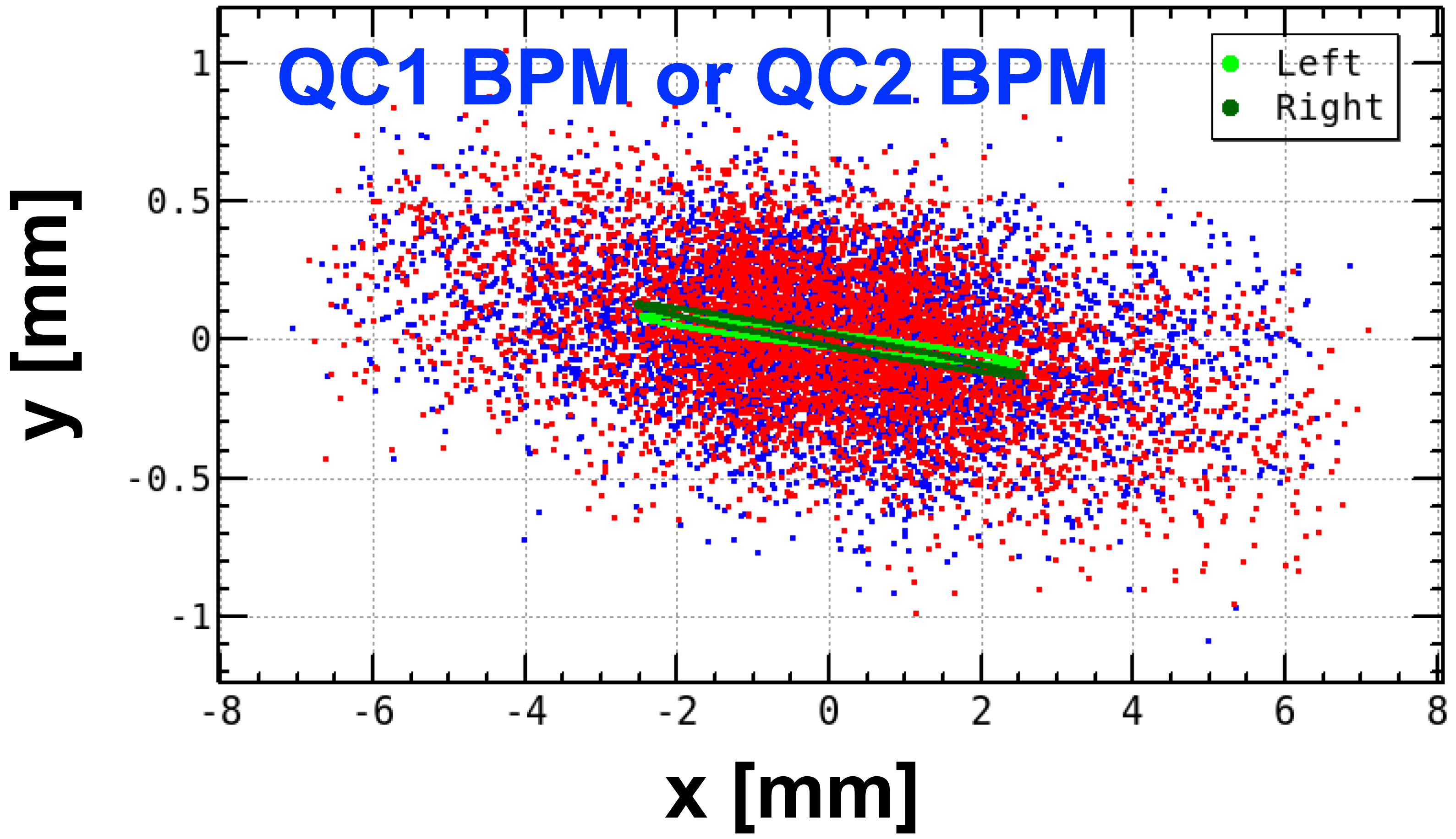




Measurement of Chromatic XY Coupling based on TbT Analysis

Reconstruct phase space at IP by using 2 BPMs





reconstruct (x, p_x, y, p_y) at IP from two BPMs

$$\begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix} = \begin{pmatrix} \mu & 0 & r_4 & -r_2 \\ 0 & \mu & -r_3 & r_1 \\ -r_1 & -r_2 & \mu & 0 \\ -r_3 & -r_4 & 0 & \mu \end{pmatrix} \begin{pmatrix} u \\ p_u \\ v \\ p_v \end{pmatrix}$$

physical coordinate

$$\mu^2 + (r_1 r_4 - r_2 r_3) = 1$$

normal coordinate (decoupled)

