Grid scan as lattice diagnostics

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13th ATF2 Project Meeting - 12 January 2012

Motivations

Principle

Determination of scale factors

Implementation

Horizontal scan

Vertical scan

Conclusion

Headlines

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Motivations

Lattice diagnostics

- Unexplained emittance growth during extraction
- Verification of the transfer matrices
- Some studies needs very low BPM scale errors

Grid scan[1]

- Little influence of correctors scale errors
- Determine if there are BPM scale errors
- Clear evidence of non-linearities

[1] from SLAC-PUB 5554

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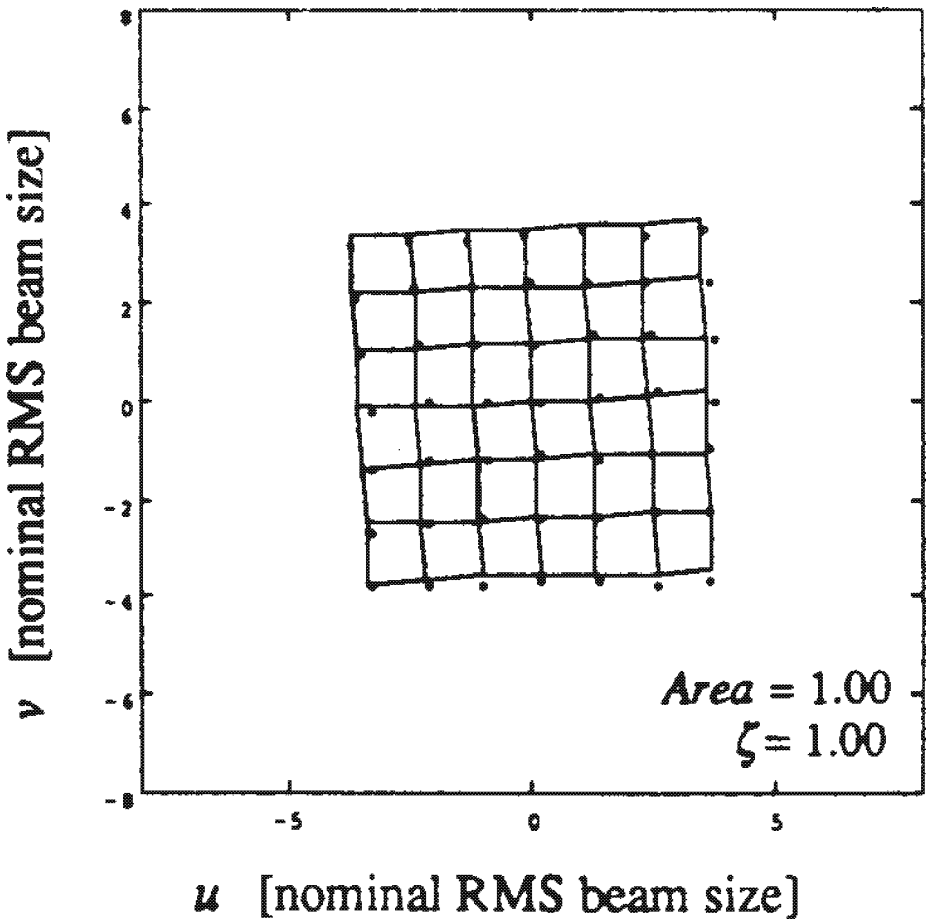
Grid Scan Principle

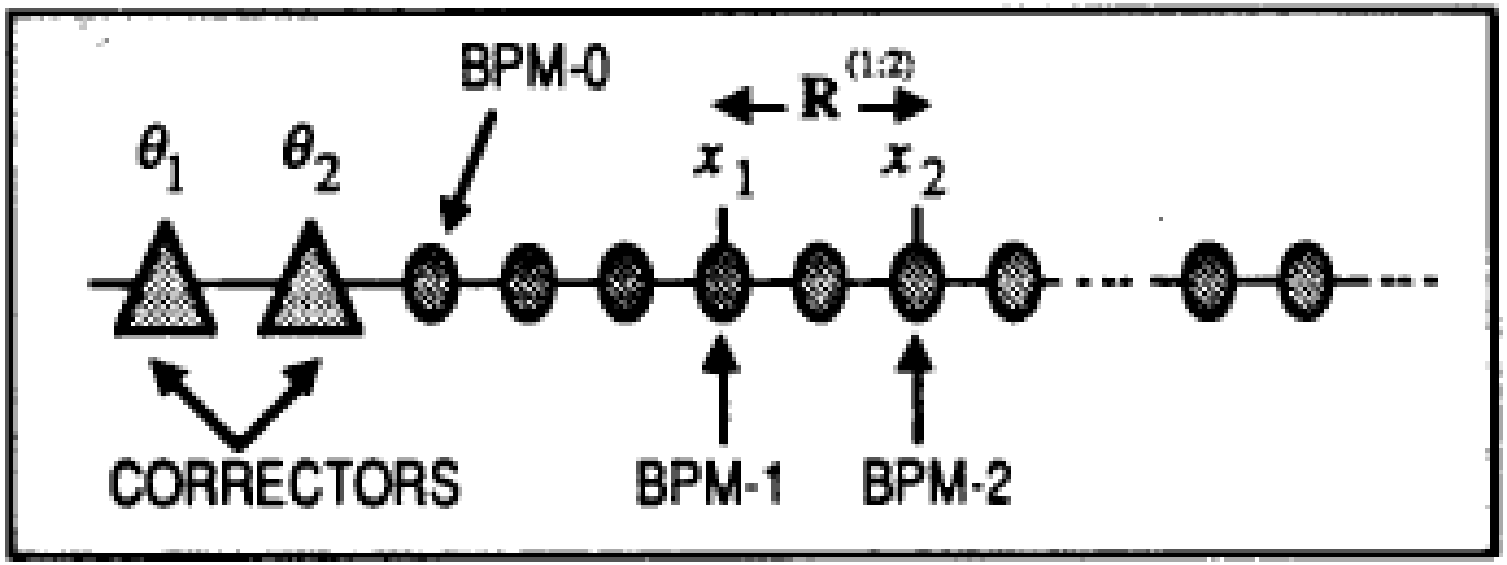
- Use 2 correctors to scan a grid in x and x' or in y and y'
- Use 2 BPMs to measure that grid.



Angle Measurement

$$\begin{bmatrix} x_1 \\ x_1' \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ R_{11}^{(1:2)} & R_{12}^{(1:2)} \end{bmatrix}^{-1} \times \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

- Any BPM downstream of the correctors can be used.
- X_1' measurement affected by:
  - BPM scale errors ($A_1 and B_1$).
  - errors on transfer matrices
- These errors deform the grid.



Phase Space Normalization

Normalization

- Phase space normalization :

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} \sqrt{1/\epsilon\beta_1} & 0 \\ \sqrt{\alpha_1/\epsilon\beta_1} & \sqrt{\beta_1/\epsilon} \end{bmatrix} \times \begin{bmatrix} x_1 \\ x_1' \end{bmatrix}$$

  with u and v in σ units.

