minimizing the dislinearity & coupling issues in the 4 button's BPM block

and dealing with other inevitable dyssymmetries

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Libera workshop 2018

minimizing the dislinearity & coupling issues in the 4 button's BPM block and dealing with other inevitable dyssymmetries

Outline :

1) the cause of dislinearity & coupling → the simplistic δ/Σ formula (DoS)

2) examples of ESRF BPMs, now and for LE-Ring

3) why is it an issue now ?

4) different solutions : Polynomials and/or Voltage Inversion

5) examples : Bpmlab from Andriy Nosych (ALBA)

6) electric offset of the BPM-block, due to non identical Buttons

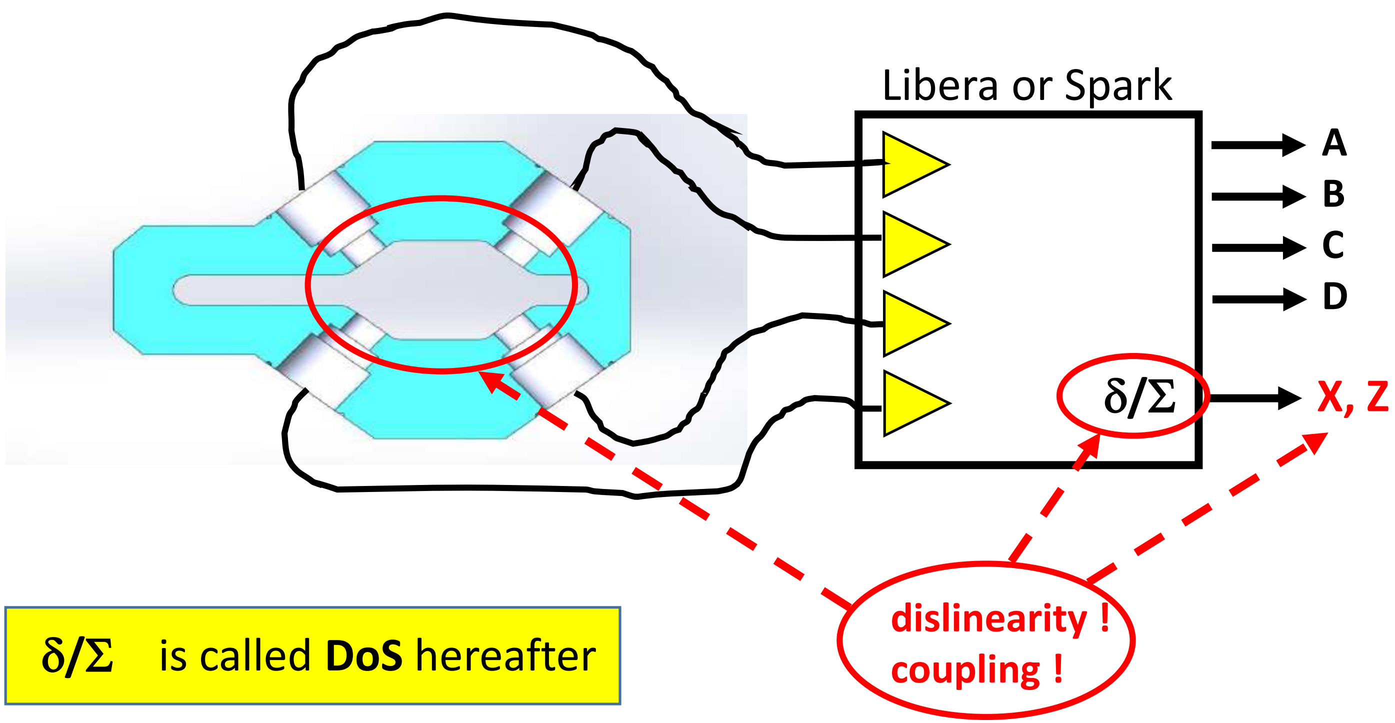
7) also : correct calculation of Sum and Q

dislinearity & coupling :

the electronics measure the strength of the RF signals of the 4 buttons, with very good linearity and low noise & stability & reproducibility etc. etc. → **perfect !**
but ..... with **very simplistic formulae** to convert these 4 signals into **X** & **Z values** :

