LHC optics studies with MAD-X, PTC, and beam measurements

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Thanks to:
M.Carmen Alabau

Structure

1) Chromatic beta-beating studies with MAD-X and PTC

2) Dispersion measurements

3) BPM failure detection

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Beta-beating:

$$\frac{\Delta\beta}{\beta} = \frac{\beta_{measured} - \beta_{model}}{\beta_{model}}$$

- No measurements → We played with two parameters: δp and seed (errors)

1) As function of δp:

$$\frac{\Delta\beta}{\beta} = \frac{\beta_{seed}(\delta p) - \beta_{seed}(0)}{\beta_{seed}(0)}$$

2) As function of the seed:

$$\frac{\Delta\beta}{\beta} = \frac{\beta_{seed}(\delta p) - \beta_0(\delta p)}{\beta_0(\delta p)}$$

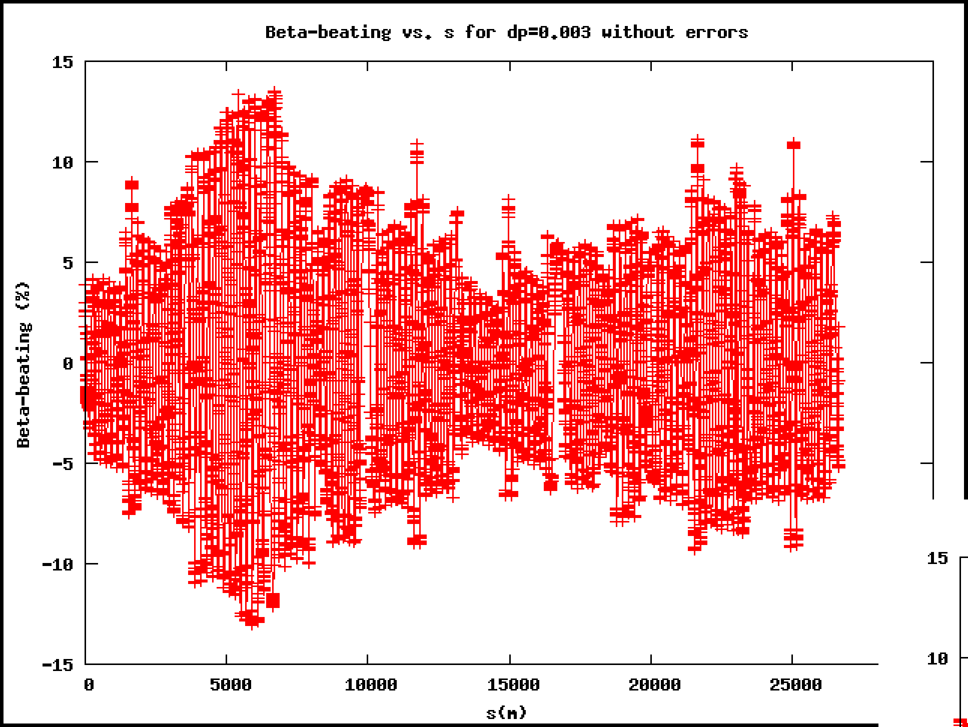
$$\delta p = \frac{\Delta p}{p}$$

3) As function of both:

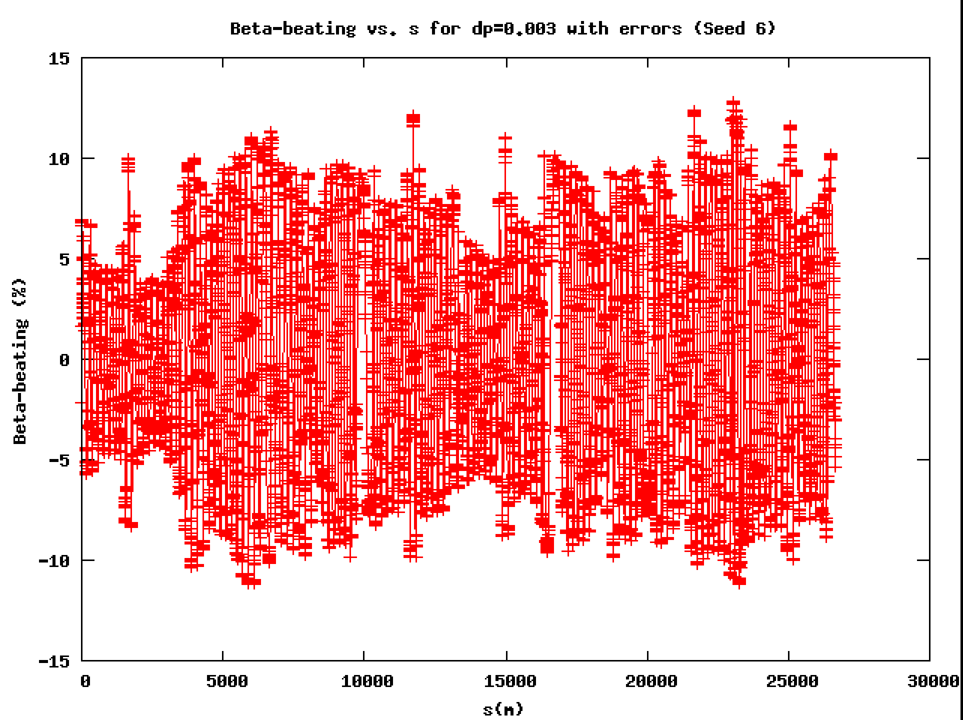
$$\frac{\Delta\beta}{\beta} = \frac{\beta_{seed}(\delta p) - \beta_0(0)}{\beta_0(0)}$$

Chromatic beta-beating studies with MAD-X and PTC

$$\frac{\Delta\beta}{\beta}(s)$$



Without error for δp=0.003

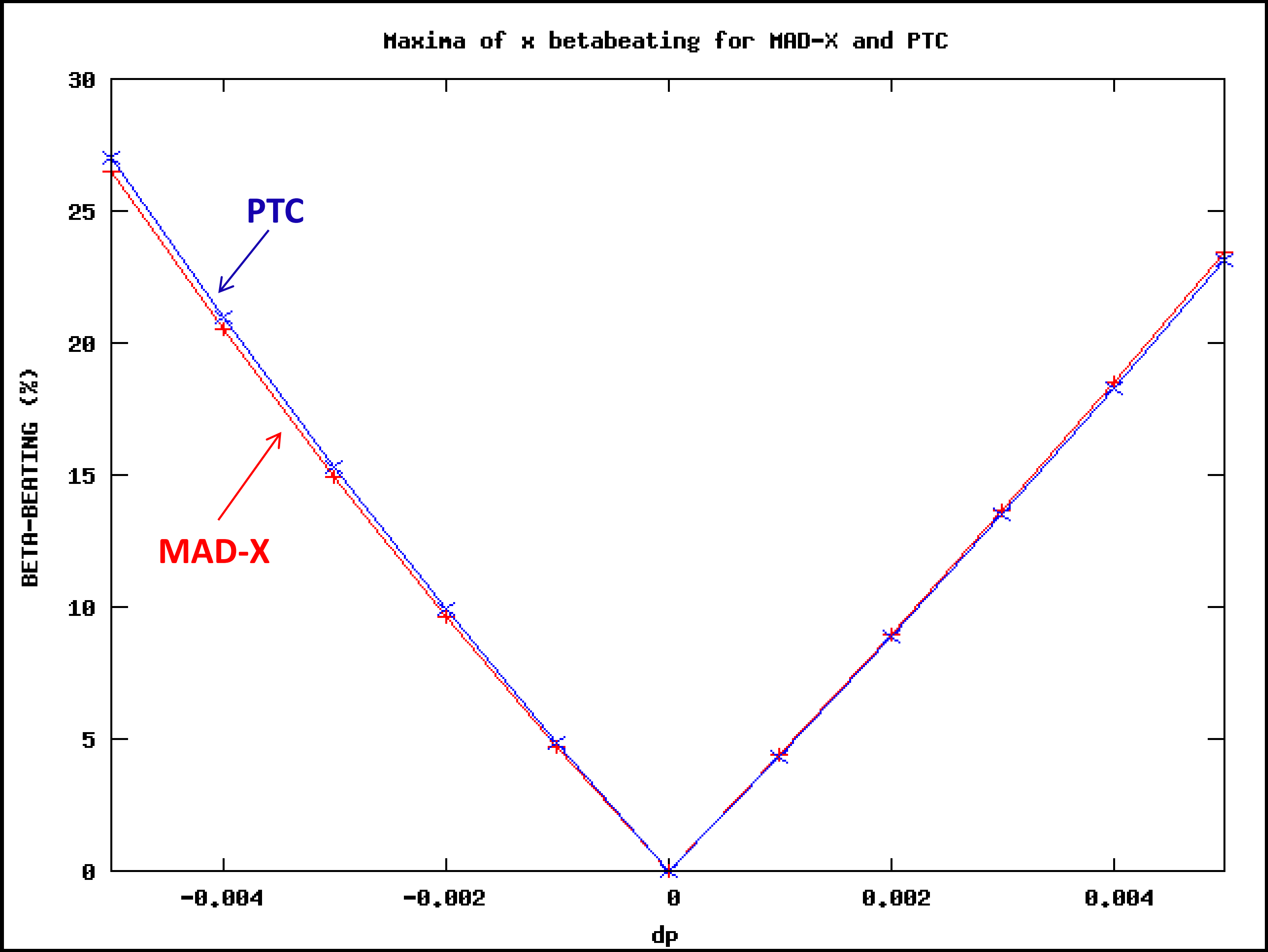


With errors for δp=0.003

(Calculated with PTC)

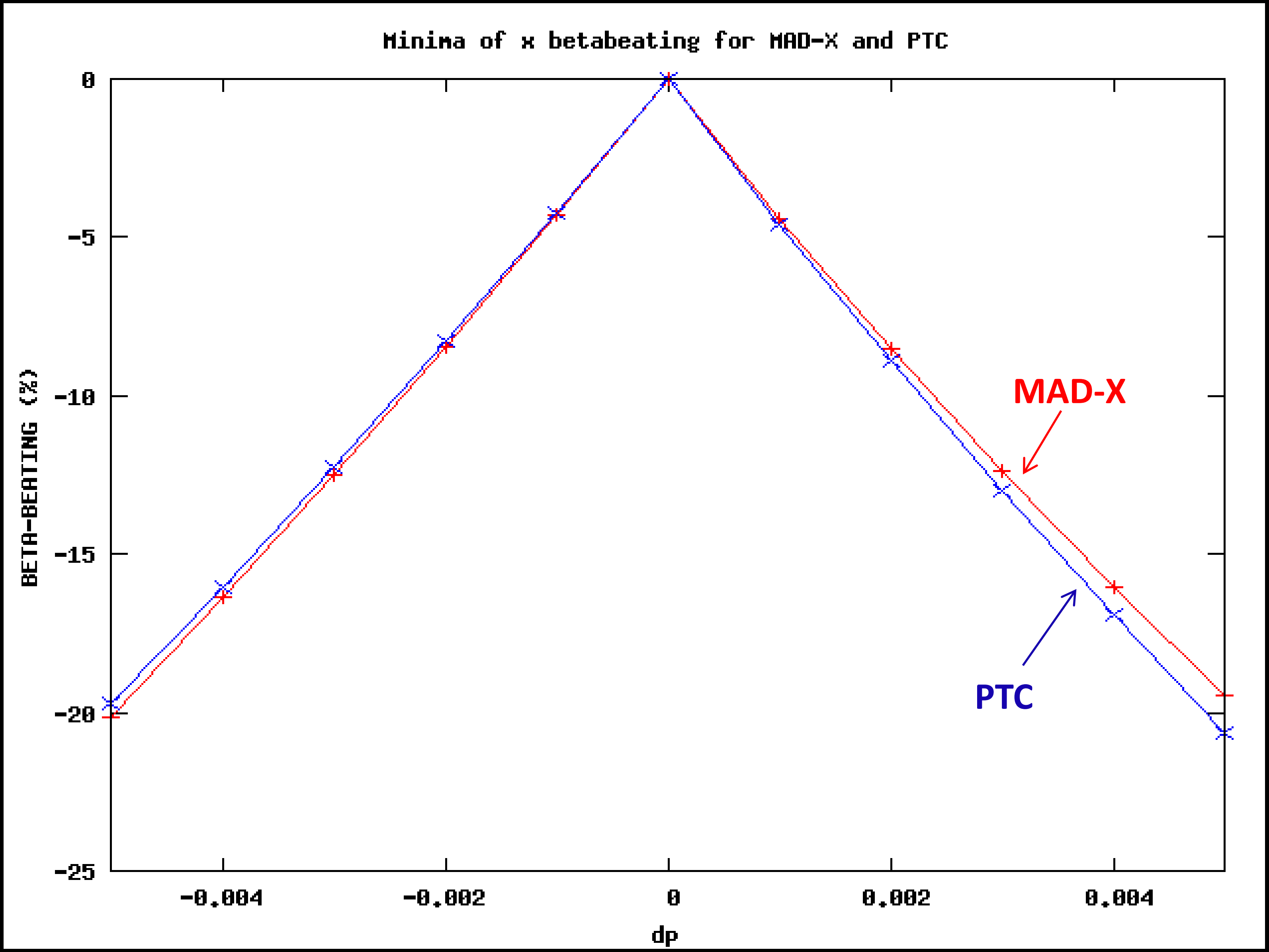
Chromatic beta-beating studies with MAD-X and PTC – No error