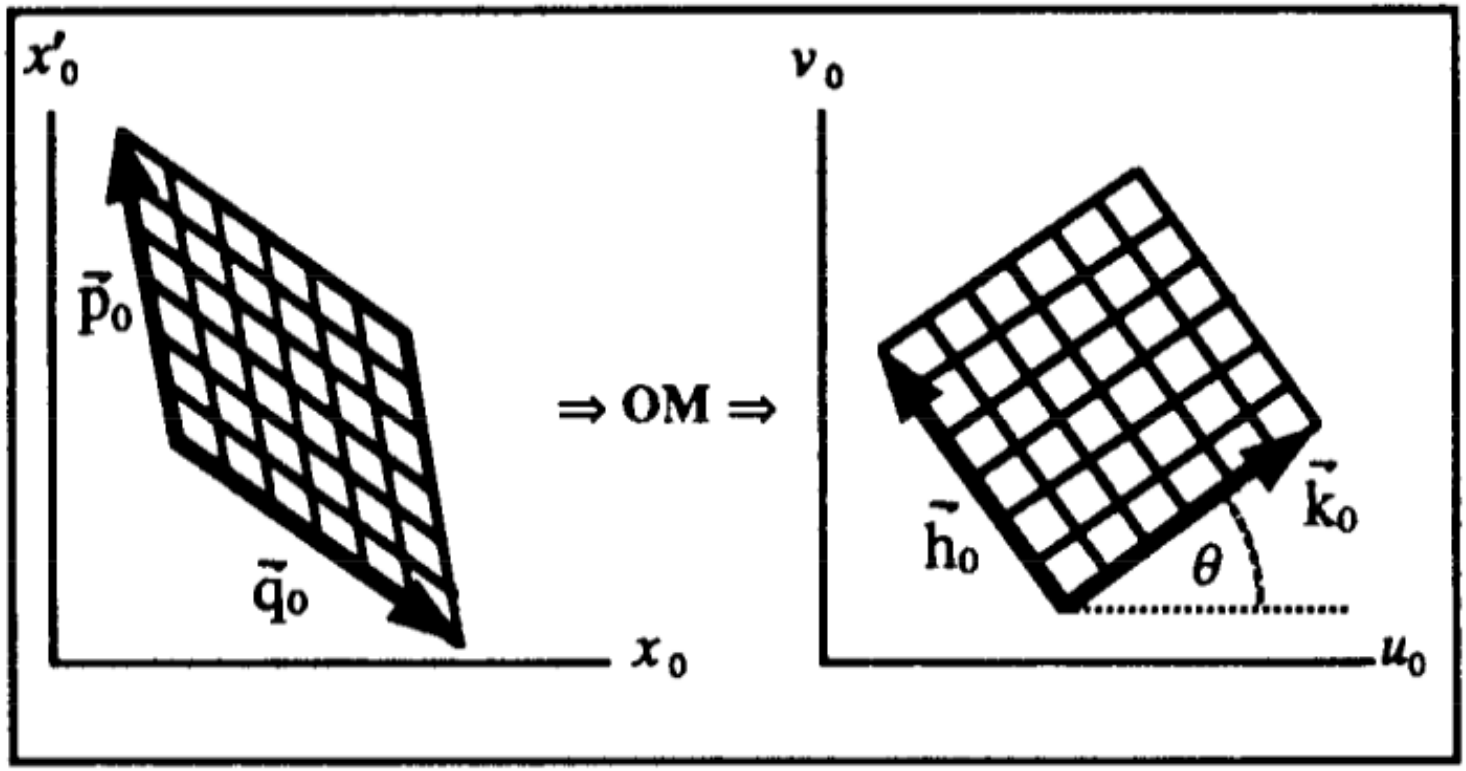
- squareness of the grid (vectors $\vec{h_i}$ and $\vec{k_i}$ define element i of the grid):

$$\chi = \frac{1}{2N} \sum_{i=1}^{N} \frac{|\vec{h_i}|^2 + |\vec{k_i}|^2}{\det(\vec{h_i}, \vec{k_i})}$$

- in normalized phase space all grids have same squareness and area

Grid Squaring

- by "choosing" the phase of the first BPM, the grid can be squared
- easier to see distortions
- squaring does not change the area of the grid
- but it does change influences of errors on the grid



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Determination of scale factors

Formalism

- a_i scale factor of BPM i ($\tilde{x}$ is the measured value):

$$x_i = a_i \tilde{x}_i$$

- as we have :

$$x'_i(j) = \frac{x_j - R_{11}^{i:j} x_i}{R_{12}^{i:j}}$$

- we got :

$$x'_i(j) = \frac{a_j \tilde{x}_j - R_{11}^{i:j} a_i \tilde{x}_i}{R_{12}^{i:j}}$$

- the area A(i,j) of the grid measured by BPM i and j is:

$$A(i,j) = \Delta u_i \Delta v_i(j)$$

with $\Delta \tilde{u}_i$ and $\Delta \tilde{v}_i(j)$ variating as $\tilde{x}_i$ and $\tilde{x}'_i(j)$

Determination of scale factors

System of equations

- From previous equations it comes that :

$$\tilde{A}(i,j) = a_i a_j A(i,j) - \frac{R_{11}^{i:j}}{R_{12}^{i:j}} \left(1 - \frac{a_i}{a_j}\right) \Delta u_i$$

- In EXT there is 24 BPMs, so for each plane :
  - 24 a_i to determine
  - 300 non linear, coupled equations !!

Trick

- $a_i \sim a_j \simeq 1$ => most of the cases (if $\frac{R_{11}^{i:j}}{R_{12}^{i:j}} < 1$):

$$\tilde{A}(i,j) = a_i a_j A(i,j)$$

Algorithm

Trick 2

- I don't know how to solve such a system :-(
- $\Rightarrow$ Iterative method with :

$$\tilde{a}_k = < \tilde{A}(i,j) >_{i \text{ or } j=k} - < \tilde{A}(i,j) >_{i \text{ and } j \neq k} + 1$$

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Implementation
- Horizontal scan
- Vertical scan