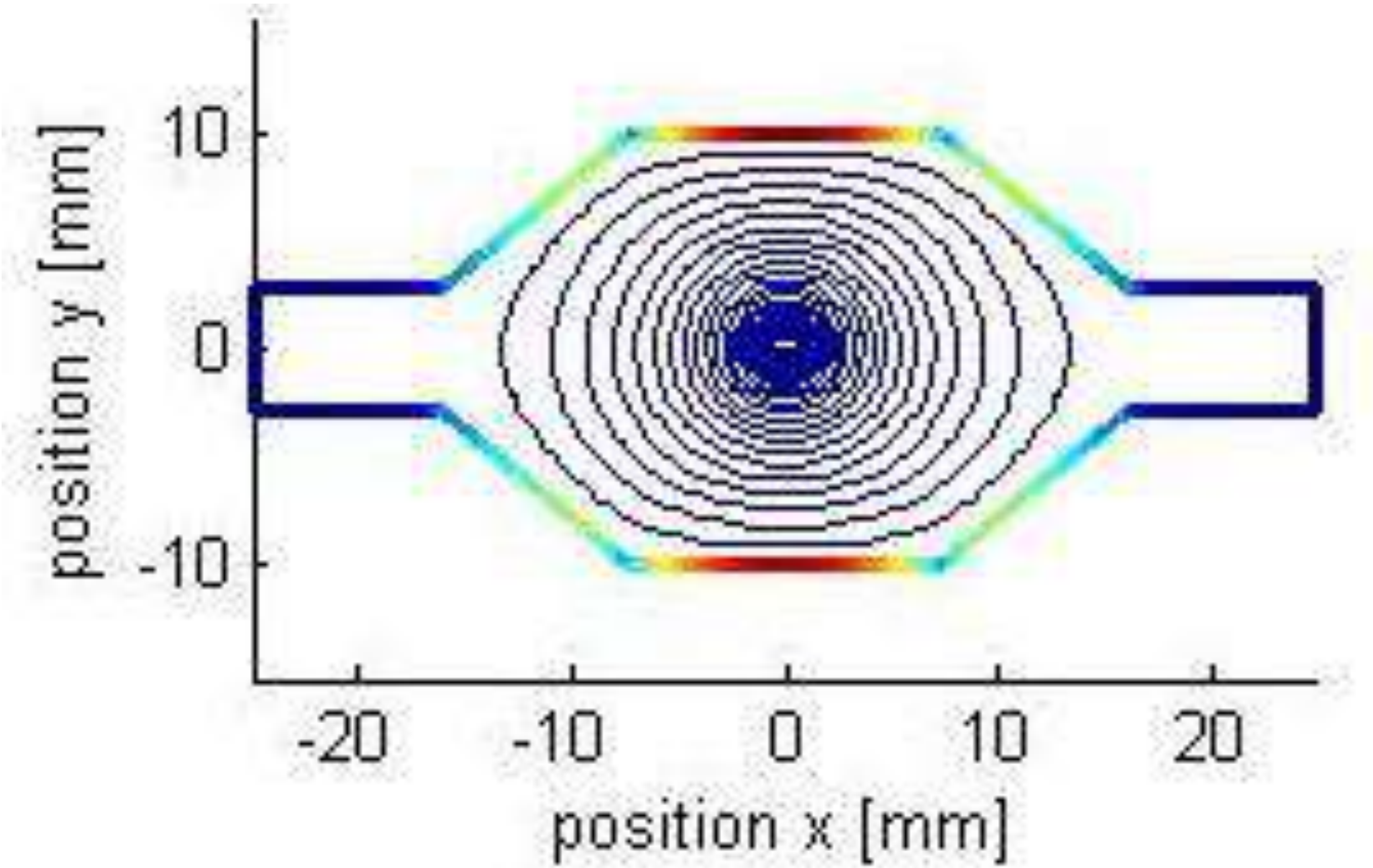
$$X = Kx \cdot (A+D-B-C) / (A+B+C+D)$$
$$Z = Kz \cdot (A+B-C-D) / (A+B+C+D)$$
$$Q = Kq \cdot (A+C-B-D) / (A+B+C+D)$$

	355KHz	10KHz	5.5KHz	40Hz
this **δ/Σ** formula applies to all data-streams & buffers :	TbT,	FA,	dec-TbT ,	SA