- Comparison between MAD-X and PTC without errors:



Chromatic beta-beating studies with MAD-X and PTC – No error

- Comparison between MAD-X and PTC without errors:



Chromatic beta-beating studies with MAD-X and PTC - Errors

- In PTC we considered errors till 11th order:

```
ON_B1S  = 0; ON_A1S  = 0;
ON_B2S  = 1; ON_A2S  = 1;
ON_B3S  = 1; ON_A3S  = 1;
ON_B4S  = 1; ON_A4S  = 1;
ON_B5S  = 1; ON_A5S  = 1;
ON_B6S  = 1; ON_A6S  = 1;
ON_B7S  = 1; ON_A7S  = 1;
ON_B8S  = 1; ON_A8S  = 1;
ON_B9S  = 1; ON_A9S  = 1;
ON_B10S = 1; ON_A10S = 1;
ON_B11S = 1; ON_A11S = 1;
```

- We took 15 seeds from “WISE” and their respective correction files:

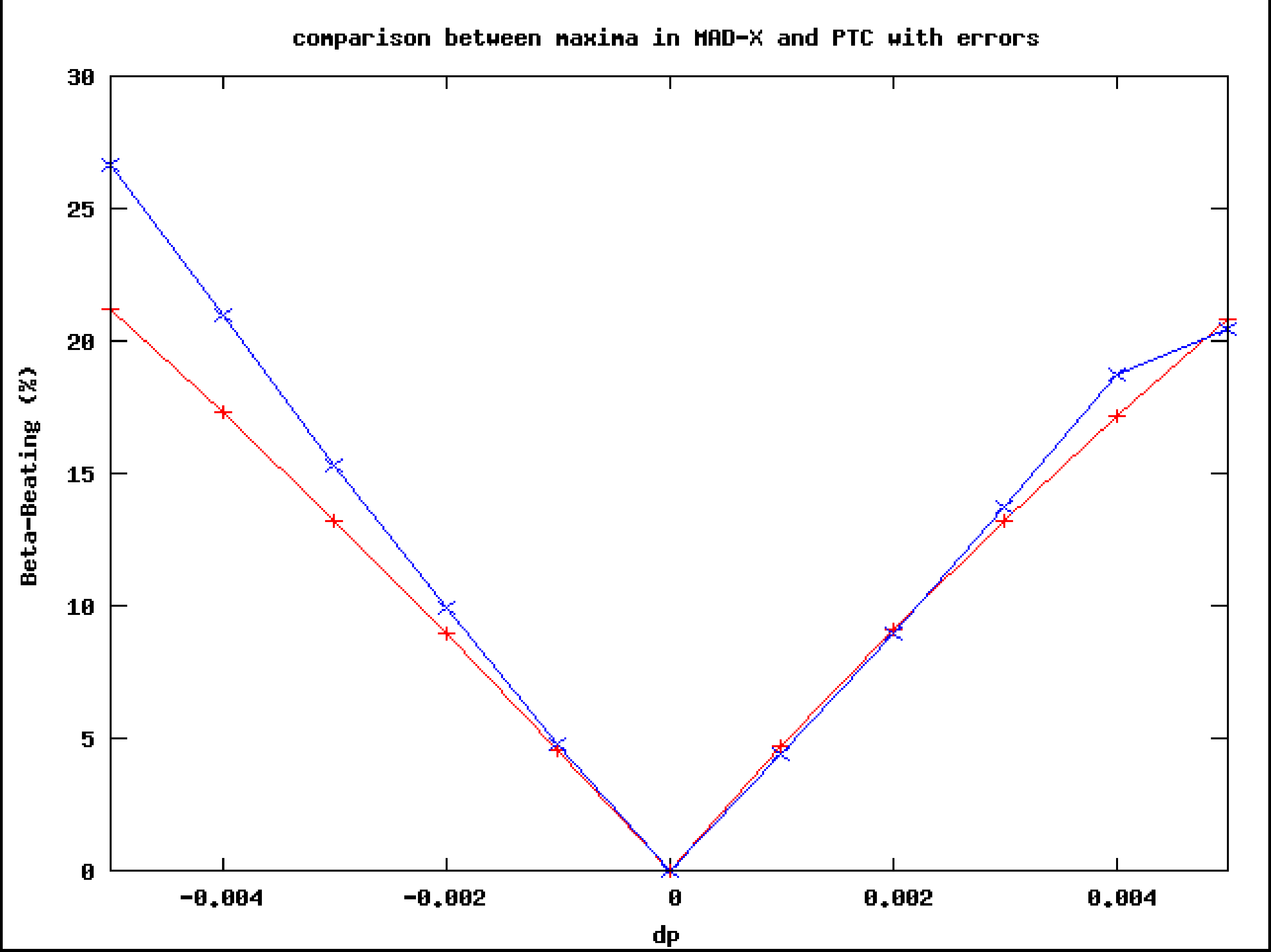
```
readtable, file="wise/injection_errors-emfqcs-1(to 15).tfs" ;

Call,file="/afs/cern.ch/eng/sl/online/om/repository/malabaup/correc
tion_harmonics/BEAM1/MB_corr_setting_O1-11_S1(to 15).mad";
```

- In MAD-X we considered only random quadrupolar errors : `ON_B2S = 1`, taken over 10 seeds

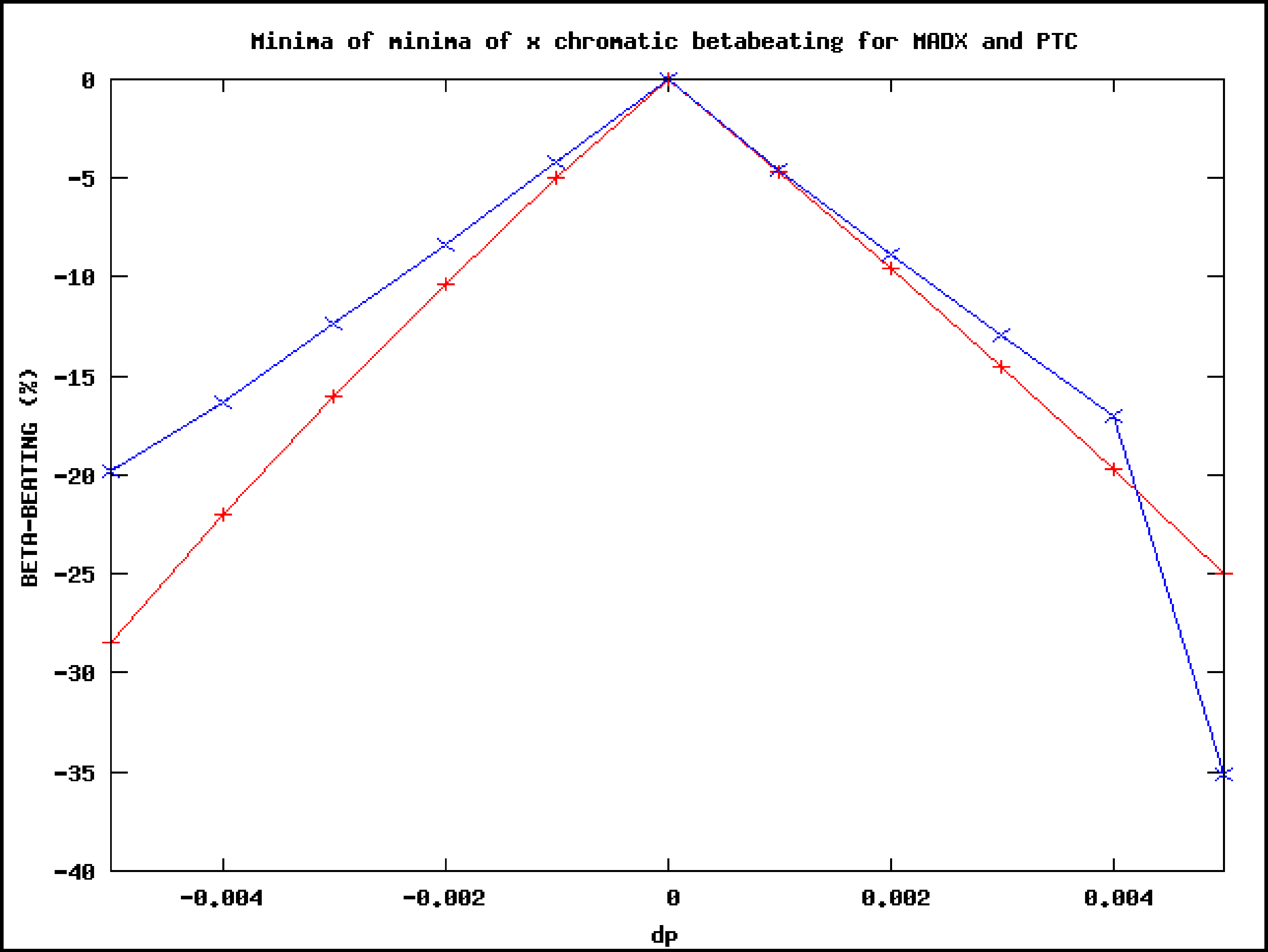
Chromatic beta-beating studies with MAD-X and PTC - Errors

- Comparison between MAD-X and PTC considering errors:



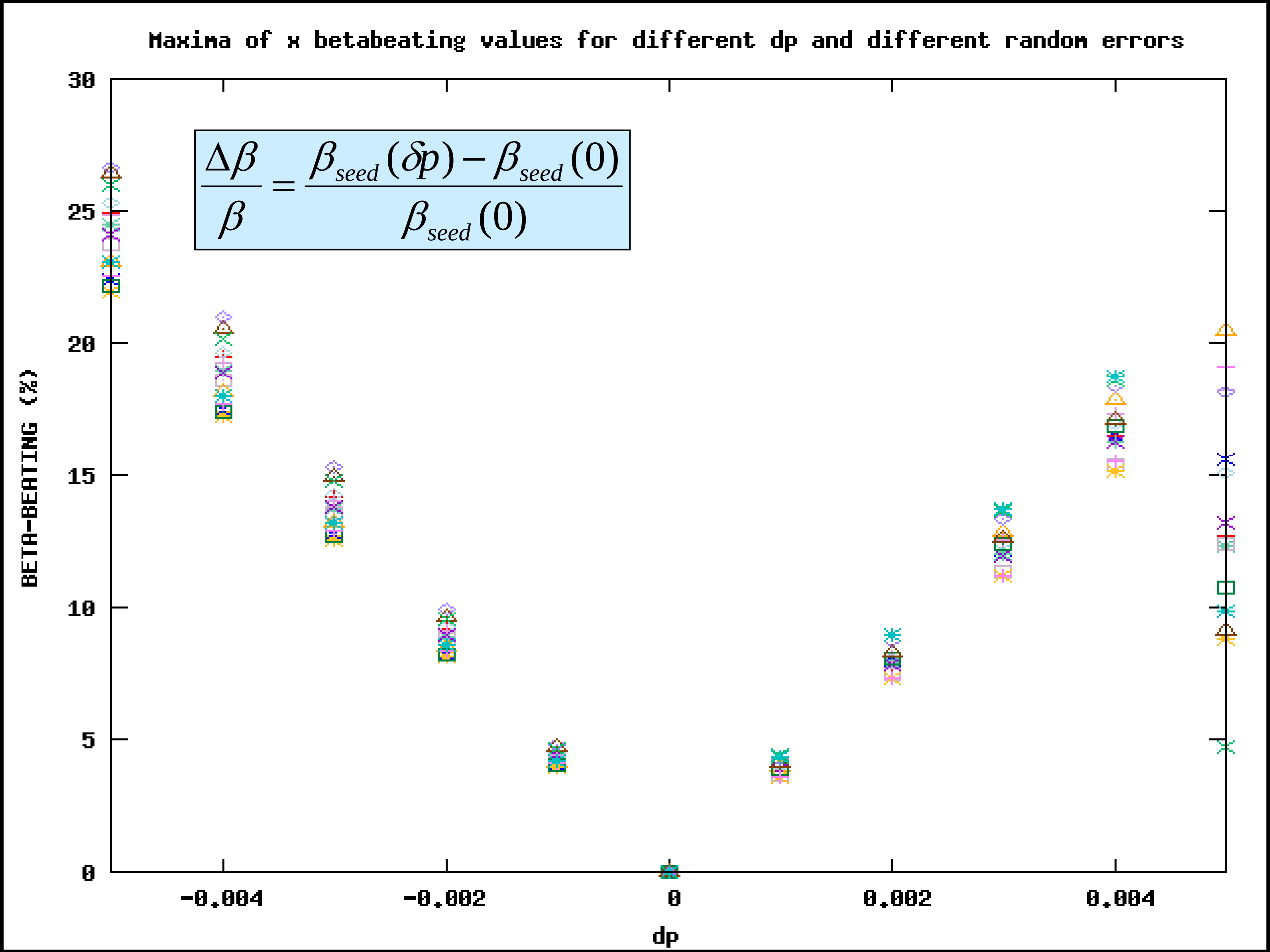
Chromatic beta-beating studies with MAD-X and PTC - Errors

- Comparison between MAD-X and PTC considering errors:



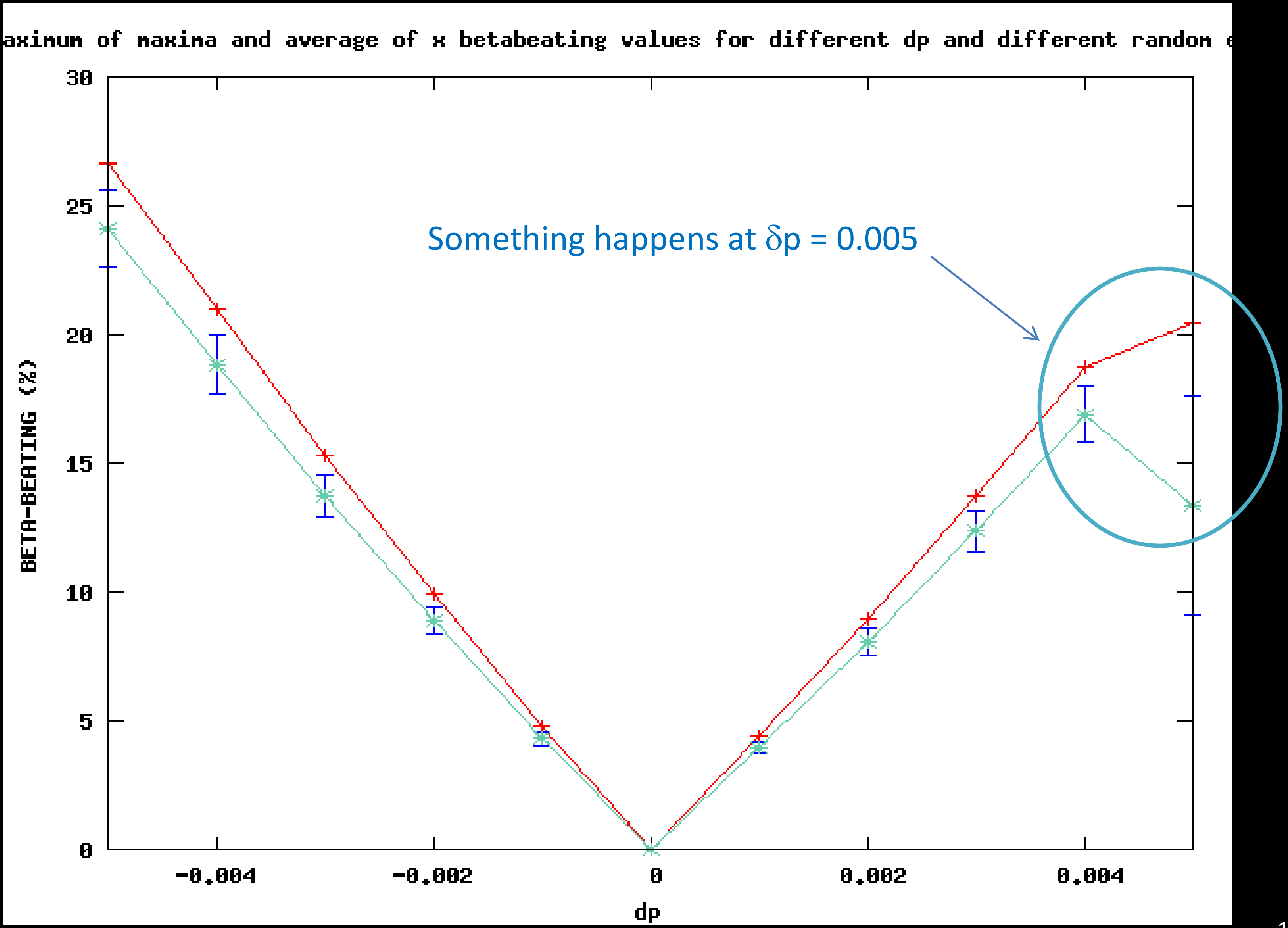
Chromatic beta-beating studies with PTC – Considering errors

- Results considering 15 seeds:

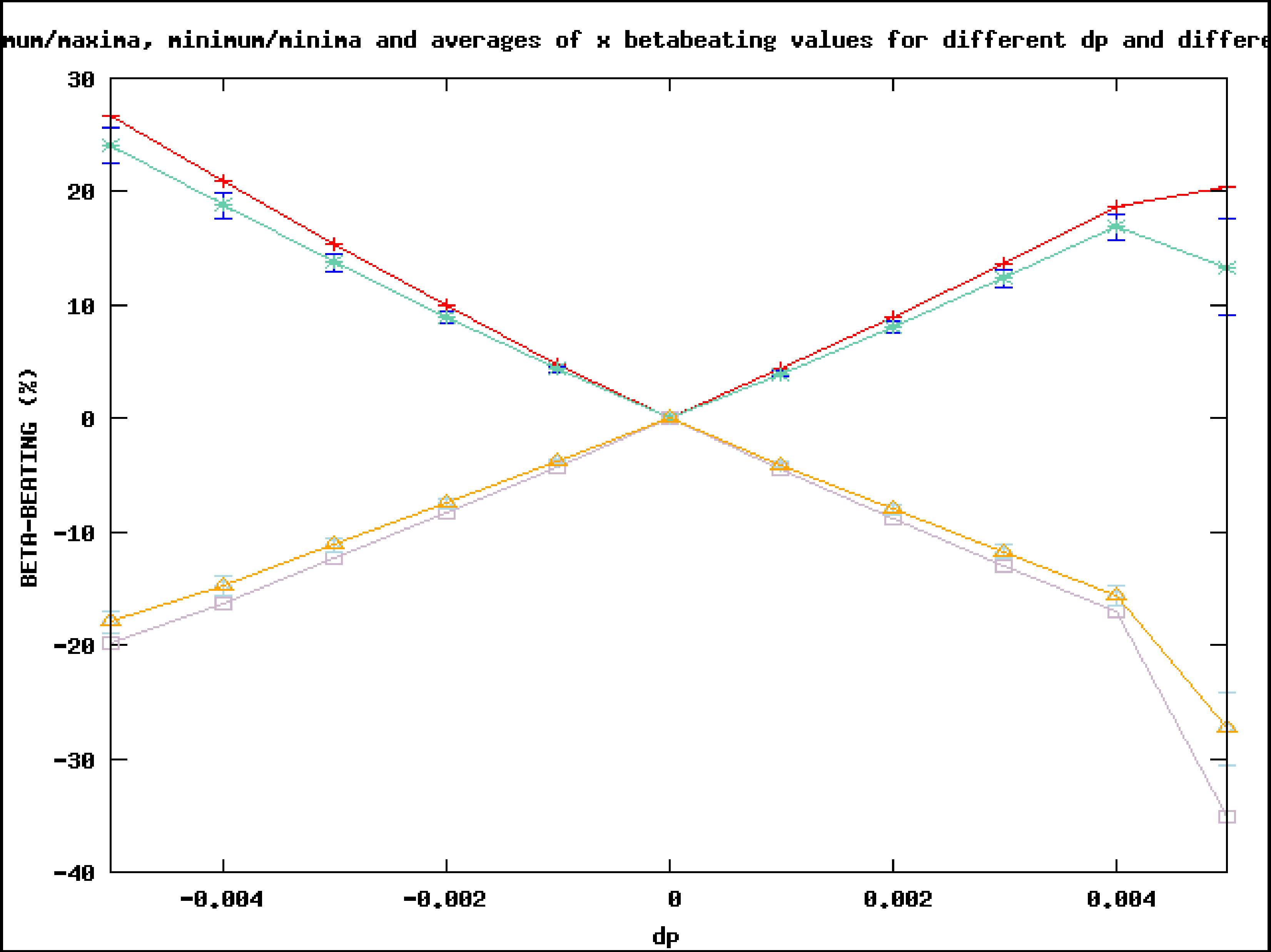


$$\frac{\Delta\beta}{\beta} = \frac{\beta_{seed}(\delta p) - \beta_{seed}(0)}{\beta_{seed}(0)}$$