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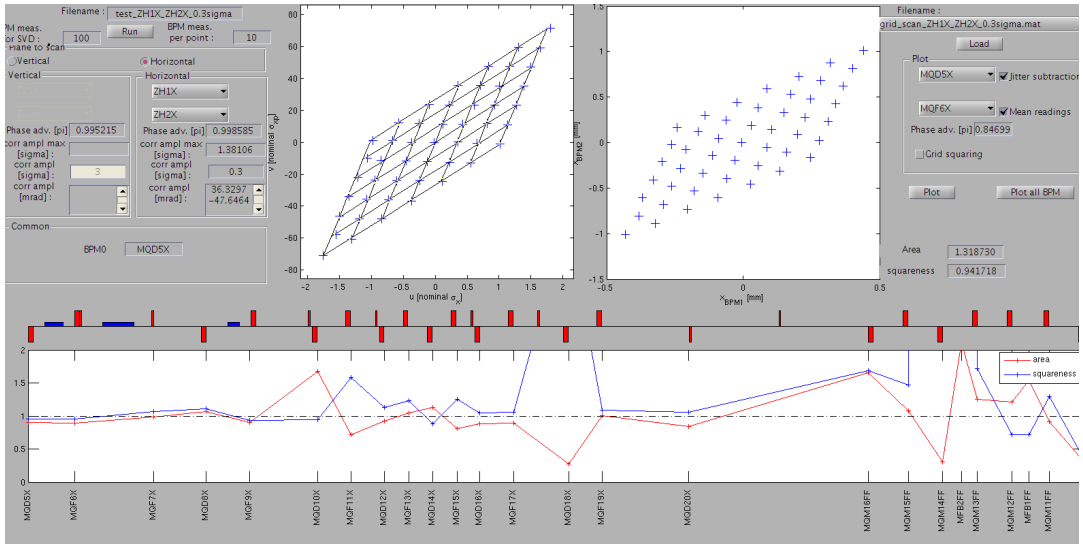
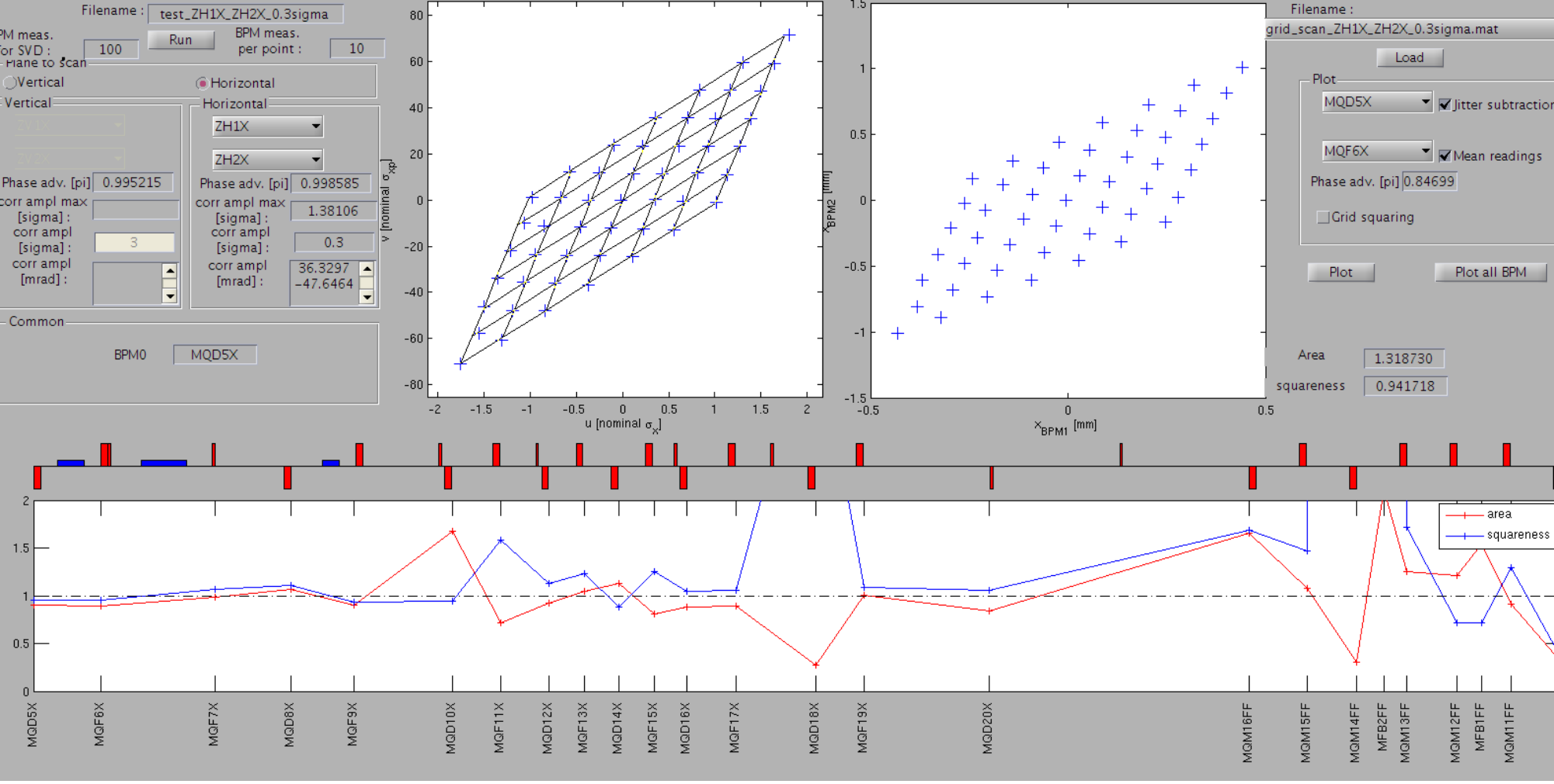
Implementation

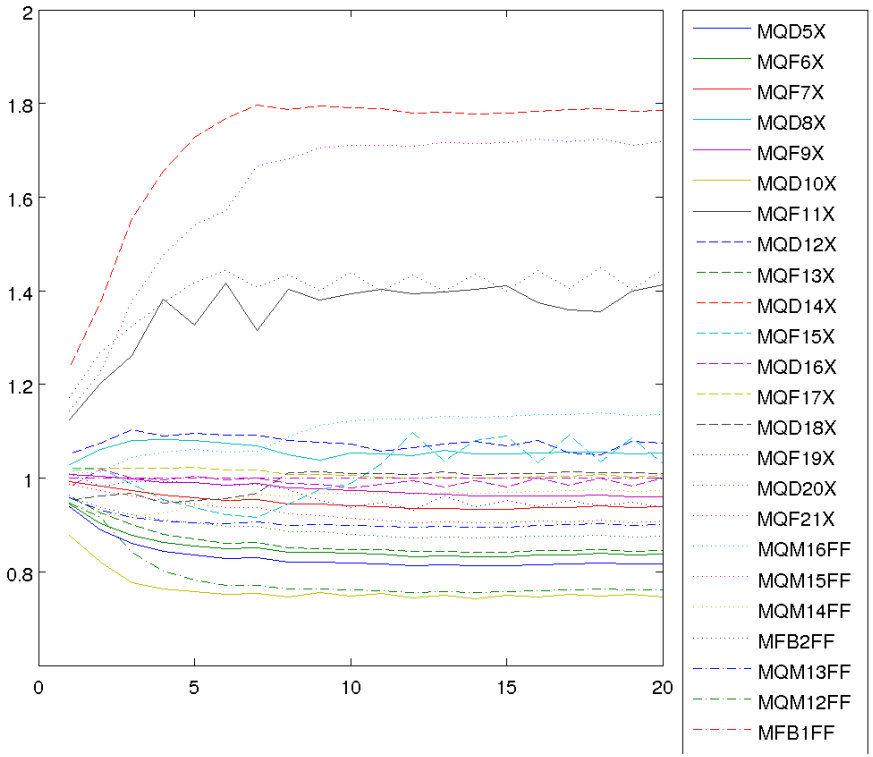
- Implemented in the Flight Simulator for both planes
- Includes jitter subtraction
- Bad pulses detection
- Optional grid squaring