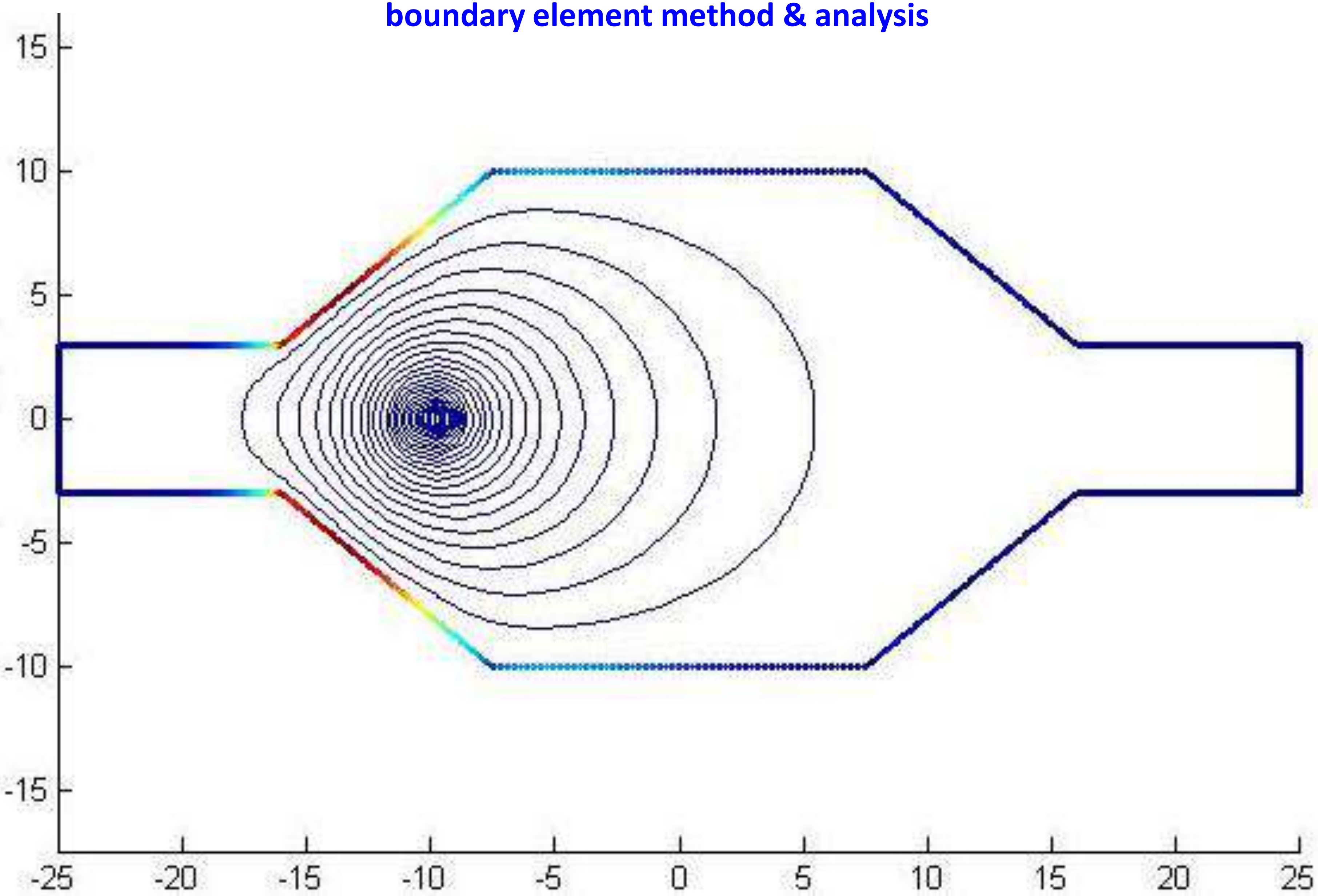
δ/Σ is called **DoS** hereafter

boundary element method & analysis



with courtesy to G.Rehm, DLS, UK

boundary element method & analysis



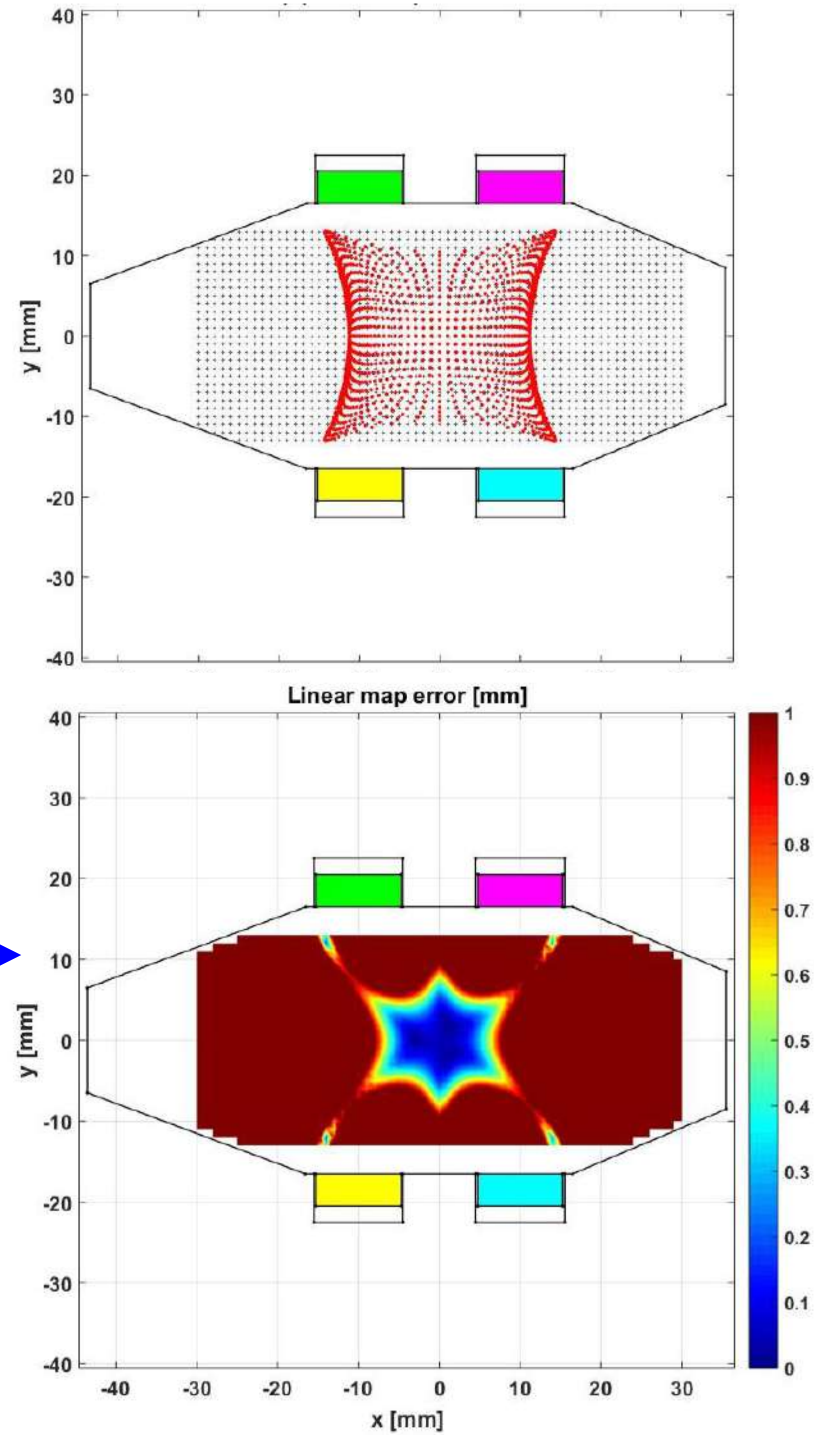
with courtesy to G.Rehm, DLS, UK

how to illustrate the problem ?