Extract normal mode of betatron oscillation

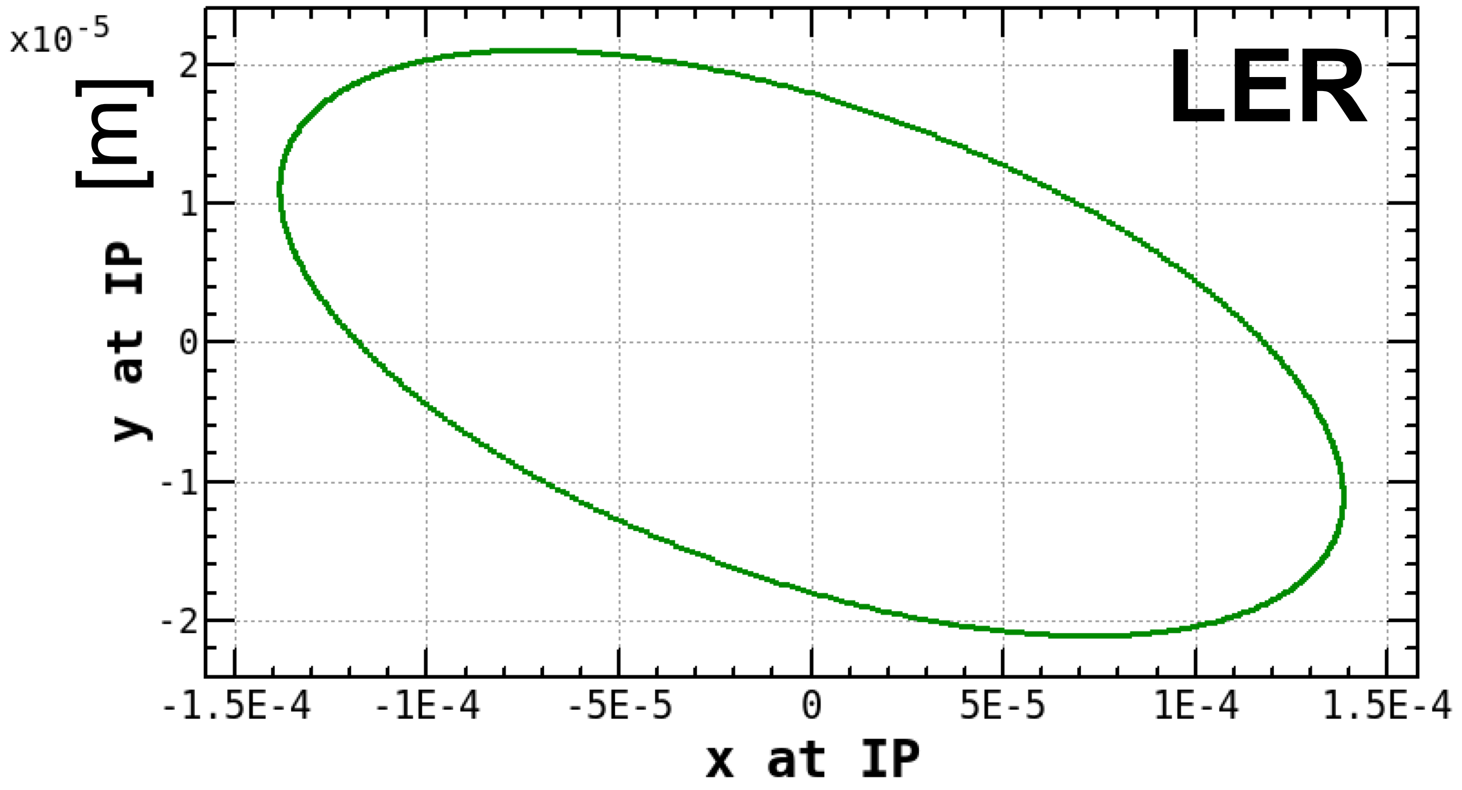
H-mode analysis

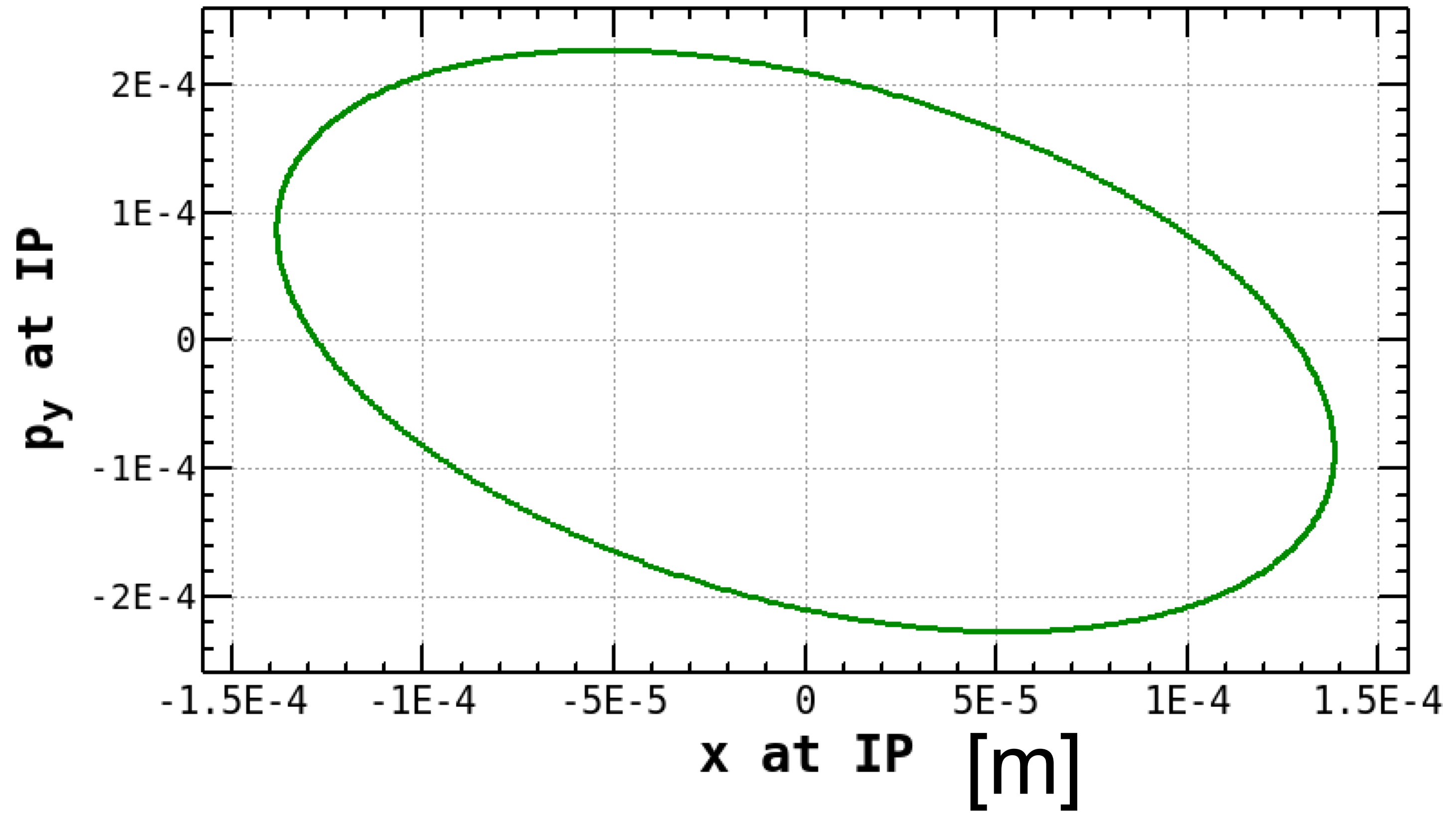
TbT Analysis