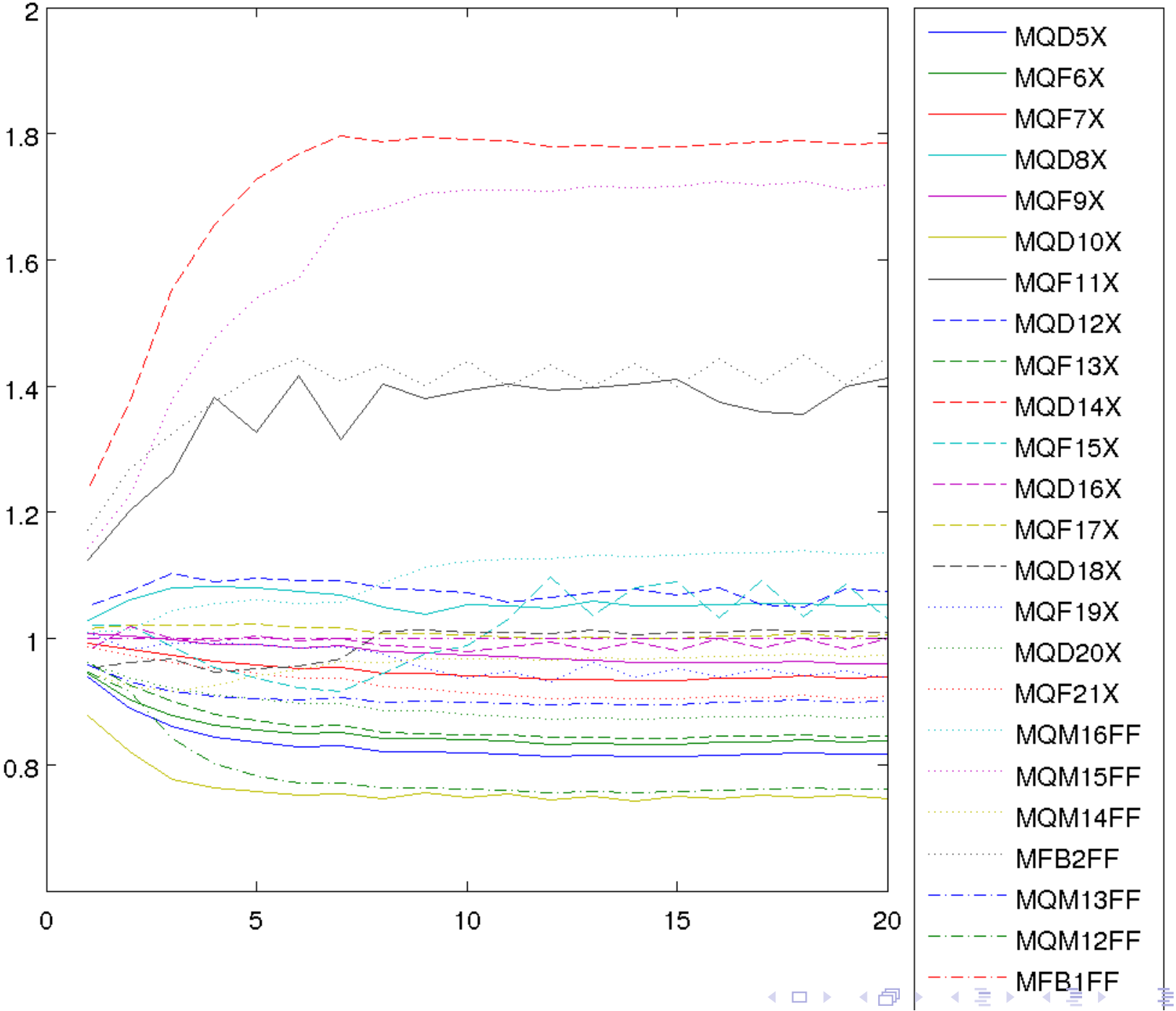



Filename :
test_ZH1X_ZH2X_0.3sigma
Run
BPM meas. per point :
10
Plane to scan
Vertical
Horizontal
Vertical
Horizontal
ZH1X
ZH2X
Phase adv. [pi]
0.995215
0.998585
corr ampl max [sigma] :
1.38106
corr ampl [sigma] :
3
0.3
corr ampl [mrad] :
36.3297
-47.6464
Common
BPM0
MQD5X
v [nominal σxp]
u [nominal σx]
xBPM2 [mm]
xBPM1 [mm]
Filename :
grid_scan_ZH1X_ZH2X_0.3sigma.mat
Load
Plot
MQD5X
Jitter subtraction
MQF6X
Mean readings
Phase adv. [pi]
0.84699
Grid squaring
Plot
Plot all BPM
Area
1.318730
squareness
0.941718
area
squareness
MQD5X
MQF6X
MQF7X
MQD8X
MQF9X
MQD10X
MQF11X
MQD12X
MQF13X
MQD14X
MQF15X
MQD16X
MQF17X
MQD18X
MQF19X
MQD20X
MQM16FF
MQM15FF
MQM14FF
MFB2FF
MQM13FF
MQM12FF
MFB1FF
MQM11FF

BPM Scale Factors Determination

- Used ZH1X and ZH2X with gain of 0.5 during iterations
- ZH1X and ZH2X have little phase advance => small amplitude scan (0.3σ).