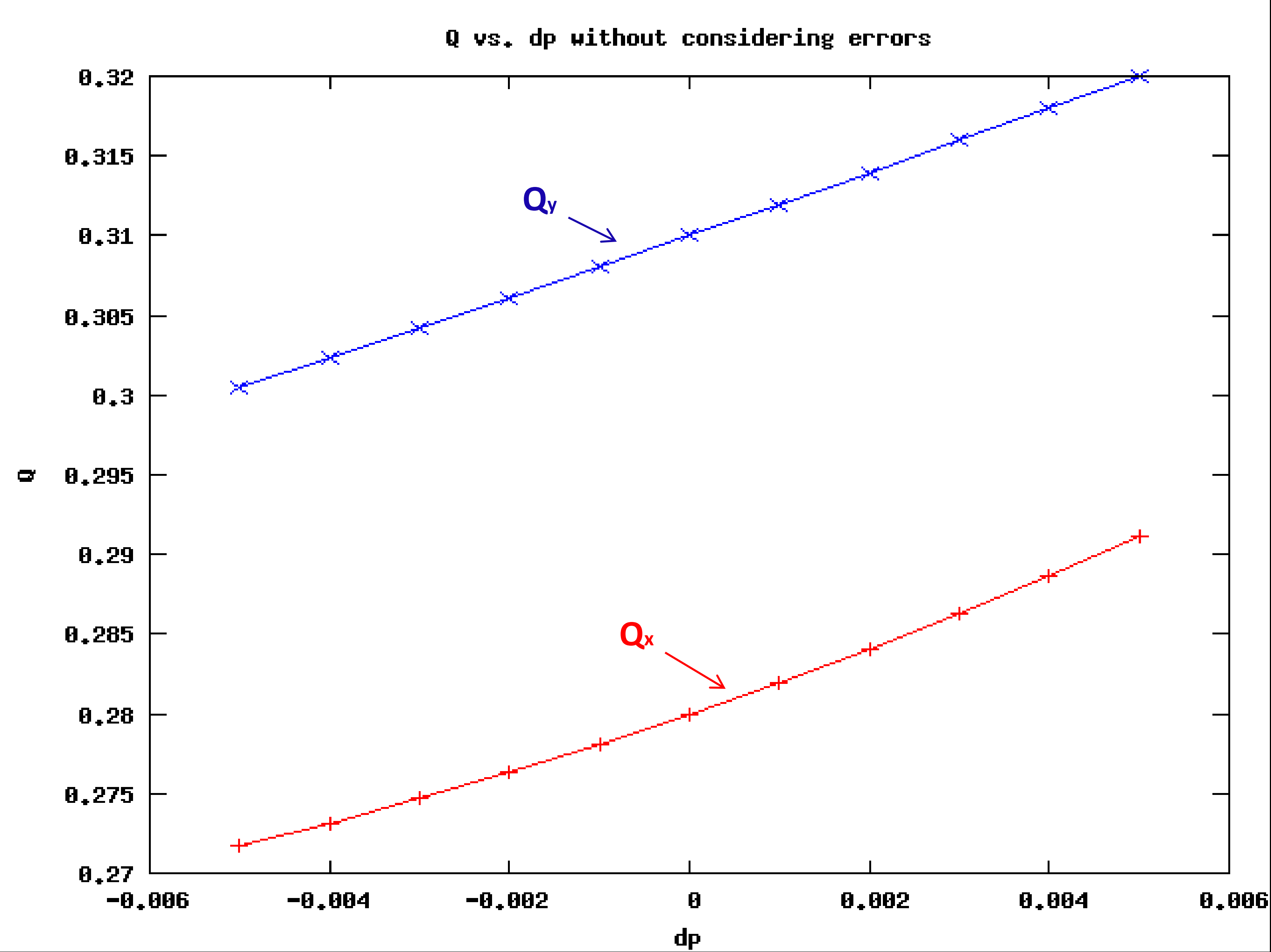
Chromatic beta-beating studies with PTC – Considering errors



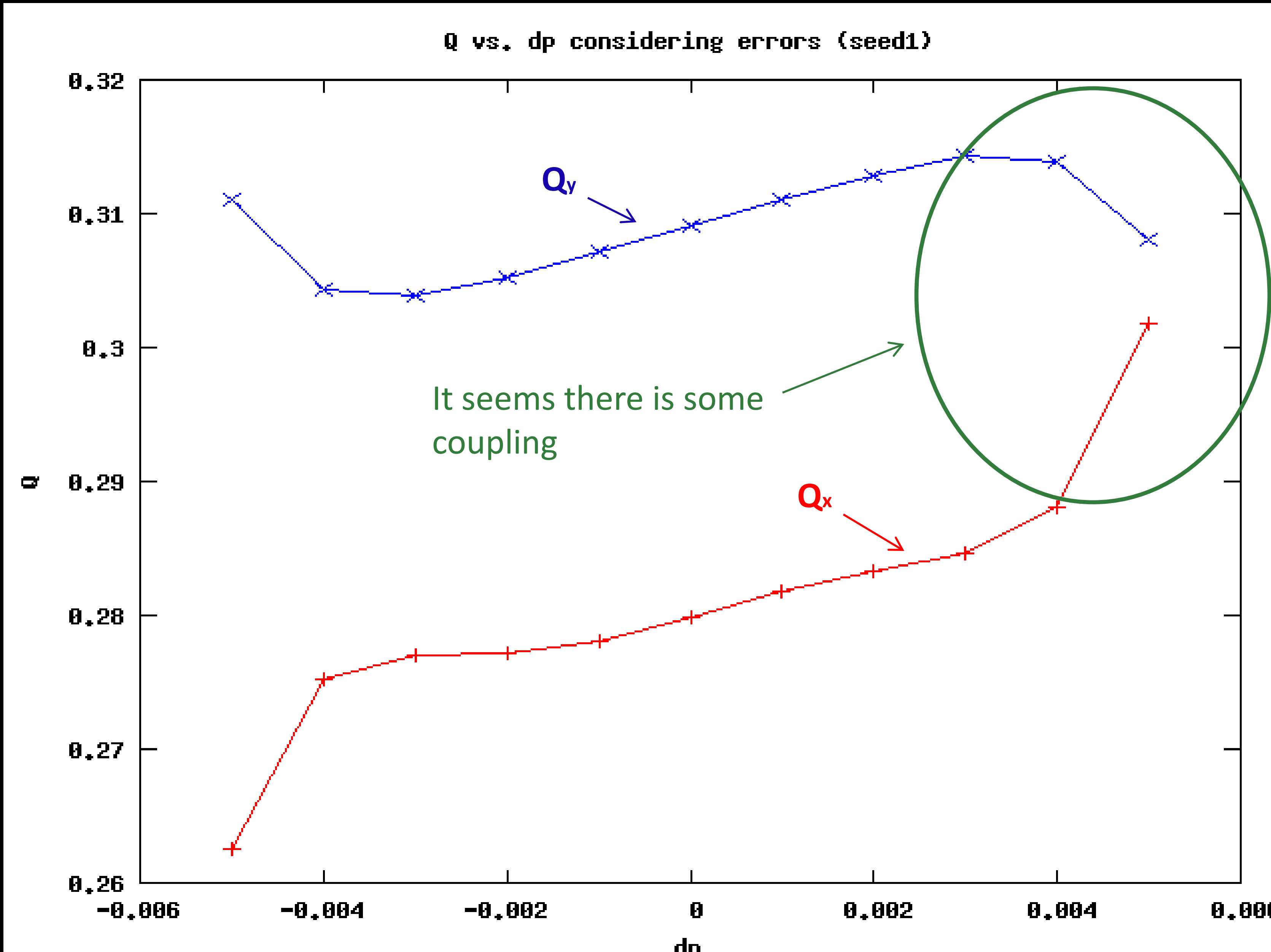
Chromatic beta-beating studies and PTC – Considering errors



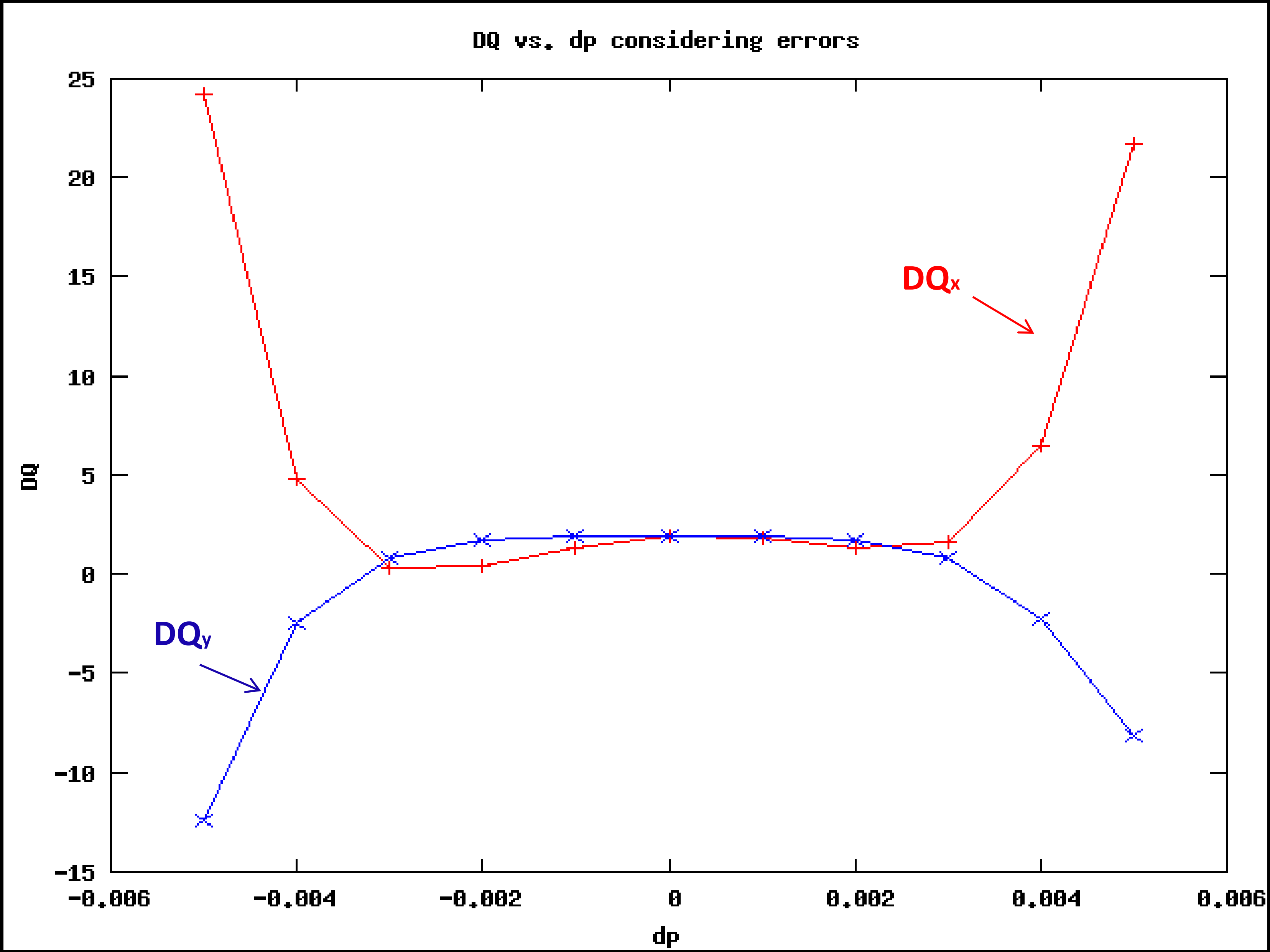
Chromatic beta-beating studies with PTC – Tune (without errors)