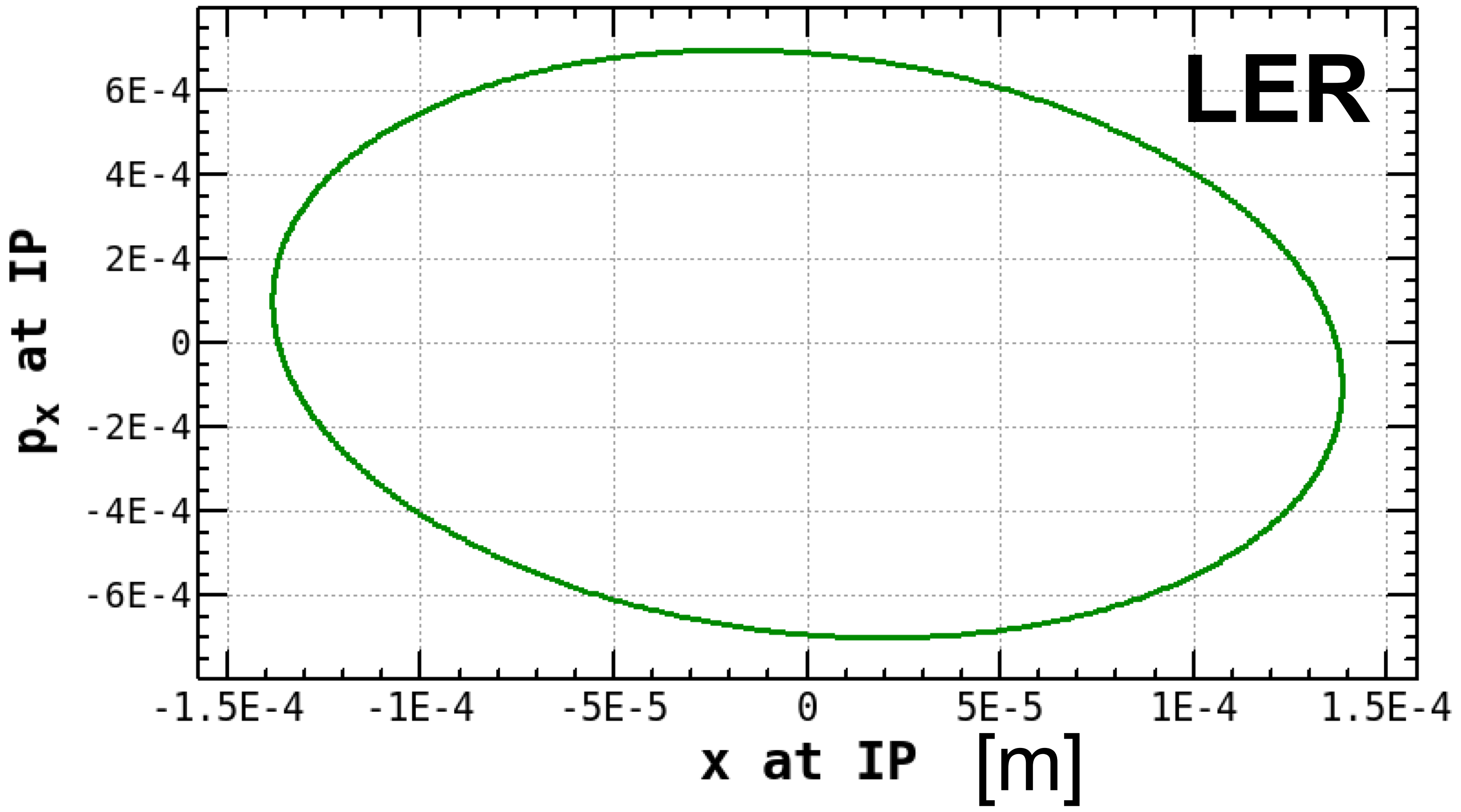
Measured phase space plot at IP

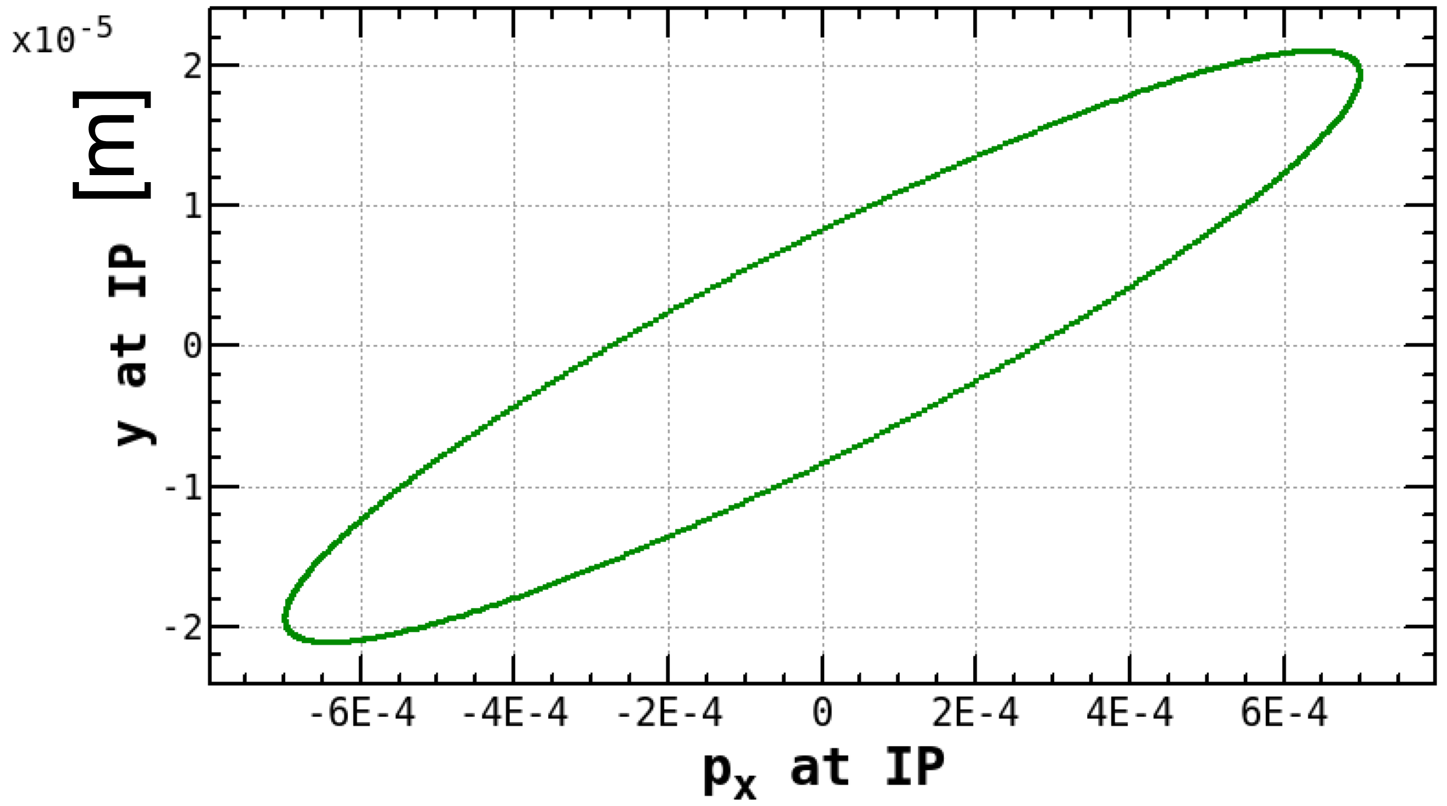
Beam is kicked by a injection kicker. (horizontal)