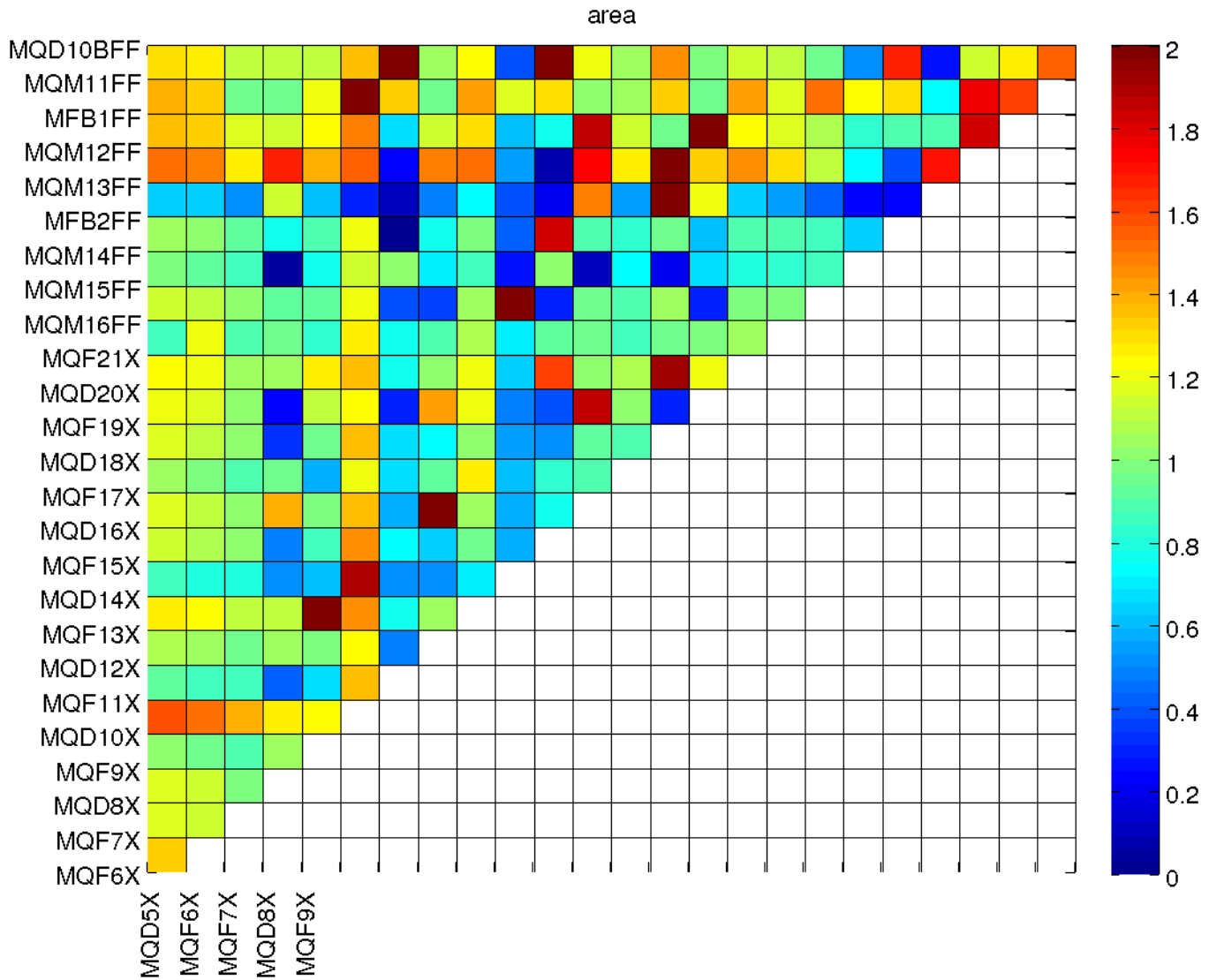

2
1.8
1.6
1.4
1.2
1
0.8
0
5
10
15
20
MQD5X
MQF6X
MQF7X
MQD8X
MQF9X
MQD10X
MQF11X
MQD12X
MQF13X
MQD14X
MQF15X
MQD16X
MQF17X
MQD18X
MQF19X
MQD20X
MQF21X
MQM16FF
MQM15FF
MQM14FF
MFB2FF
MQM13FF
MQM12FF
MFB1FF

Horizontal Scan

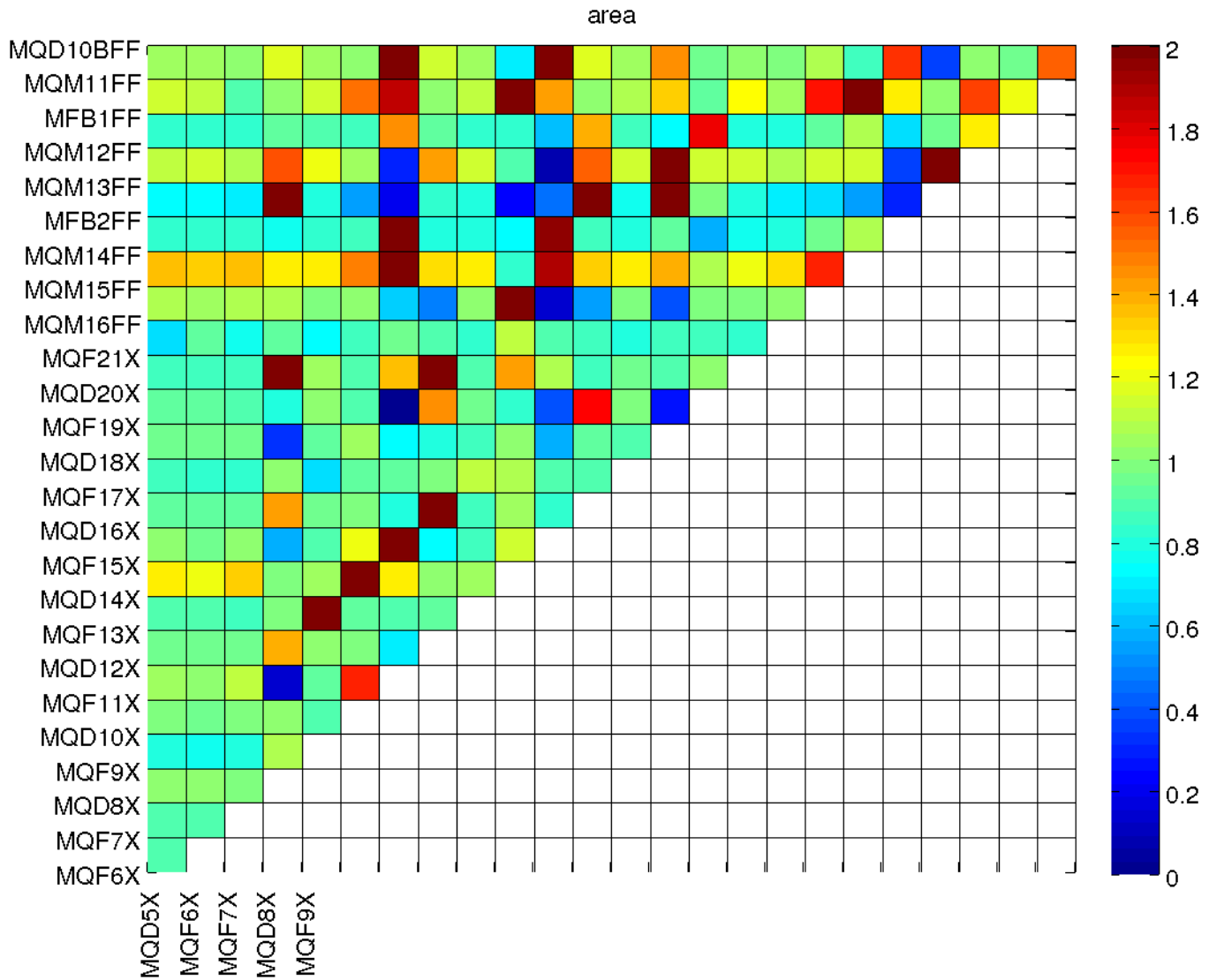
Scale Factors Results

- all EXT BPMs within 20% errors on scales except :
  - MQF11X and MQD14X
  - MQM15FF and MFB2FF (too large amplitude in FF to be believed)