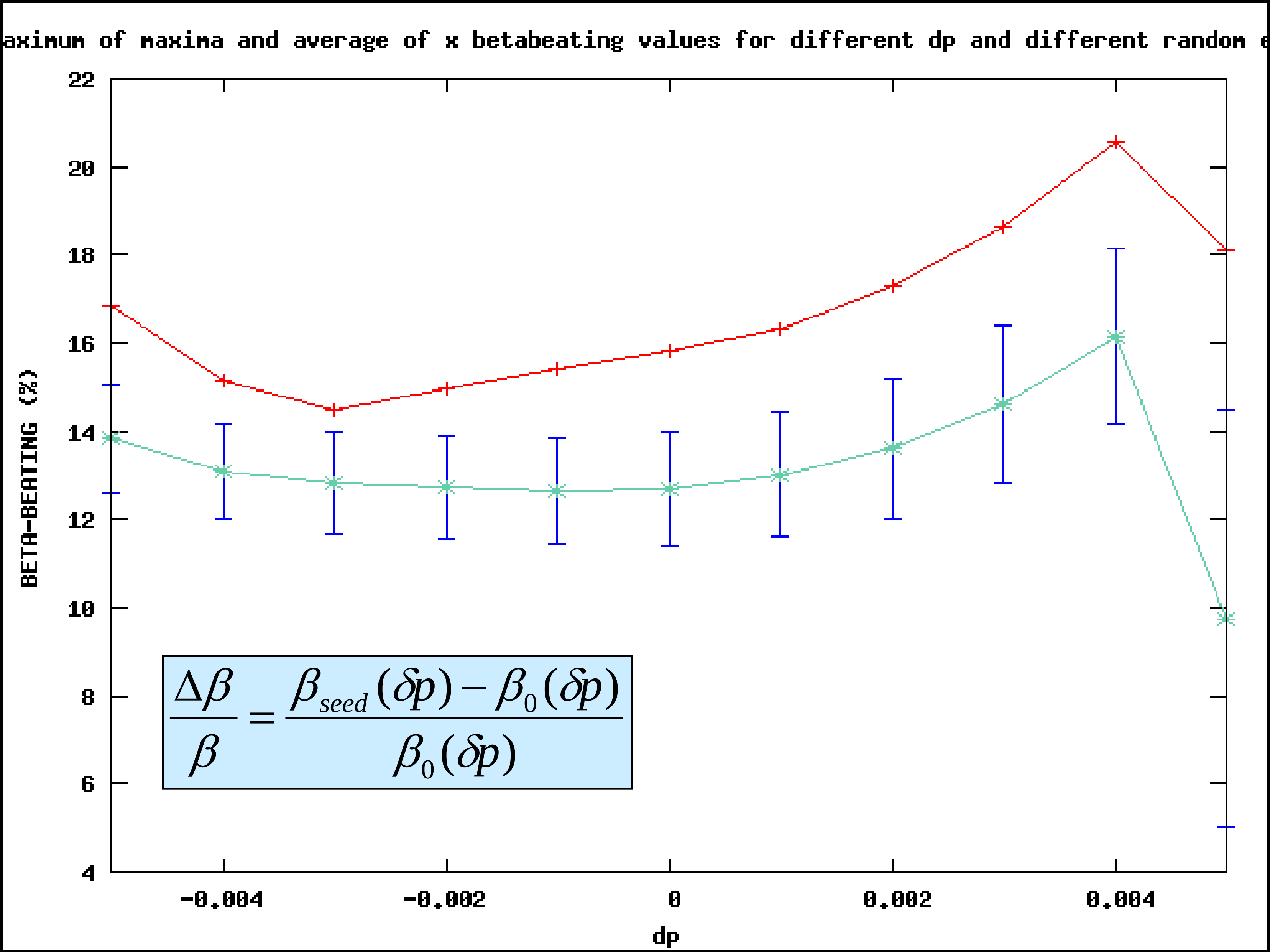
Chromatic beta-beating studies with PTC – Tune (with errors)



Chromatic beta-beating studies with PTC – Chromaticity (with errors)

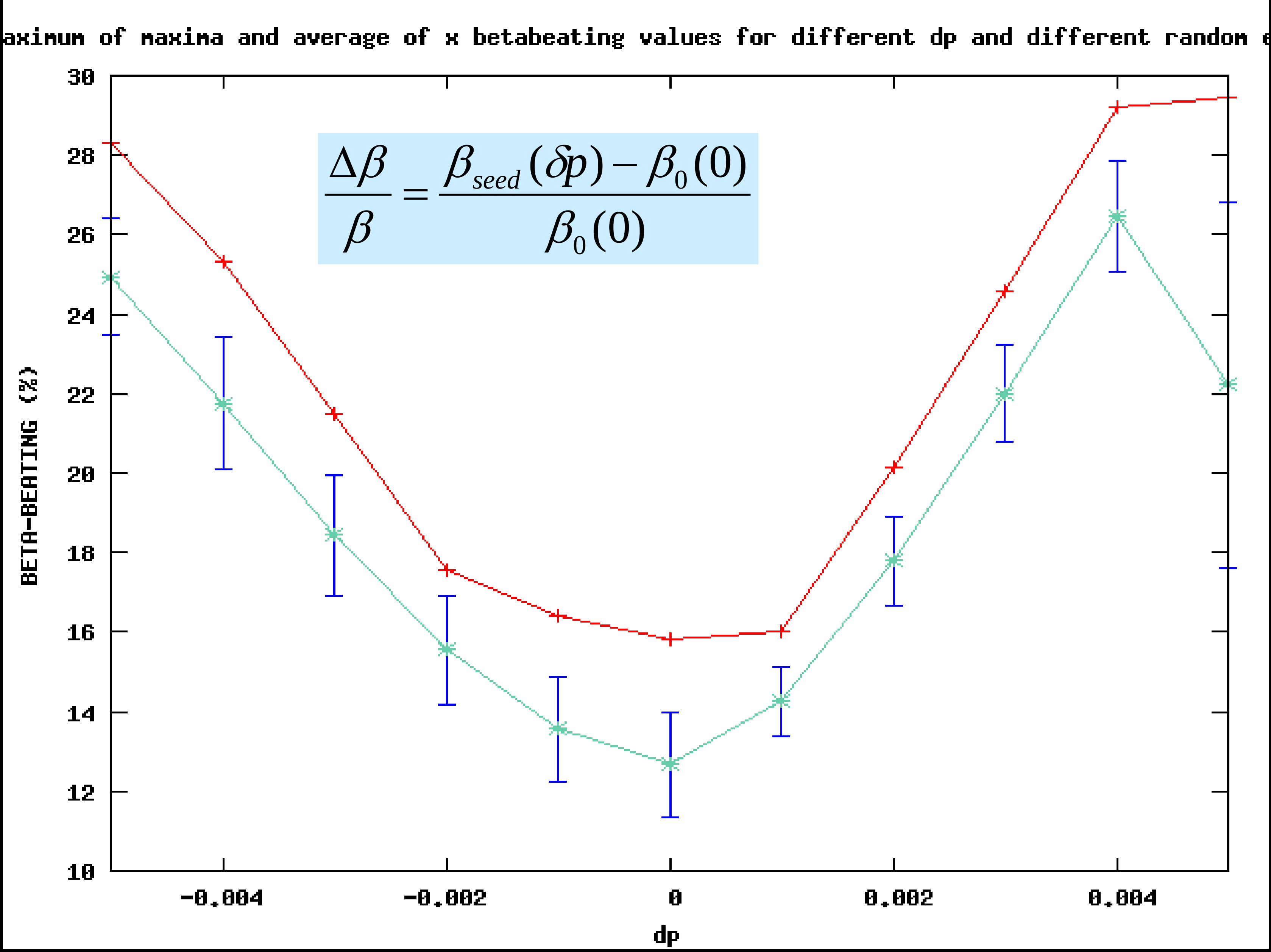


Chromatic beta-beating studies with PTC – Considering errors



$$\frac{\Delta\beta}{\beta}=\frac{\beta_{seed}(\delta p)-\beta_0(\delta p)}{\beta_0(\delta p)}$$

Chromatic beta-beating studies with PTC – Considering errors



$$\frac{\Delta\beta}{\beta} = \frac{\beta_{seed}(\delta p) - \beta_0(0)}{\beta_0(0)}$$

Chromatic beta-beating studies with MAD-X and PTC – Summary

- In the ideal model MAD-X and PTC give very similar results, as expected for the δp range we were considering

- It exists already a much bigger difference when we include errors. That justifies the further use of PTC instead of MAD-X, since higher order errors seem to be important

- For δp values bigger than 4.10^{-3} the tune vary abruptly and the chromatic coupling can lead to non-monotonic variation of the beta-beating (in addition it is essential to include an initial correction (match in PTC) setting the chromaticity to 2 units)

- We obtained the behavior of the beta-beating as a function of two parameters: δp and seed