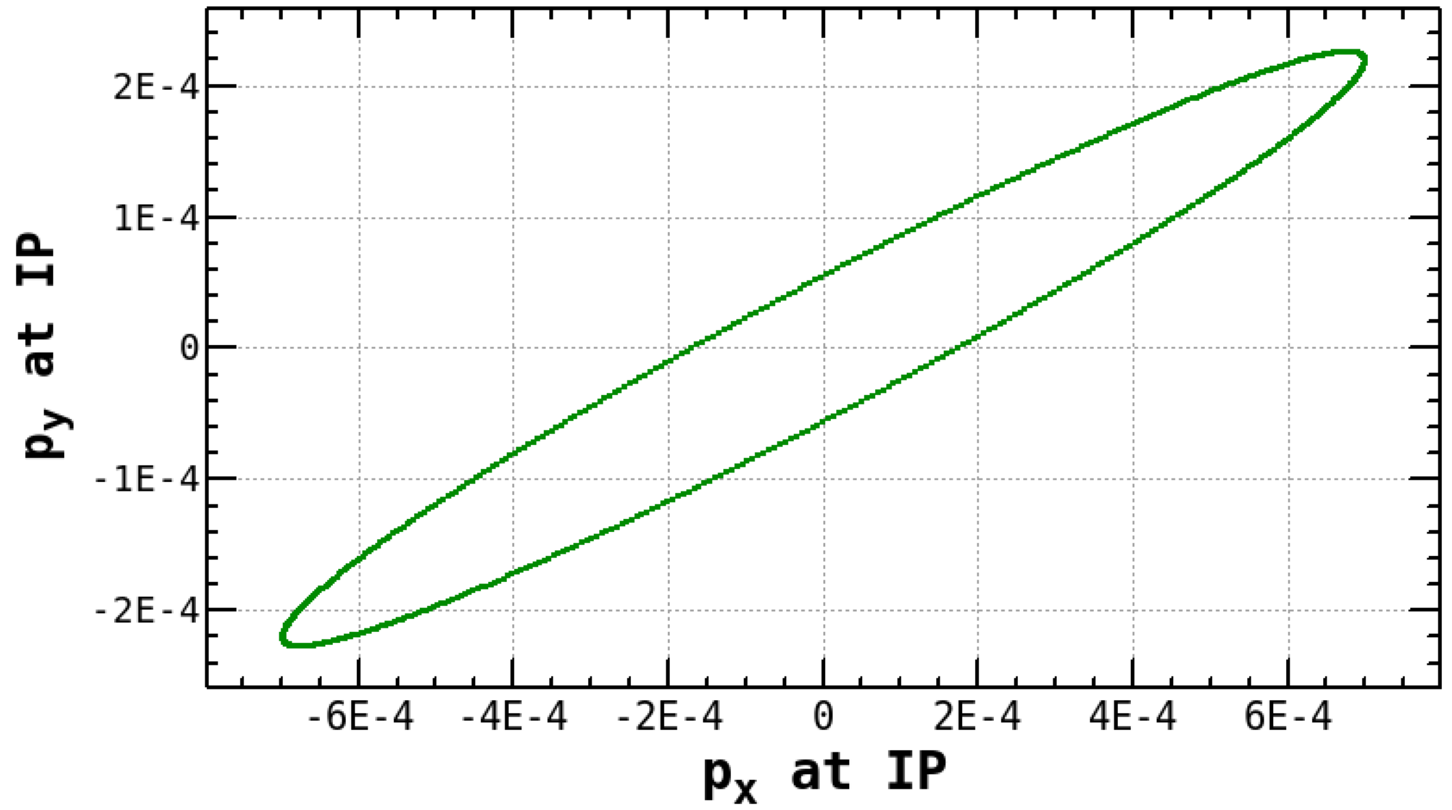
XY couplings are extracted from H-mode analysis