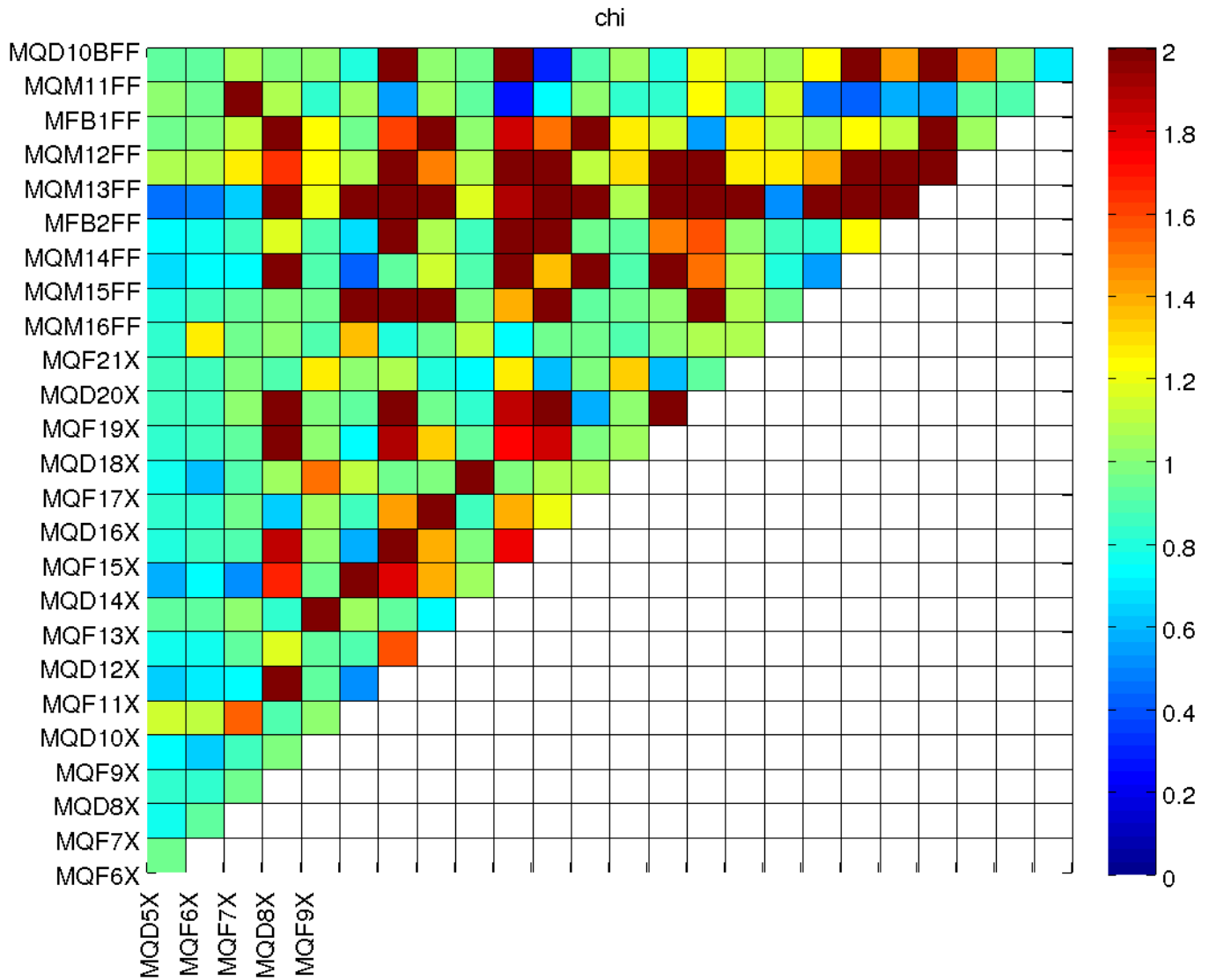
Area before BPM scale factors correction