todays BPM using DoS

mapping →

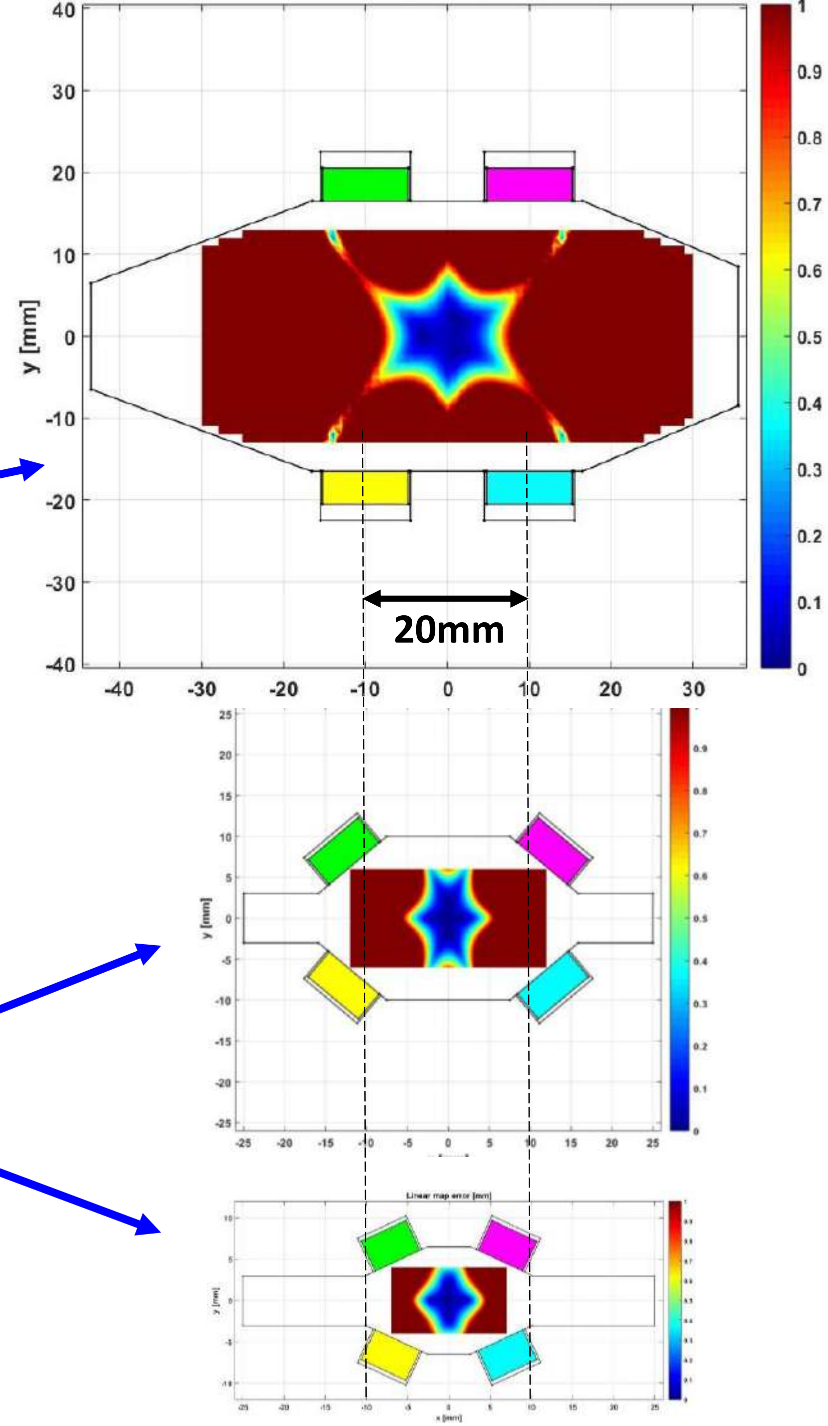
colormap of the linearity error [mm] →



todays BPM
using DoS

Linearity
error [mm]