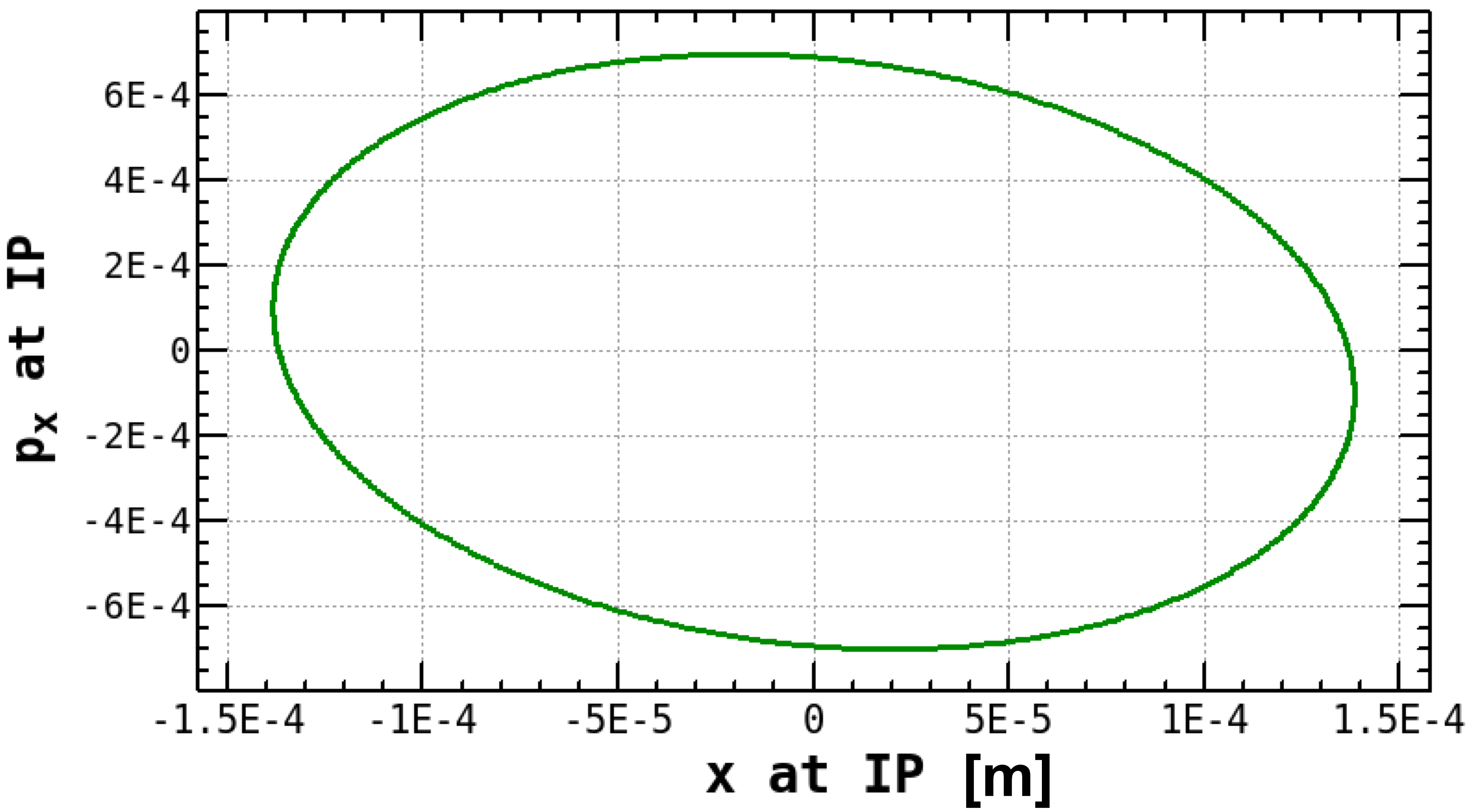




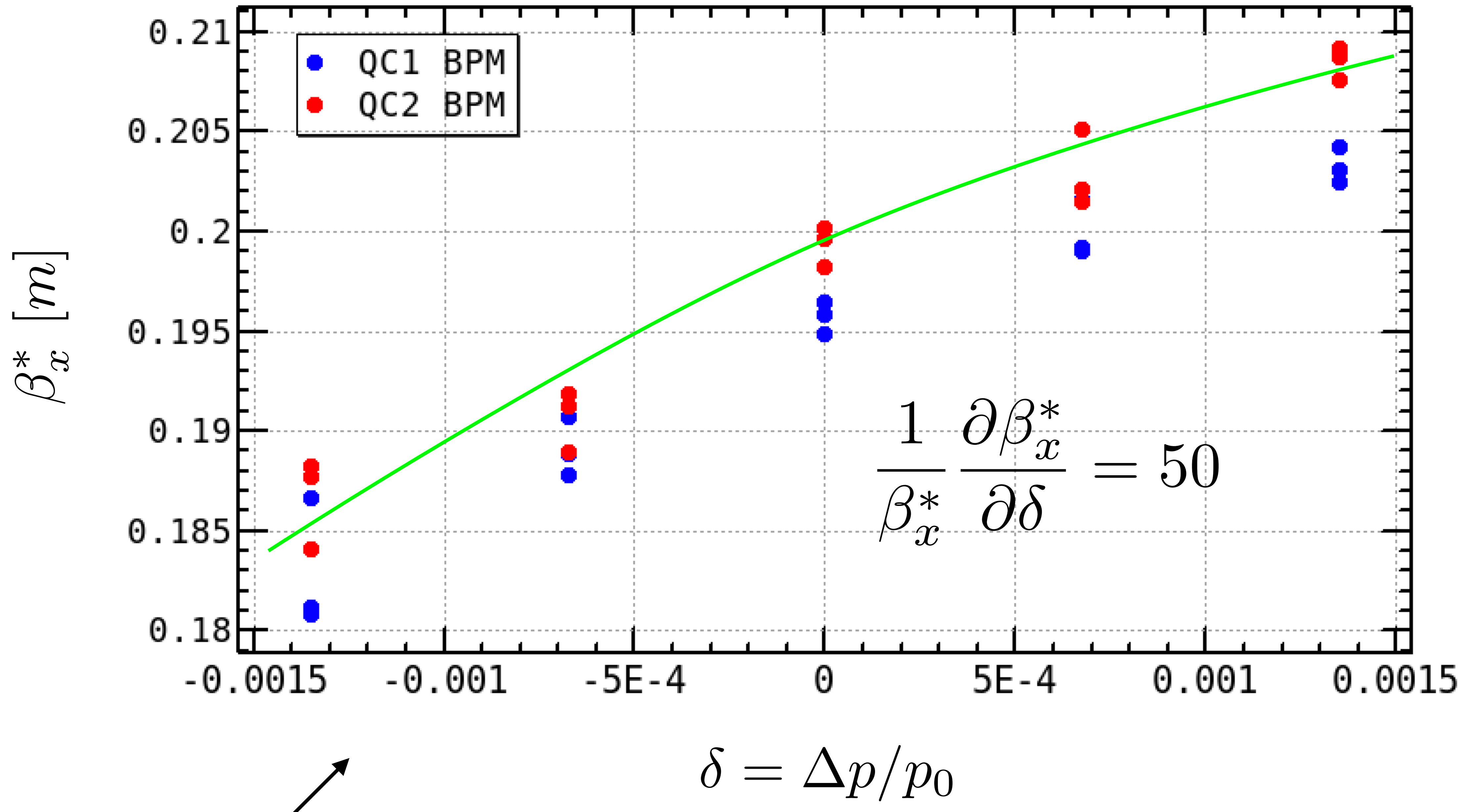