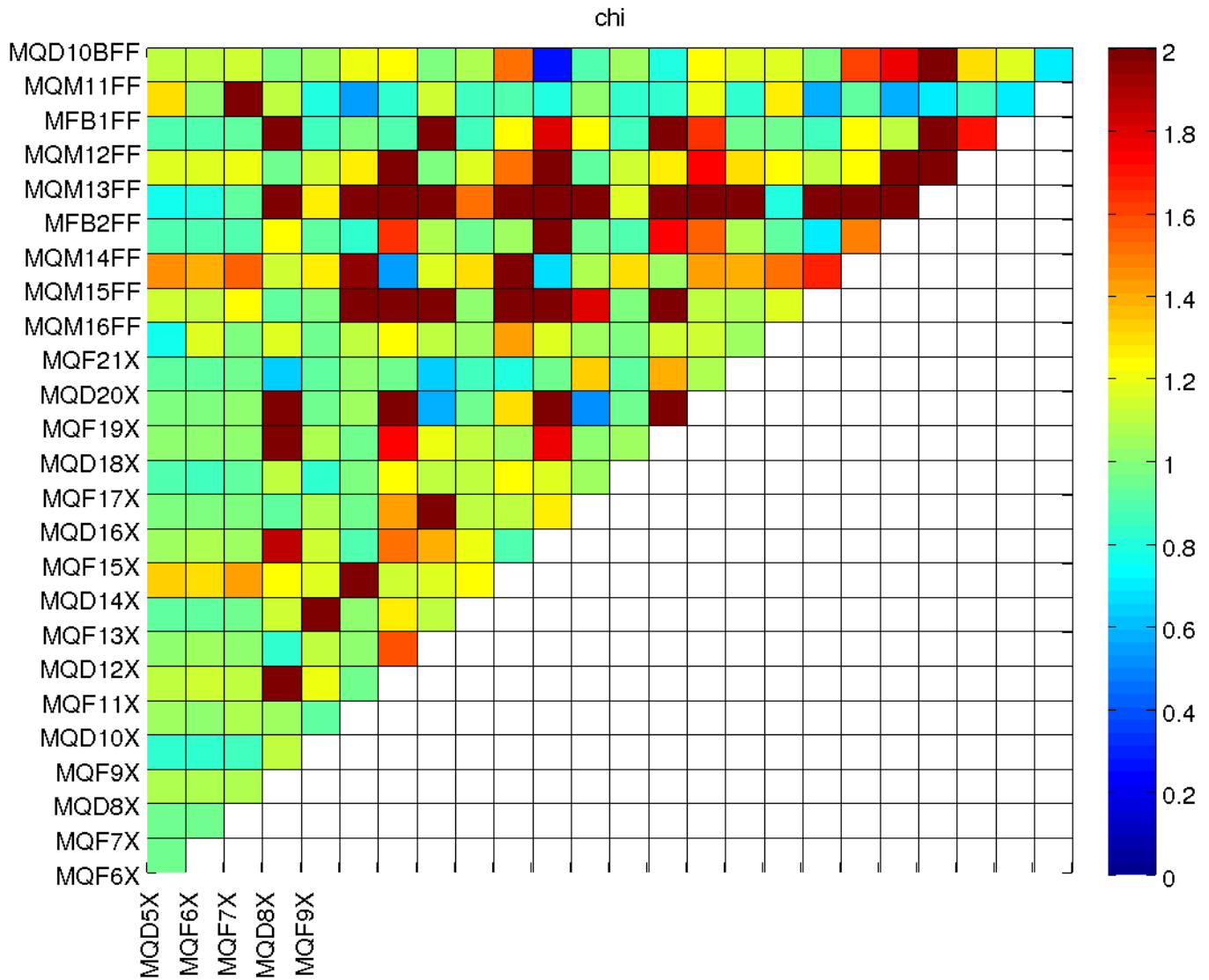
Area after BPM scale factors correction



Squareness before BPM scale factors correction

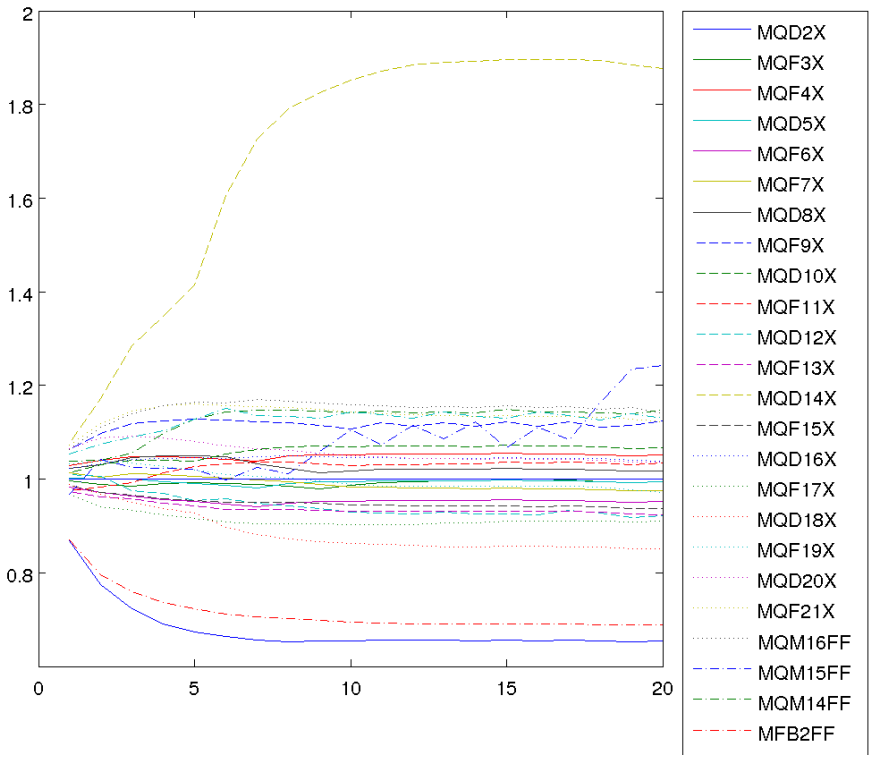


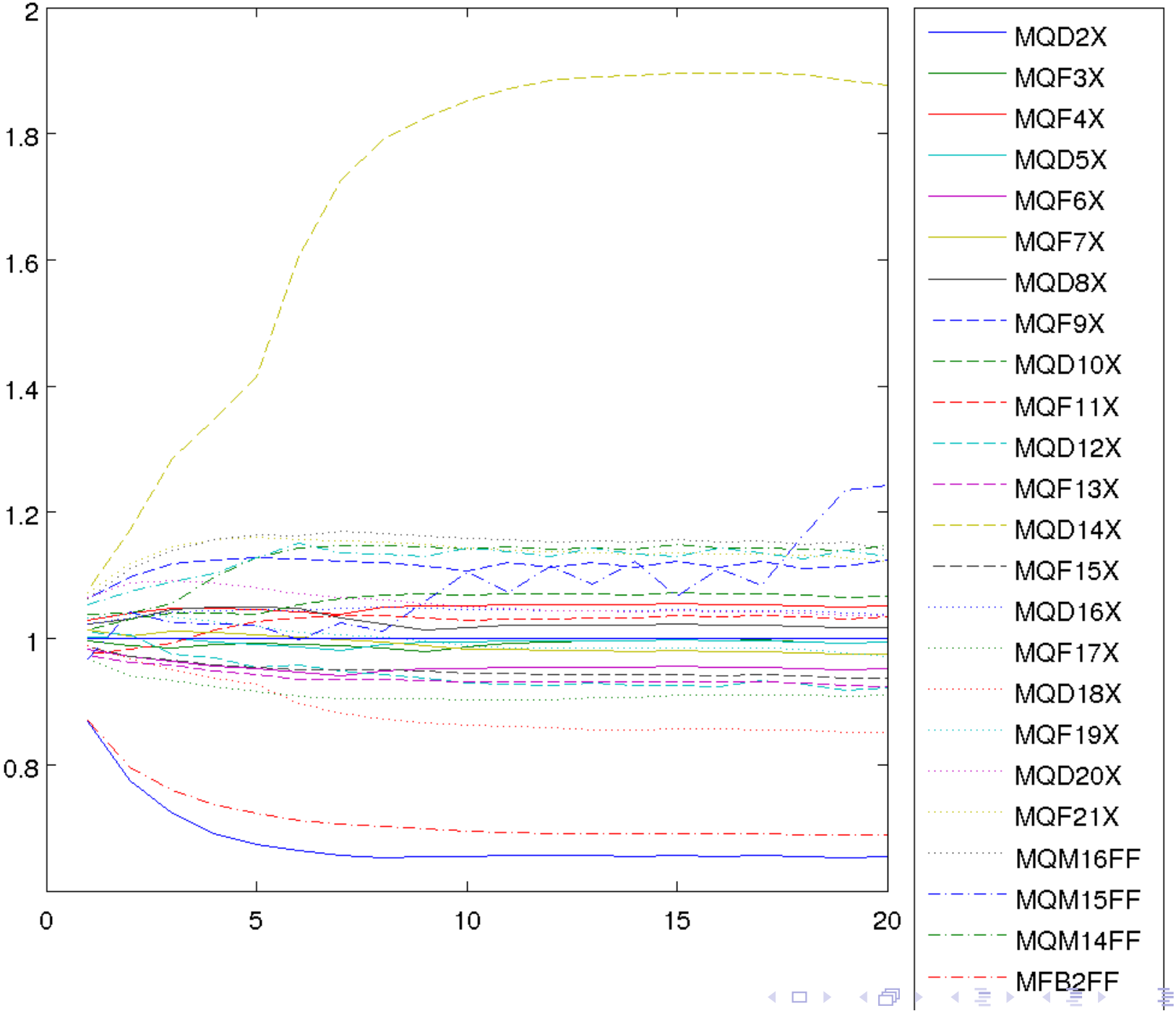
Squareness after BPM scale factors correction