Structure

1) Chromatic beta-beating studies with MAD-X and PTC

2) Dispersion measurements

3) BPM failure detection

Dispersion measurements

- $D(s)\delta \rightarrow$ Off-momentum closed orbit

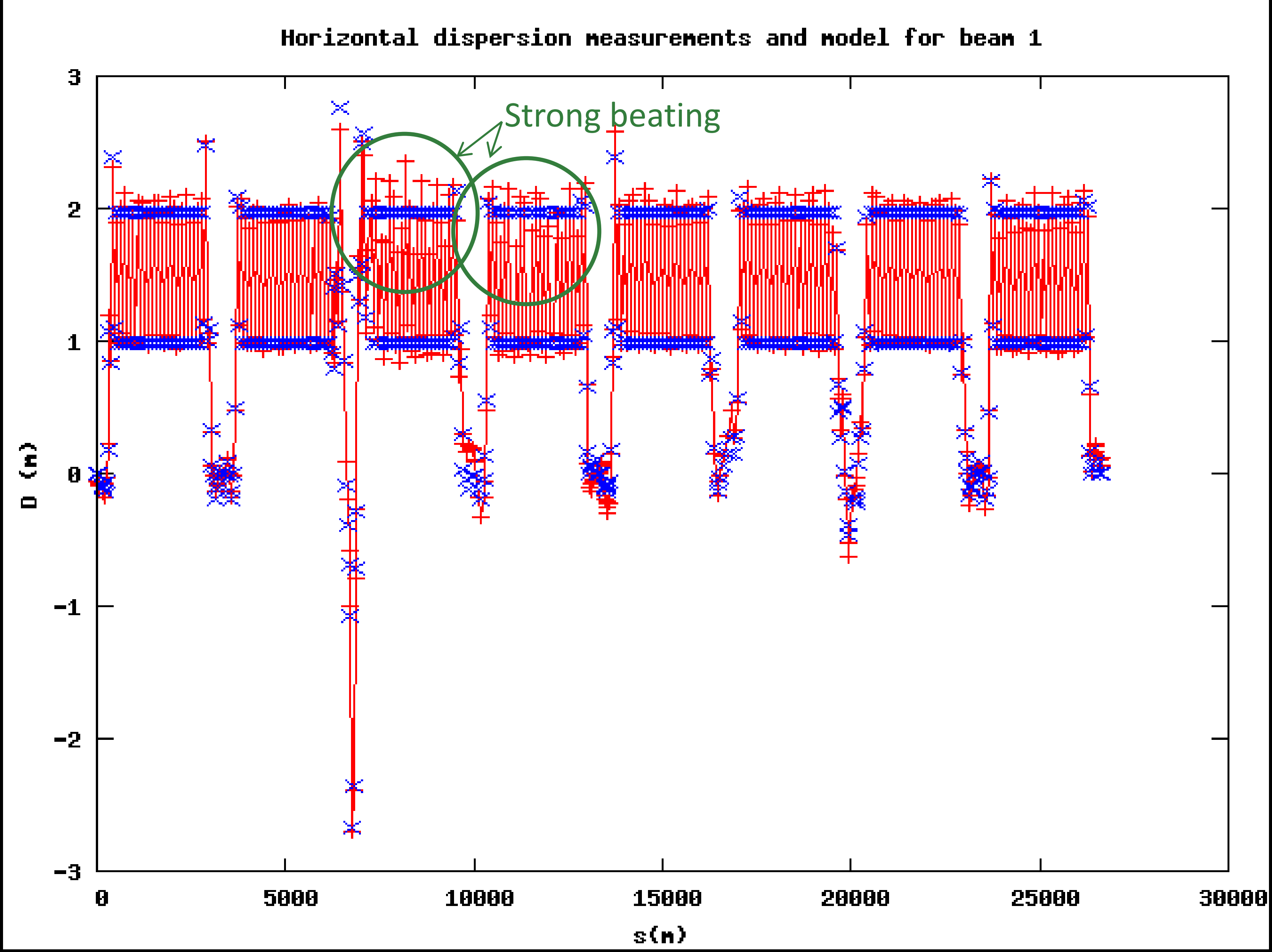
Phase-slip factor

$$D(s) = \frac{dx_{co}}{d(\delta p)} = -\eta f_0 \frac{dx_{co}}{df_0}$$

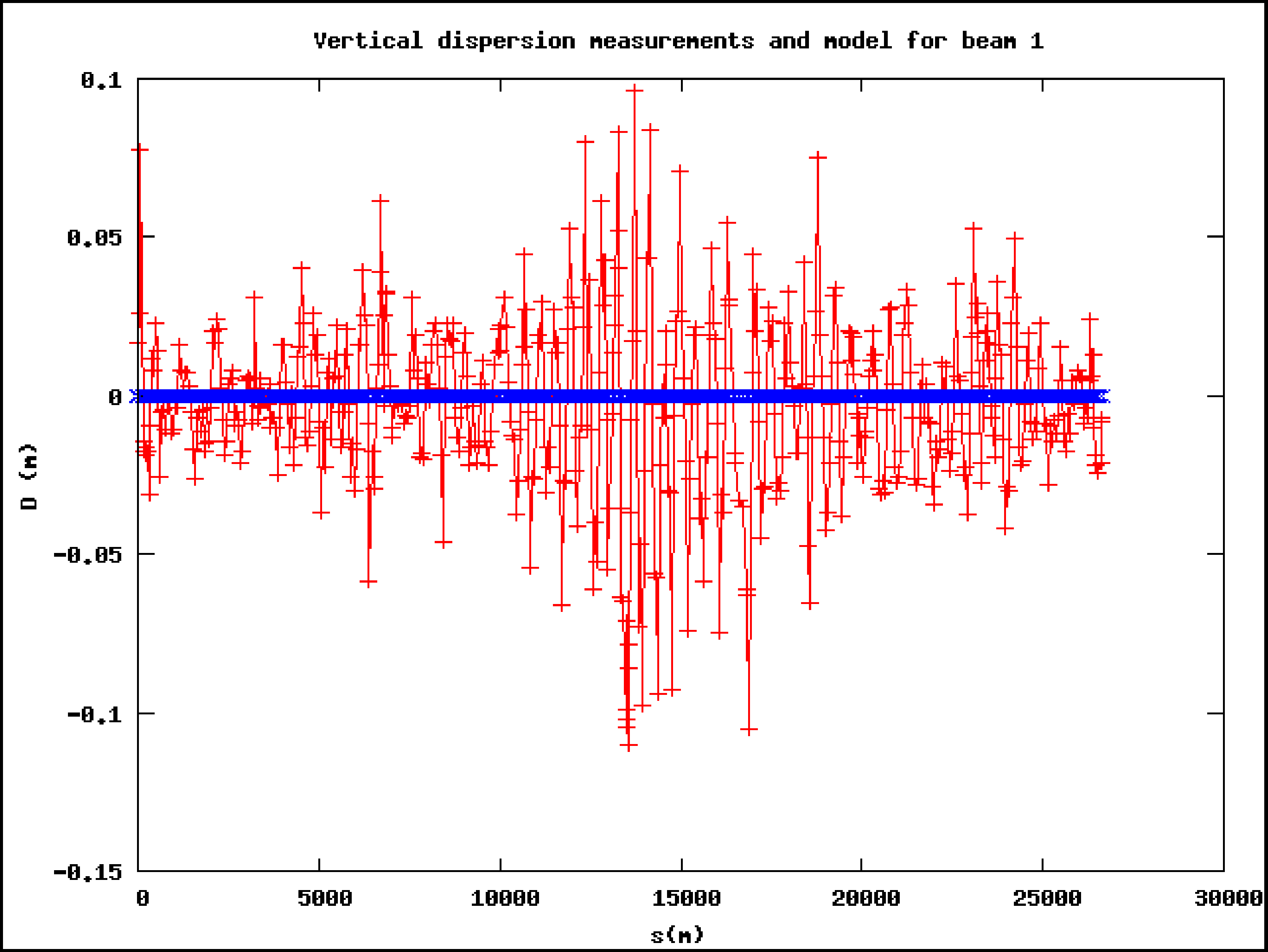
-We varied the RF frequency between -150 Hz and 150 Hz in steps of 50 Hz (134 measurements in total, taking around 20 orbits at each step)

-Performing a linear regression of the horizontal and vertical position data vs. δp we obtain the measured dispersion for all BPMs, including error estimate

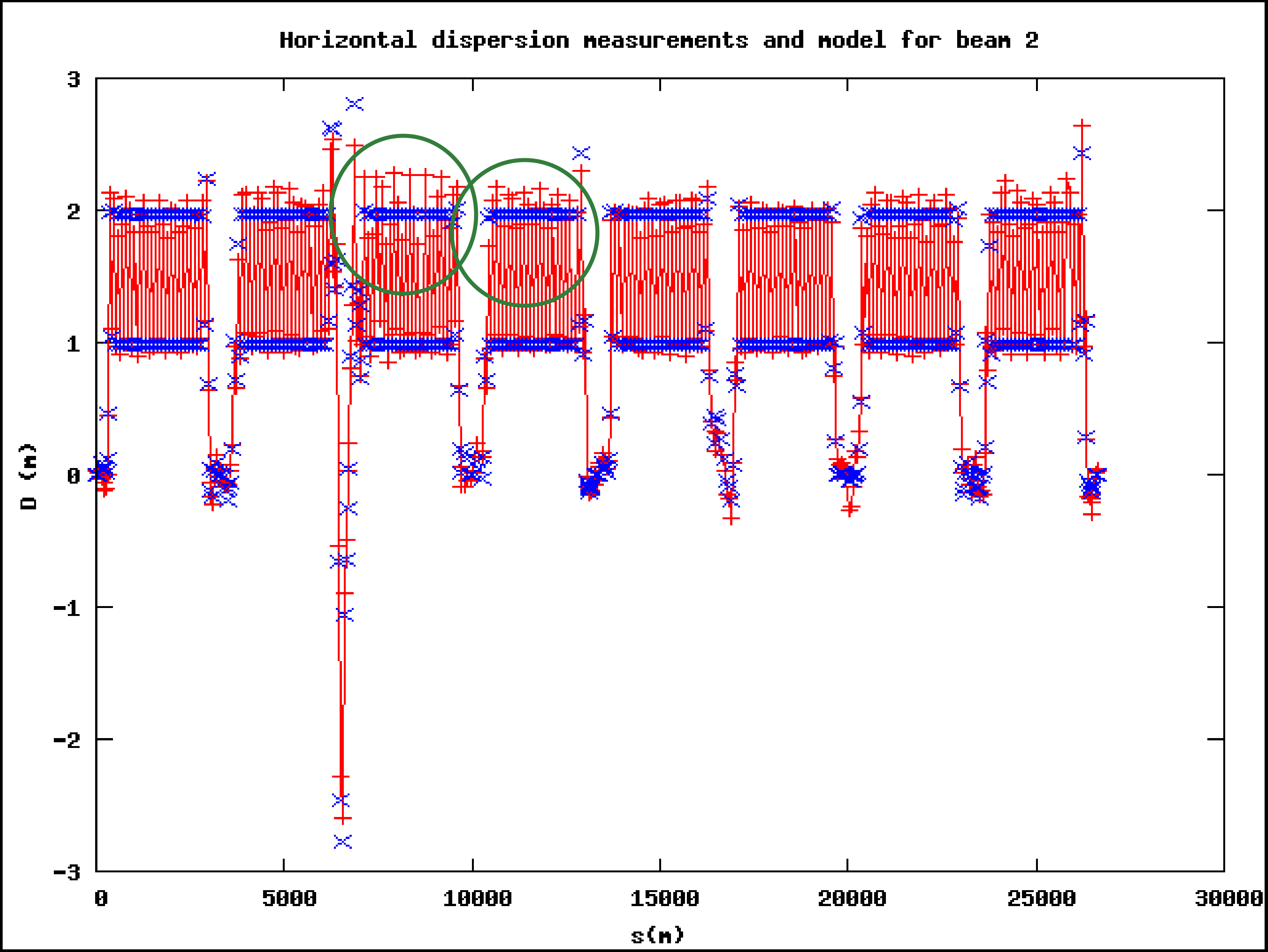
Dispersion measurements (Beam 1) – 450 GeV