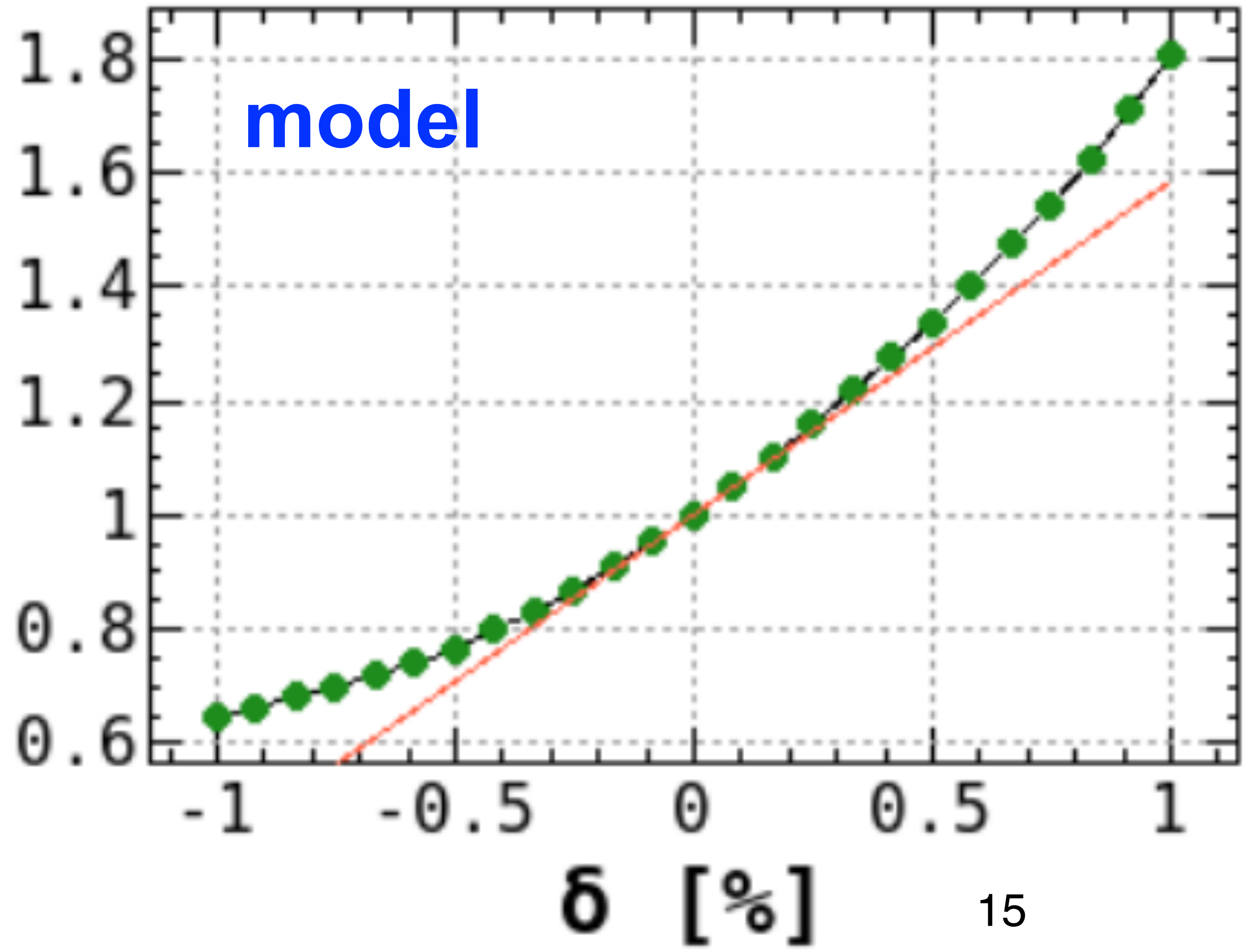
LER



LER

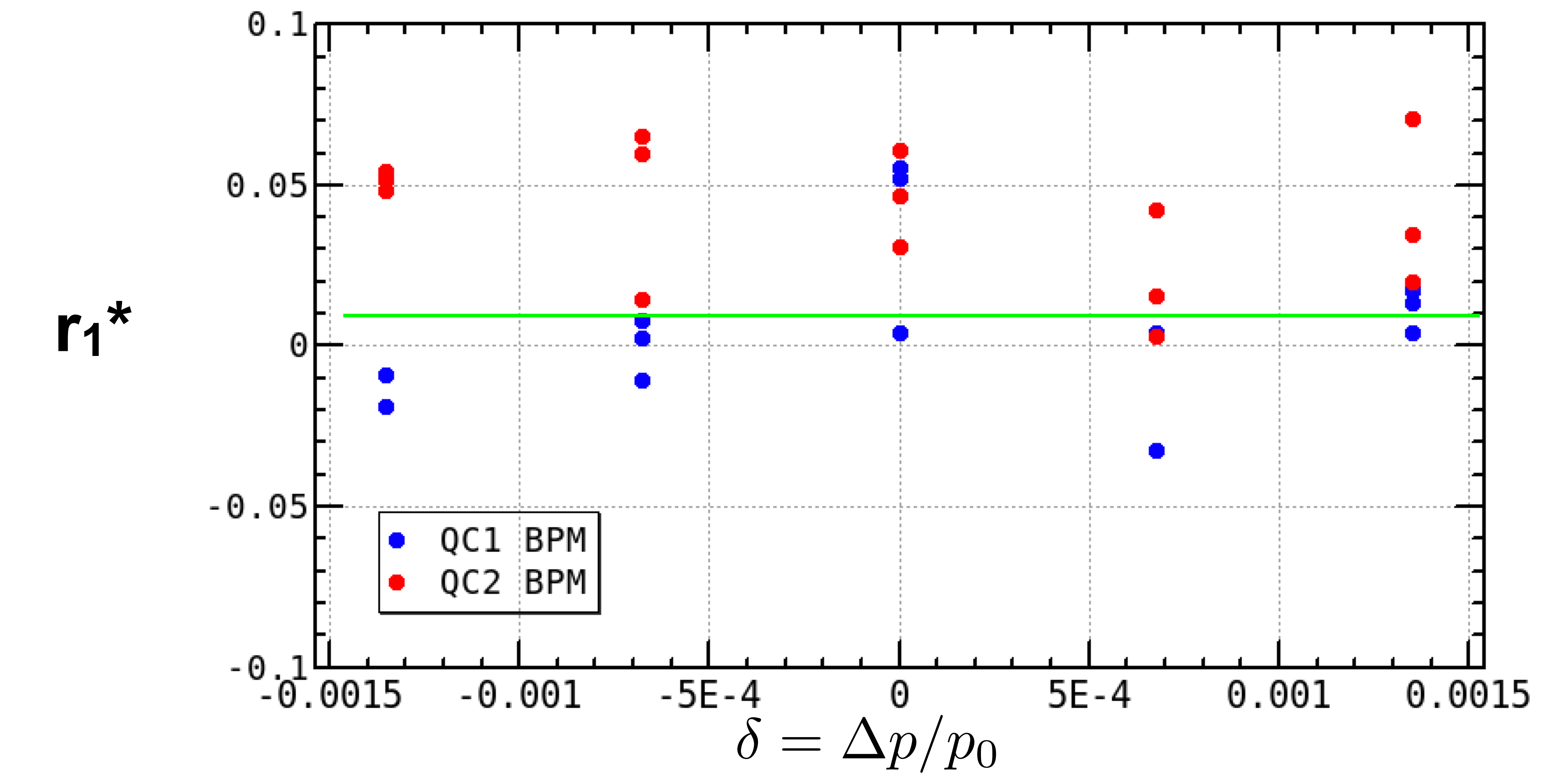