for todays BPM



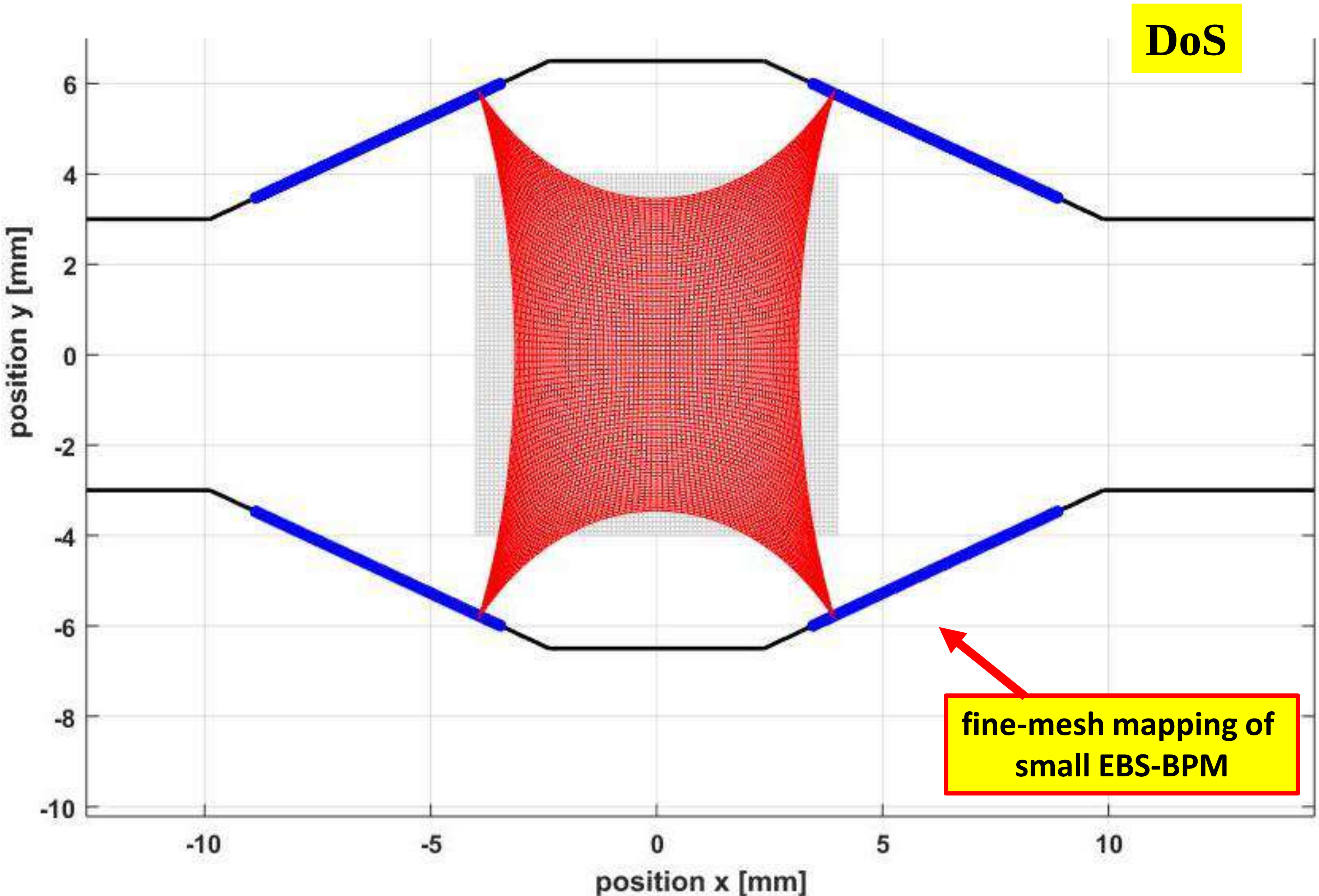
and the 2
EBS-BPMs

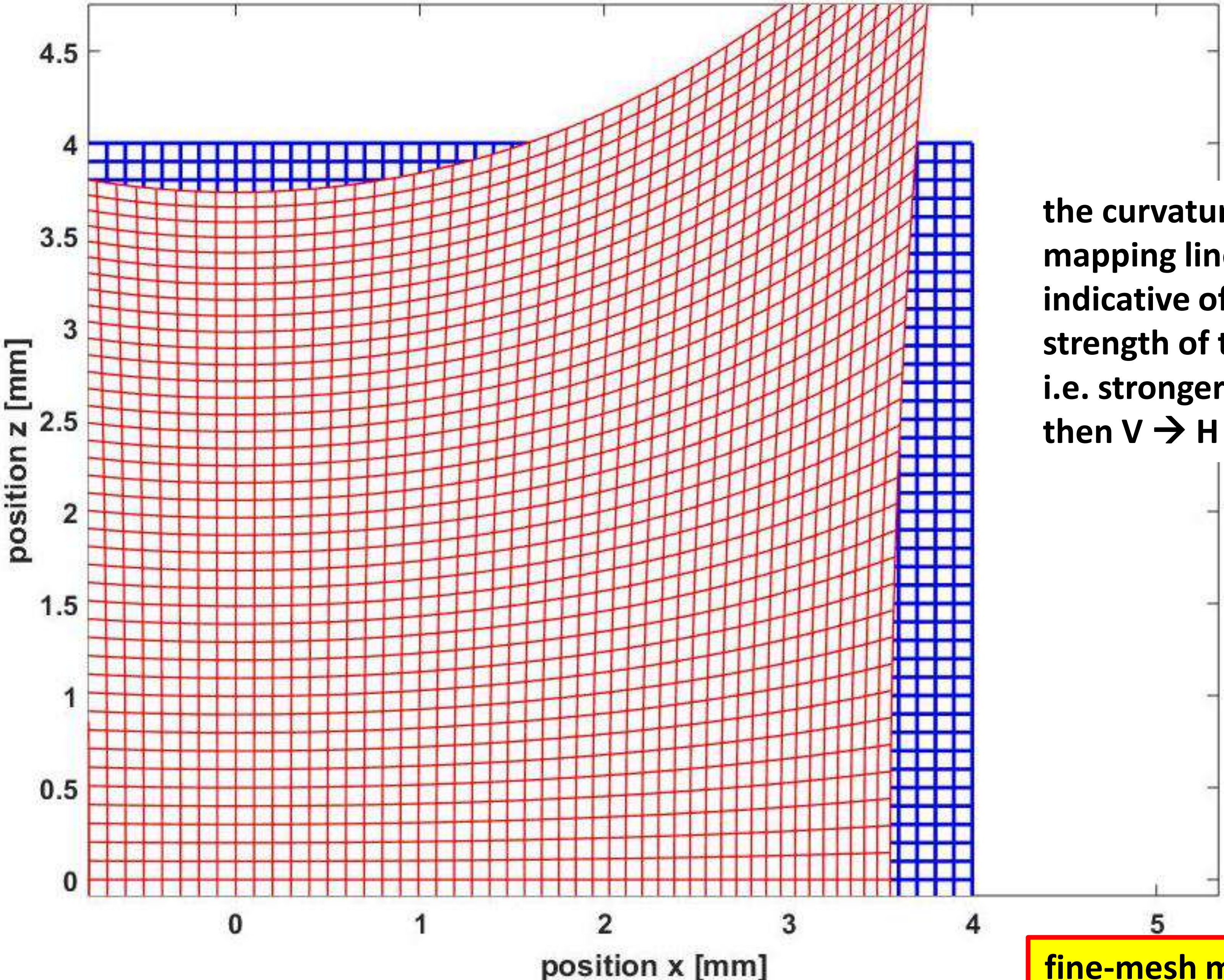
to scale

colormap scales
all the same : 1mm

Coupling(s) : H_to_V and V_to_H

calculations done in 4 x 4mm region, on the 3 BPM geometries, <u>see next slides</u>





DoS

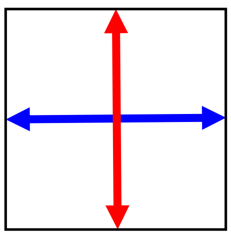
the curvatures of the mapping lines are indicative of the strength of the coupling i.e. stronger for H→ V then V → H