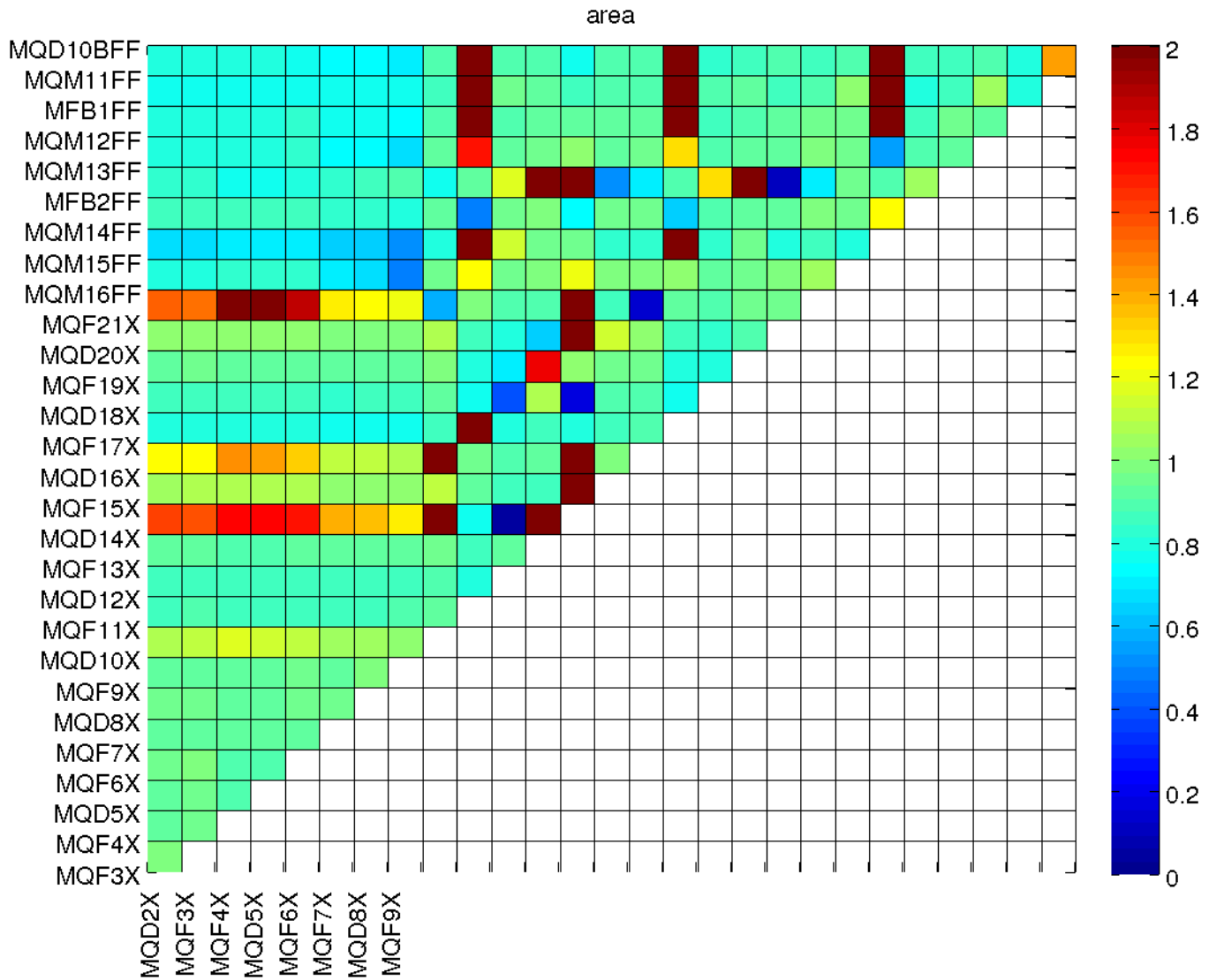
Vertical Scan

- Used ZV1X and ZV2X
- Vertical plane less sensitive to non linear fields
- 3σ scan
- 10% errors on scale factors found. (except MQD2X, MQD14X and MFB2FF)

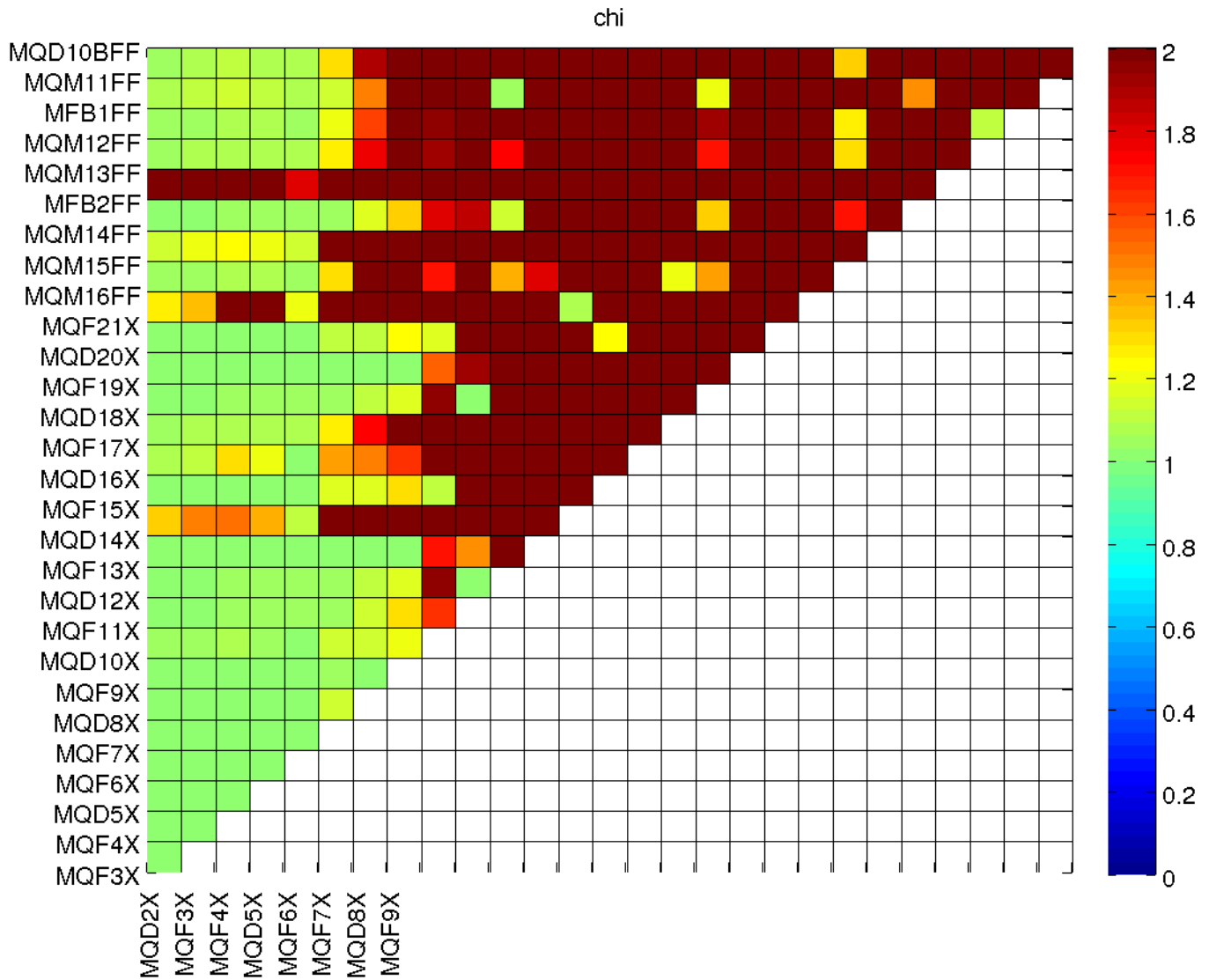



2
1.8
1.6
1.4
1.2
1
0.8
0
5
10
15
20
MQD2X
MQF3X
MQF4X
MQD5X
MQF6X
MQF7X
MQD8X
MQF9X
MQD10X
MQF11X
MQD12X
MQF13X
MQD14X
MQF15X
MQD16X
MQF17X
MQD18X
MQF19X
MQD20X
MQF21X
MQM16FF
MQM15FF
MQM14FF
MFB2FF

Area after BPM scale factors correction



Squareness after BPM scale factors correction



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Conclusions and Prospects

Conclusion

- Grid scans has been made at ATF2
- Might be used to determine BPM scale errors
- No evidence of any mismatch
- Some BPMs identified with bad scales

Prospects

- Improve scale factor fit method (any suggestions ?)