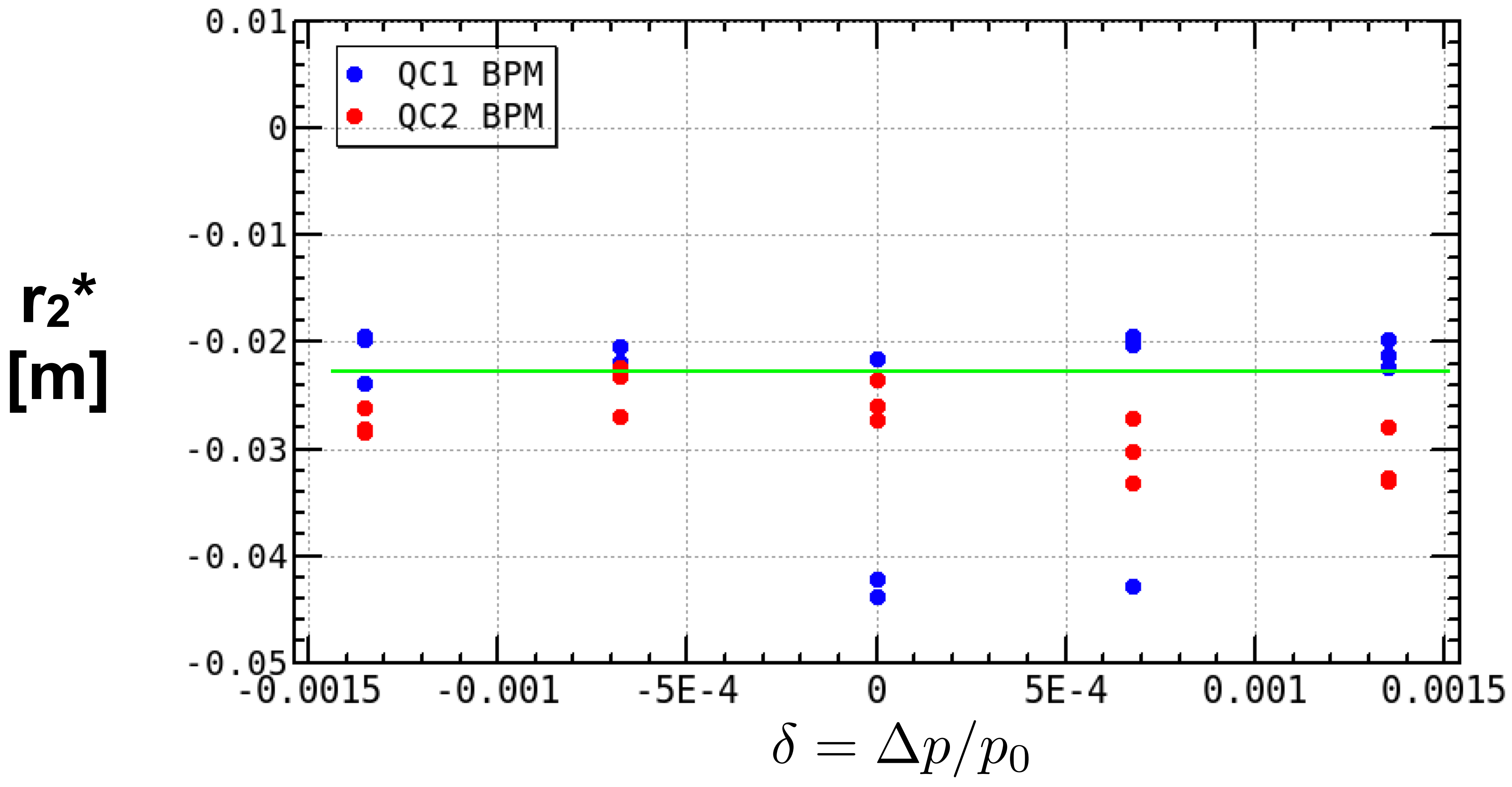
$(\partial\beta_x/\beta_x)/\partial\delta$: 58.27