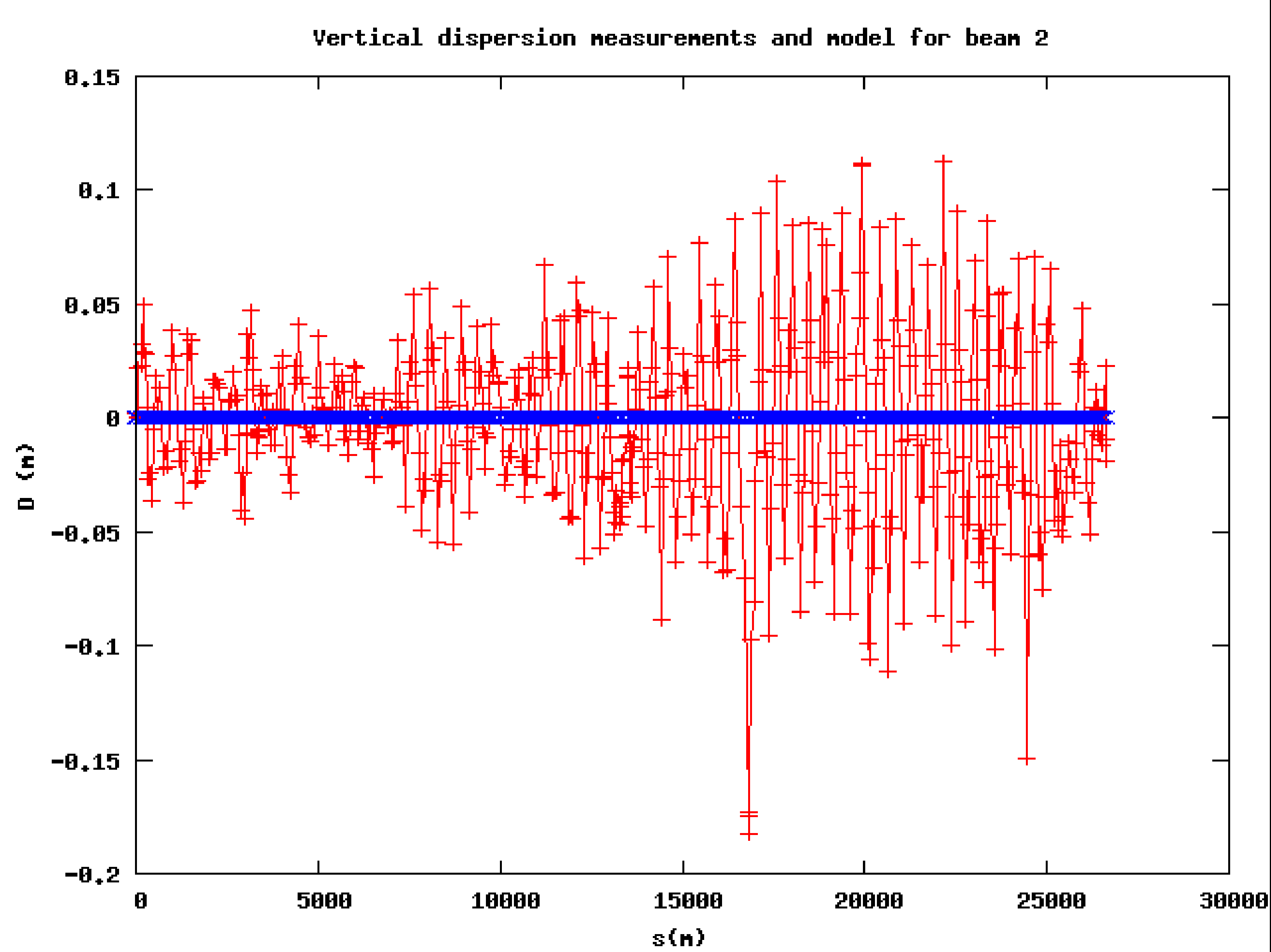
Dispersion measurements (Beam 1) – 450 GeV



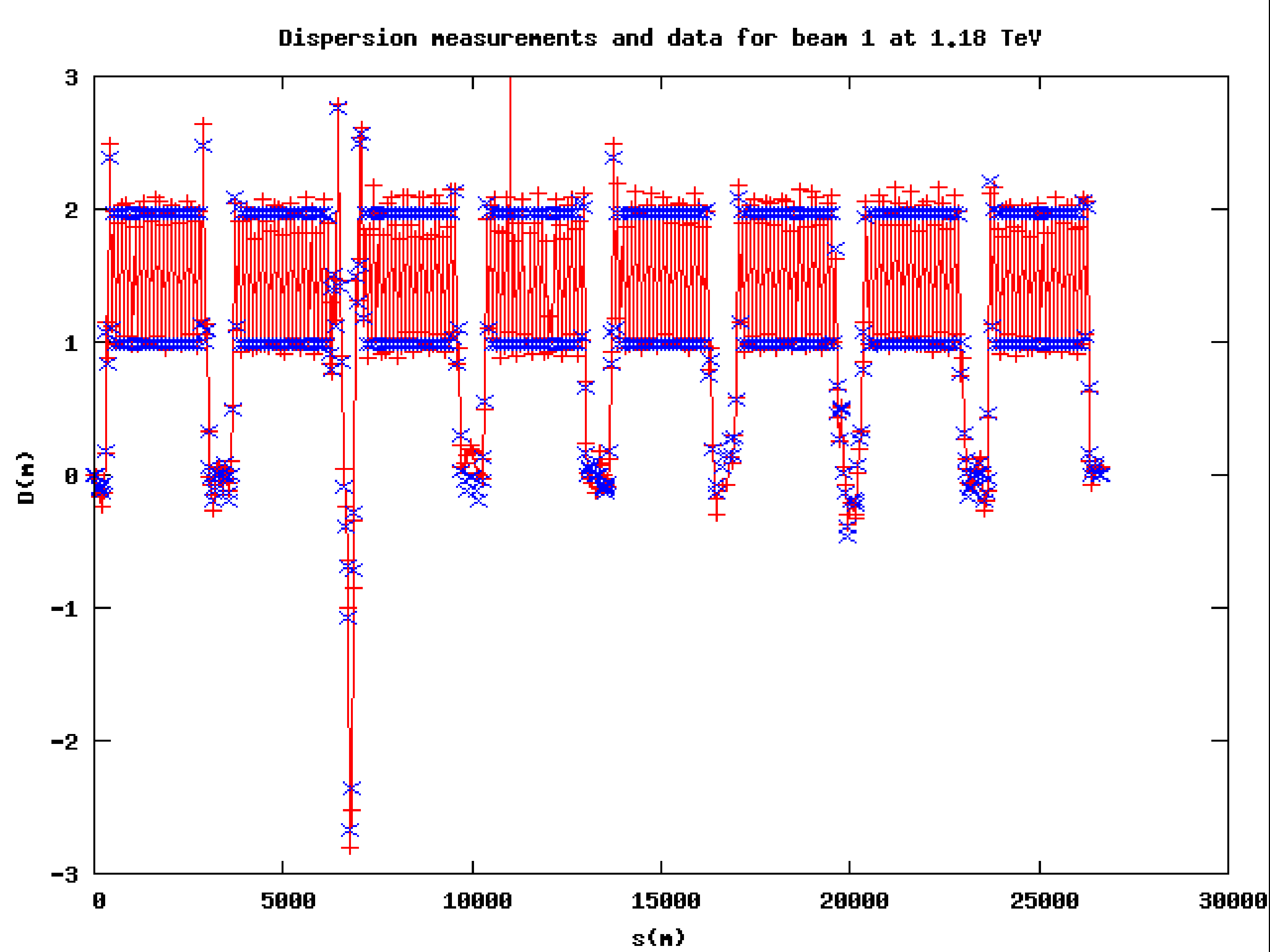
Dispersion measurements (Beam 2) – 450 GeV



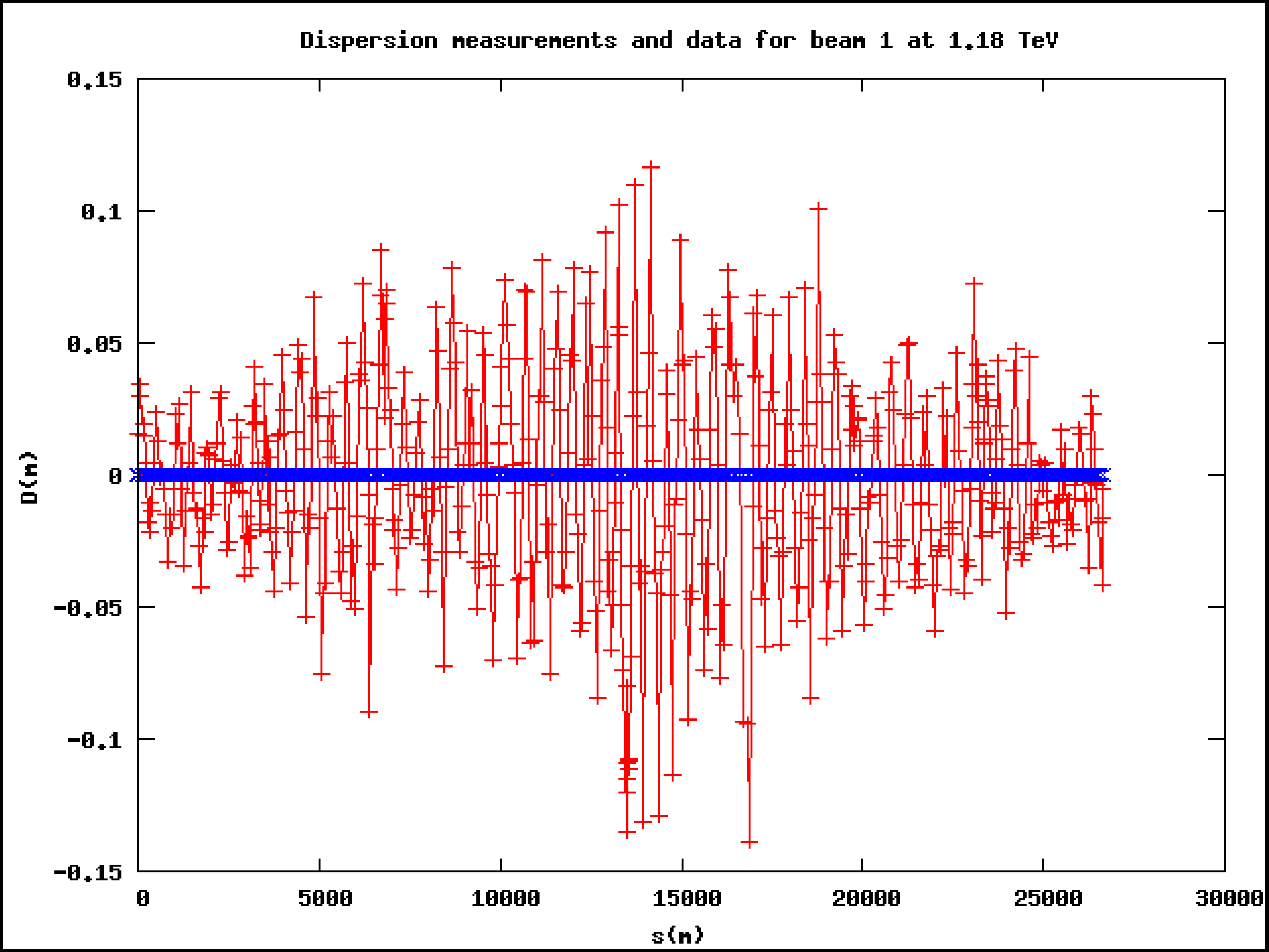
Dispersion measurements (Beam 2) – 450 GeV



Dispersion measurements (Beam 1) – 1.18 TeV



Dispersion measurements (Beam 1) – 1.18 TeV



Dispersion measurements - Summary

- We developed a script for a quick calculation of *D* and *D'* at each BPM from the YASP row data, for later combination with beta beating analysis

450 GeV, after pre-cycling:

- D_x shows ~10% beating, especially in S3-4 and S4-5; it is quite similar for both beams, but a bit smaller for beam 2

- D_y is small in both planes, slightly bigger for beam 2

1.18 TeV:

- D_y for both energies looks almost the same

- D_x shows still beating in S3-4 & S4-5, but about half as large, and it's slightly larger in S2-3 & S7-8

Structure

1) Chromatic betabbeating studies with MAD-X and PTC

2)Dispersion measurements

3) BPM failure detection

BPM failure detection - Method

1) We calculate in our model the phase advance difference for consecutive BPMs for 100 seeds and subtracts from this value the value for the ideal case without error for each BPM:

$$\Delta(\Delta\phi) = \Delta\phi_{we} - \Delta\phi_{ne}$$

2) We calculate the rms, maximum and the minimum values for each BPM

3) We calculate the percentage of beta-beating of our measurement by computing:

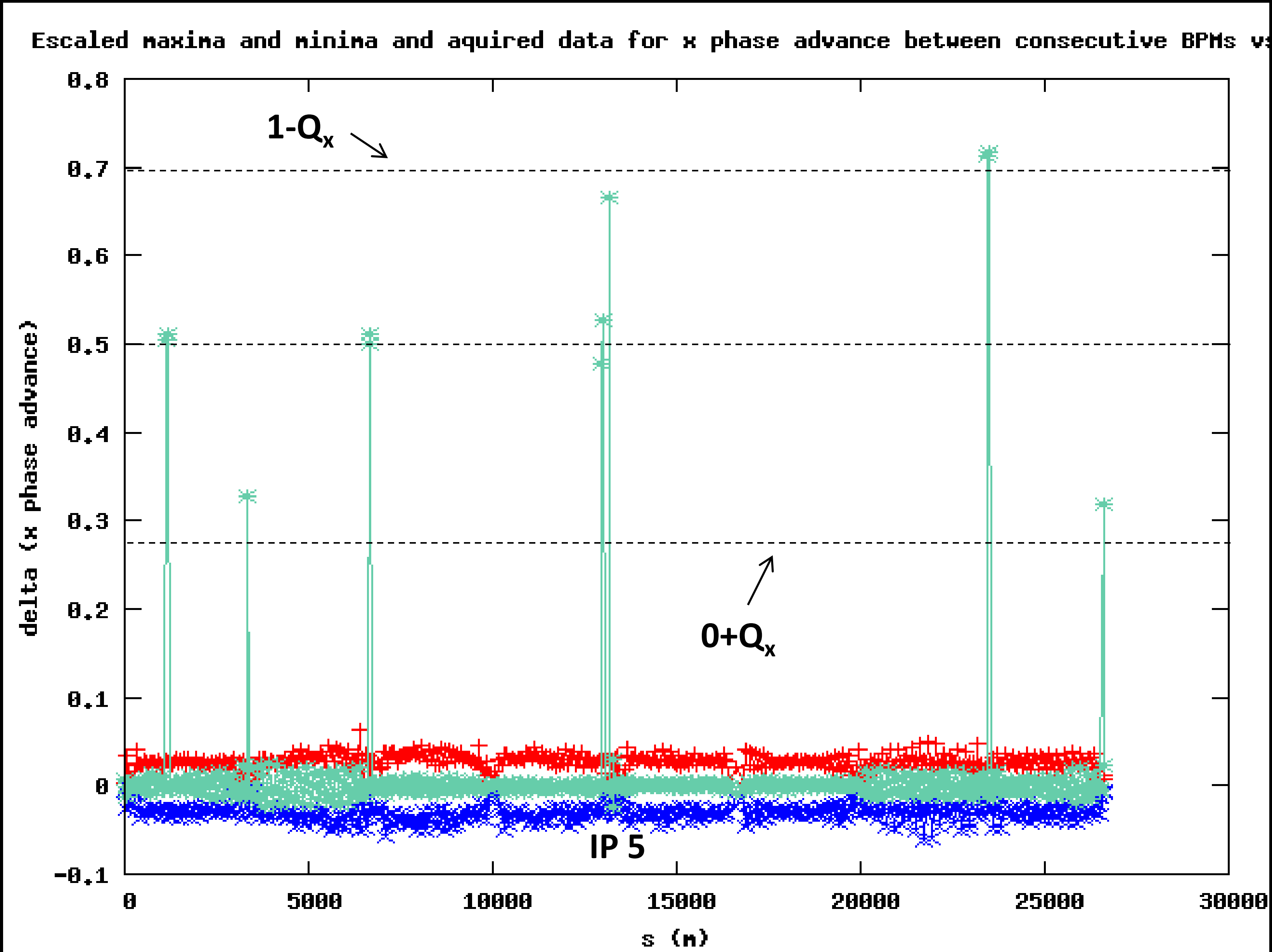
$$\frac{< \Delta(\Delta\phi)^{measured} >_{rms}}{< \Delta(\Delta\phi)^{model}_{rms} >_{rms}}$$

(rms taken over all BPMs)

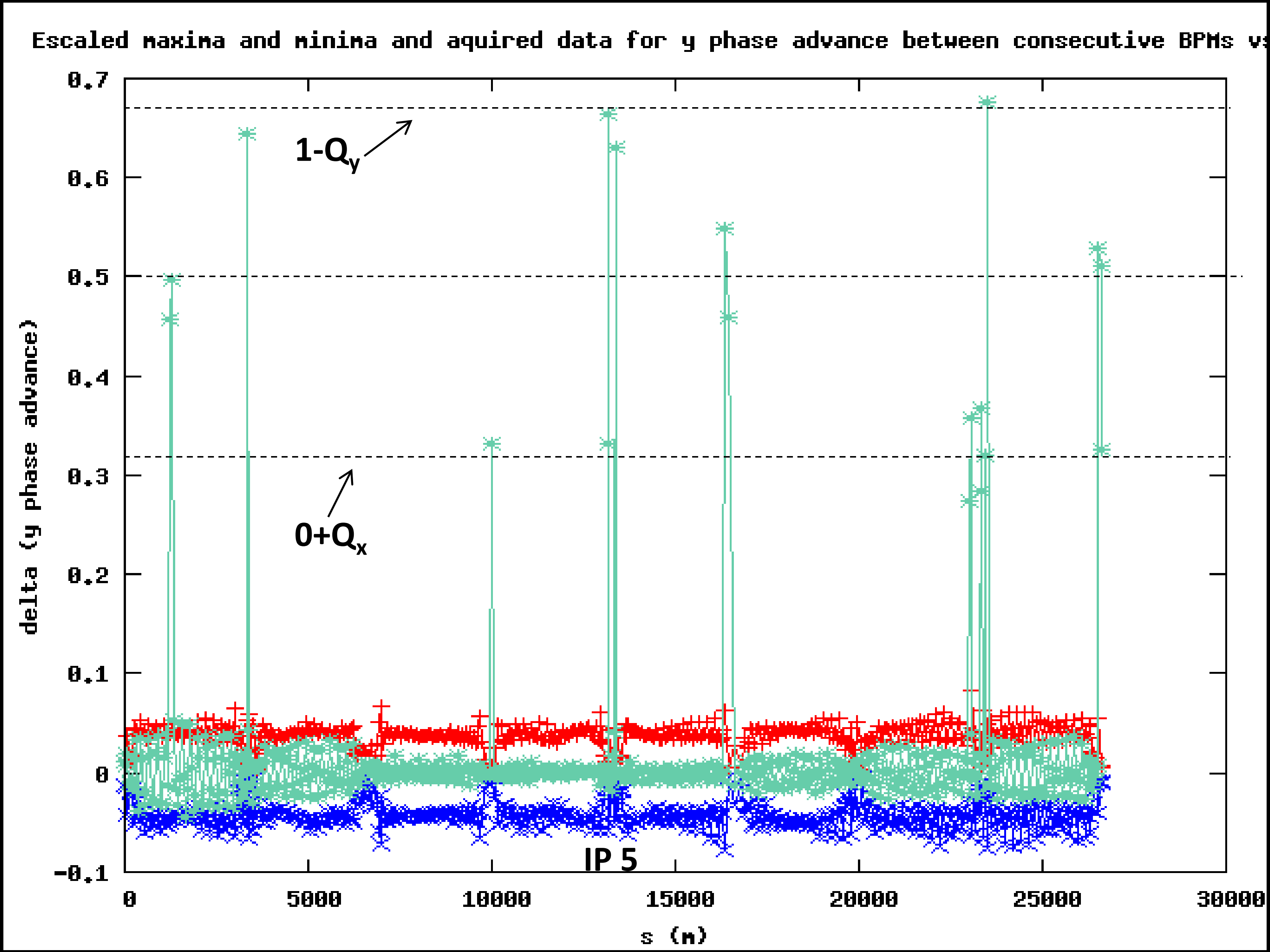
4) We multiply this value times the maxima and minima from model calculated before, and these values will form our “envelope”

5) We represent the measurements together with the created “envelope”

BPM failure detection – Beam 2, Horizontal plane



BPM failure detection – Beam 2, Horizontal plane



BPM failure detection – Problematic BPM couples

Horizontal plane:

"BPMYB.5R8.B2" "BPMR.6R8.B2"
"BPMSY.4L1.B2" "BPMS.2L1.B2"
"BPMS.2L1.B2" "BPMSW.1L1.B2"
"BPMSW.1R1.B2" "BPMS.2R1.B2"
"BPM.24R1.B2" "BPM.25R1.B2"
"BPM.25R1.B2" "BPM.26R1.B2"
"BPMSW.1R2.B2" "BPMS.2R2.B2"
"BPMS.2R2.B2" "BPMSX.4R2.B2"
"BPMW.4L3.B2" "BPMW.4R3.B2"
"BPMW.4R3.B2" "BPMWE.4R3.B2"
"BPM.9L5.B2" "BPM.8L5.B2"
"BPM.8L5.B2" "BPM.7L5.B2"
"BPMWB.4L5.B2" "BPMWT.B4L5.B2"
"BPMWT.B4L5.B2" "BPMWT.A4L5.B2"
"BPMS.2L5.B2" "BPMSW.1L5.B2"
"BPMSW.1R8.B2" "BPMS.2R8.B2"
"BPMYB.4R8.B2" "BPMYB.5R8.B2"
"BPMS.2R1.B2" "BPMSY.4R1.B2"
"BPMS.2L2.B2" "BPMSW.1L2.B2"
"BPMYB.4R2.B2" "BPM.5R2.B2"
"BPMSY.4L5.B2" "BPMS.2L5.B2"

Vertical plane:

"BPMYB.5R8.B2" "BPMR.6R8.B2"
"BPMWB.4L1.B2" "BPMSY.4L1.B2"
"BPMSY.4L1.B2" "BPMS.2L1.B2"
"BPMS.2L1.B2" "BPMSW.1L1.B2"
"BPMS.2R1.B2" "BPMSY.4R1.B2"
"BPM.26R1.B2" "BPM.27R1.B2"
"BPM.27R1.B2" "BPM.28R1.B2"
"BPM.28R1.B2" "BPM.29R1.B2"
"BPM.32R1.B2" "BPM.33R1.B2"
"BPM.32L2.B2" "BPM.31L2.B2"
"BPMSW.1R2.B2" "BPMS.2R2.B2"
"BPMR.6R2.B2" "BPM_A.7R2.B2"
"BPMWE.4L3.B2" "BPMW.4L3.B2"
"BPMWB.4L5.B2" "BPMWT.B4L5.B2"
"BPMWT.B4L5.B2" "BPMWT.A4L5.B2"

"BPMS.2L5.B2" "BPMSW.1L5.B2"
"BPMSW.1R5.B2" "BPMS.2R5.B2"
"BPMS.2R5.B2" "BPMSY.4R5.B2"
"BPM.8L6.B2" "BPMYB.5L6.B2"
"BPMYB.5L6.B2" "BPMYA.4L6.B2"
"BPM.8L8.B2" "BPM.7L8.B2"
"BPM.7L8.B2" "BPM.6L8.B2"
"BPMS.2L8.B2" "BPMSW.1L8.B2"
"BPMSW.1R8.B2" "BPMS.2R8.B2"
"BPMS.2R8.B2" "BPMSX.4R8.B2"
"BPMYB.4R8.B2" "BPMYB.5R8.B2"
"BPMSY.4L5.B2" "BPMS.2L5.B2"
"BPMSX.4L8.B2" "BPMS.2L8.B2"

BPM failure detection - Summary

-We observe BPMs out of envelope:

1) Values near 0.5: The polarity of a BPM can be wrong
2) Values near 1-Q or 0+Q: Possibly there is a synchronization problem

- The operation team has already detected some of these failure BPMs confirming our study

- Some bad BPMs from our dispersion measurement are in the above list

- Further studies are necessary to know what happens for BPMs with values far from 0.5, 1-Q and 0+Q

- These studies can be very helpful for the operation team as well as for optics measurements

- The same procedure has to be done with beam 1