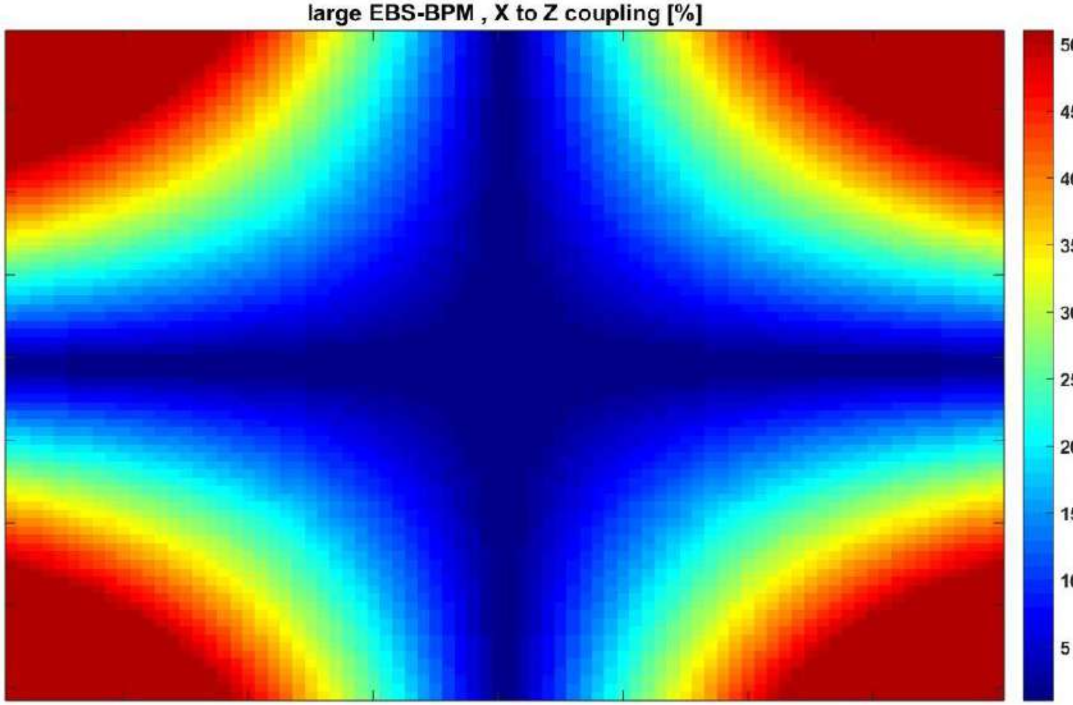
fine-mesh mapping of large EBS-BPM

large EBS BPM

DoS

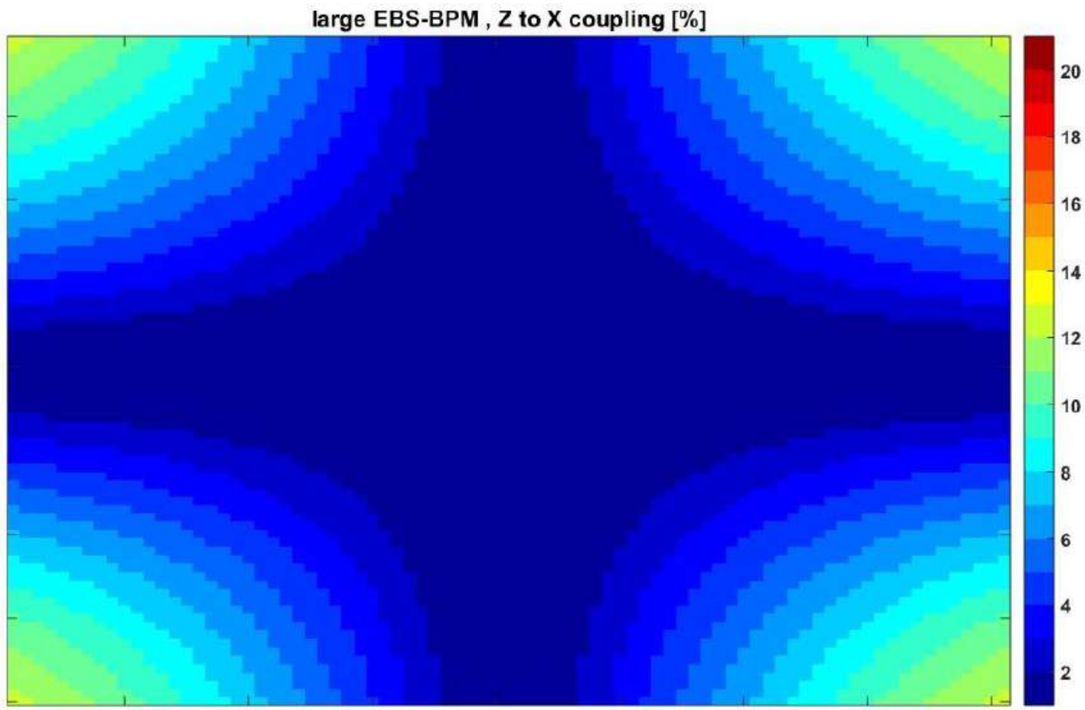
each image represents 4 x 4 mm region





50%

X → Z