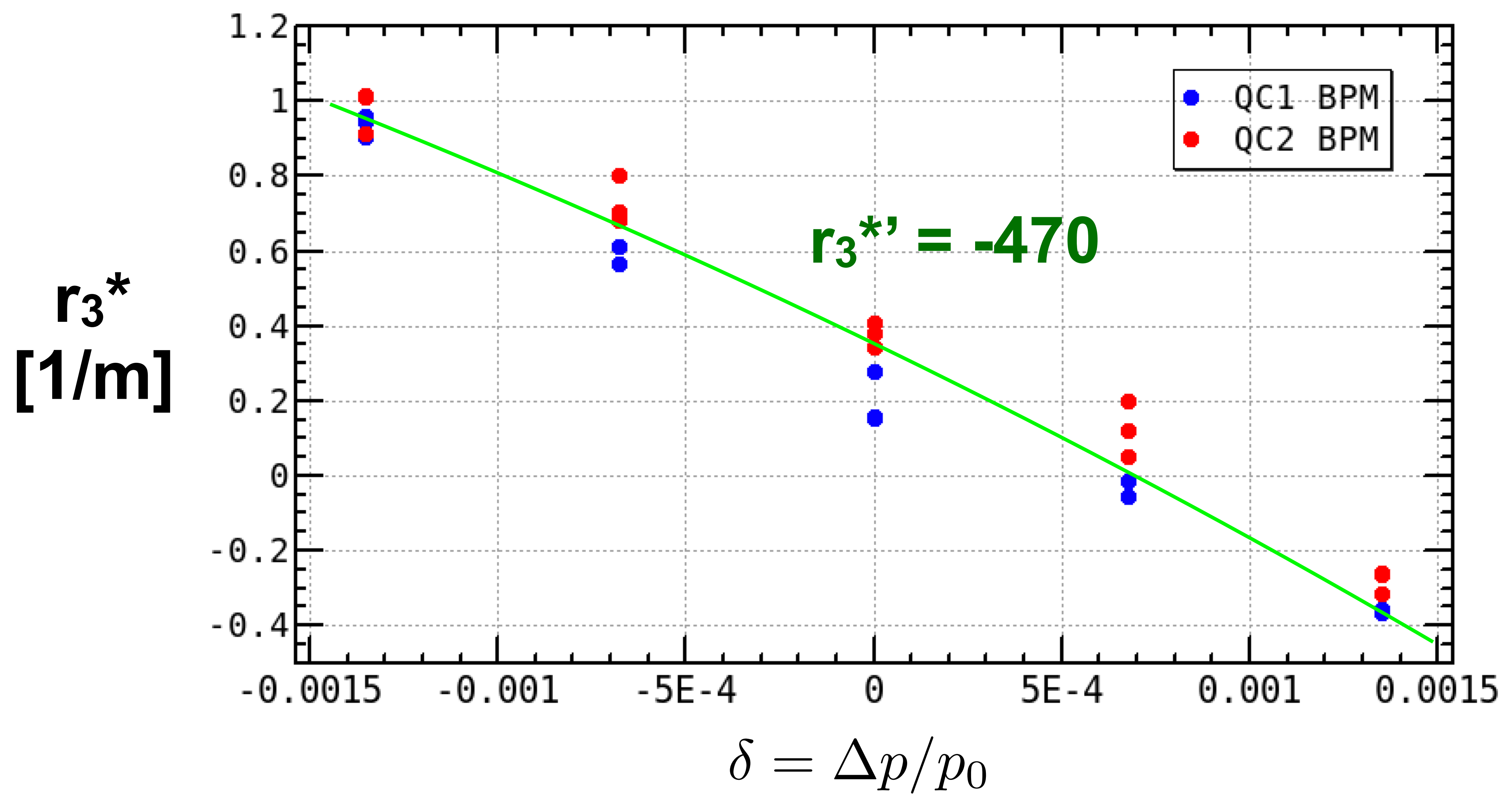


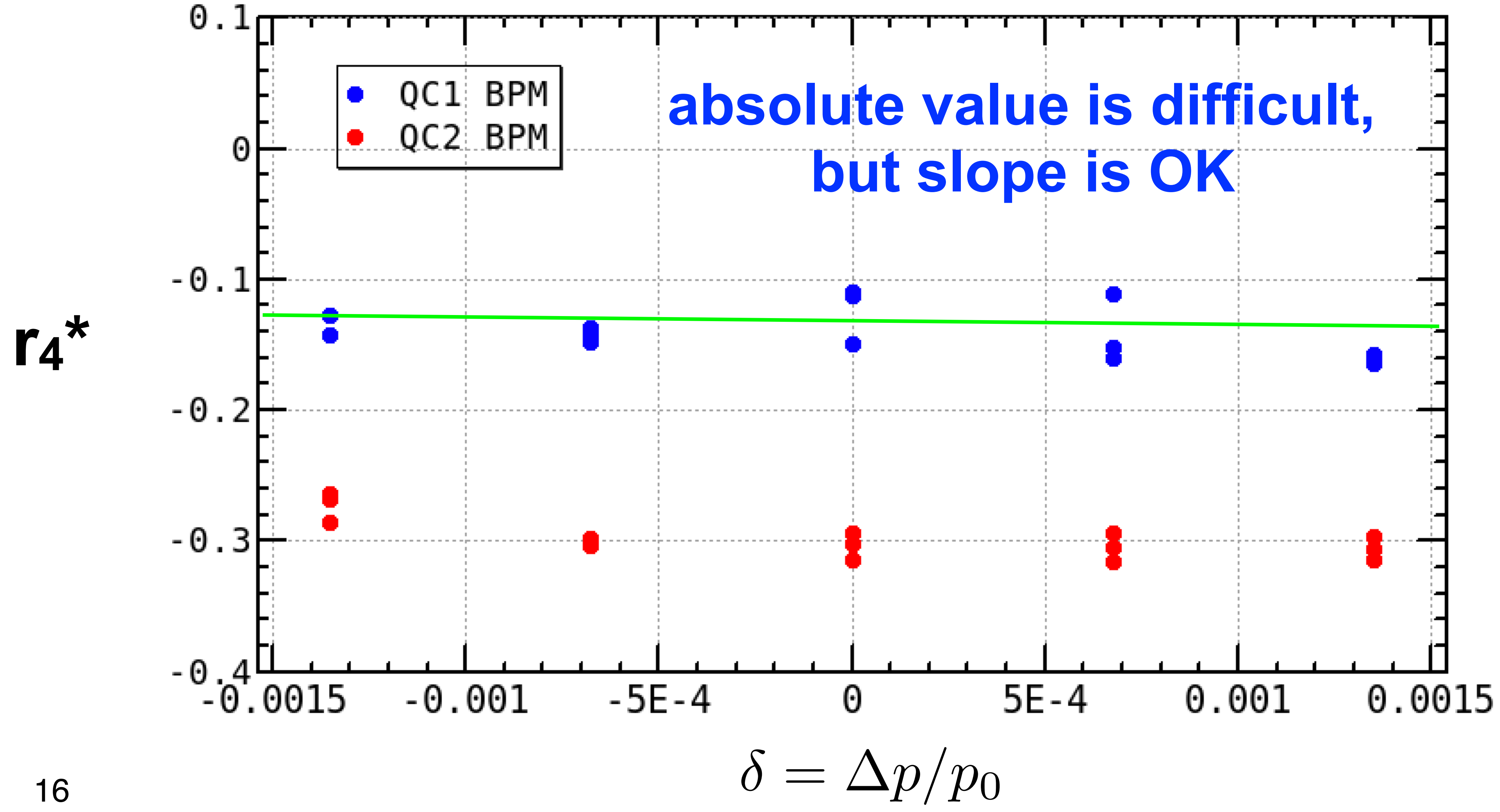
Horizontal beta* chromaticity

Chromatic XY Coupling in LER









Summary

- We have measured chromatic phase advance and correct them by sextupole magnets.
  - comparison between Phase 1(w/o QCS) and Phase 2(with QCS)
- Chromatic XY coupling at the IP also measured by using TbT BPMs.
- Measurement and correction of chromatic optical functions will be important to improve dynamic aperture and luminosity performance.