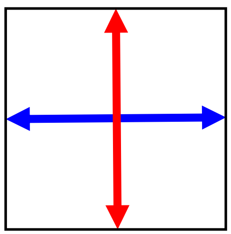
20%

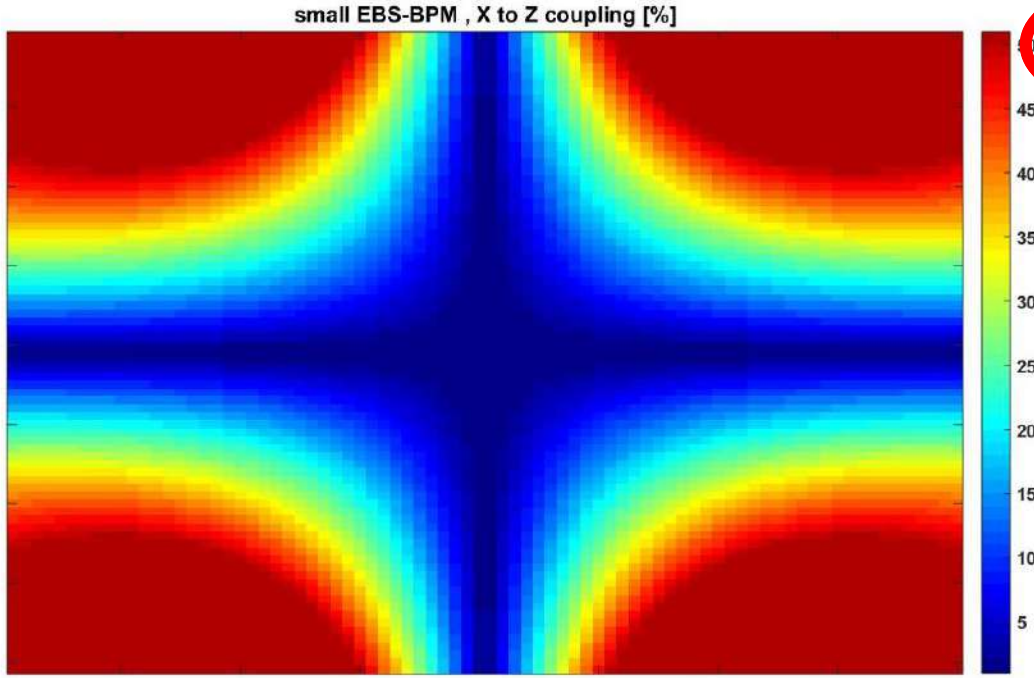
Z → X

small EBS BPM

DoS

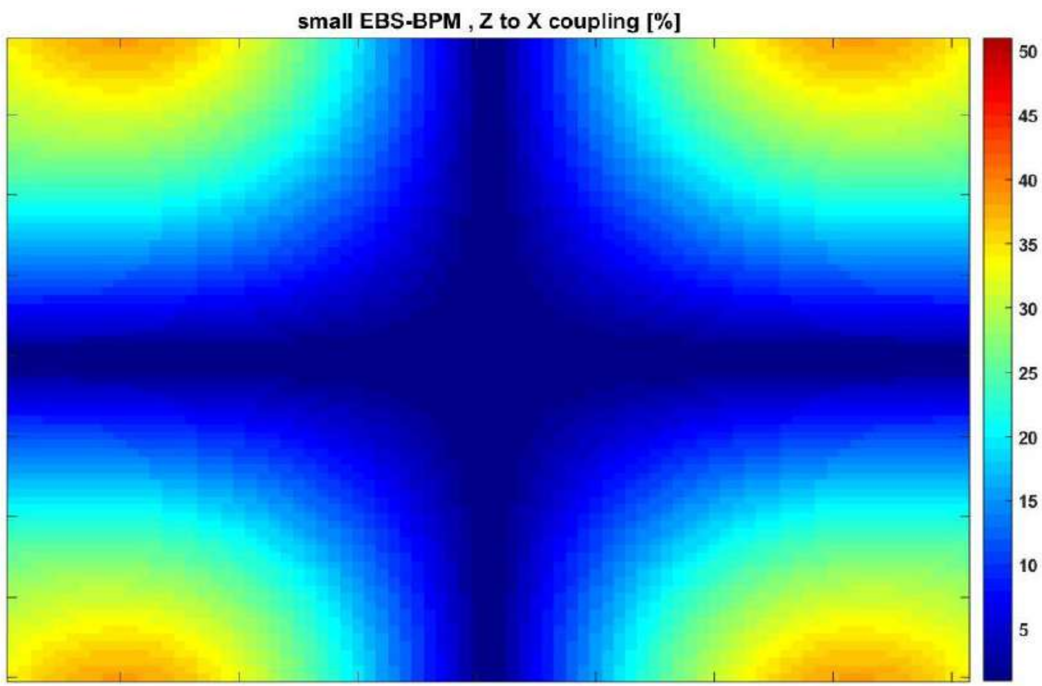
each image represents
4 x 4 mm region





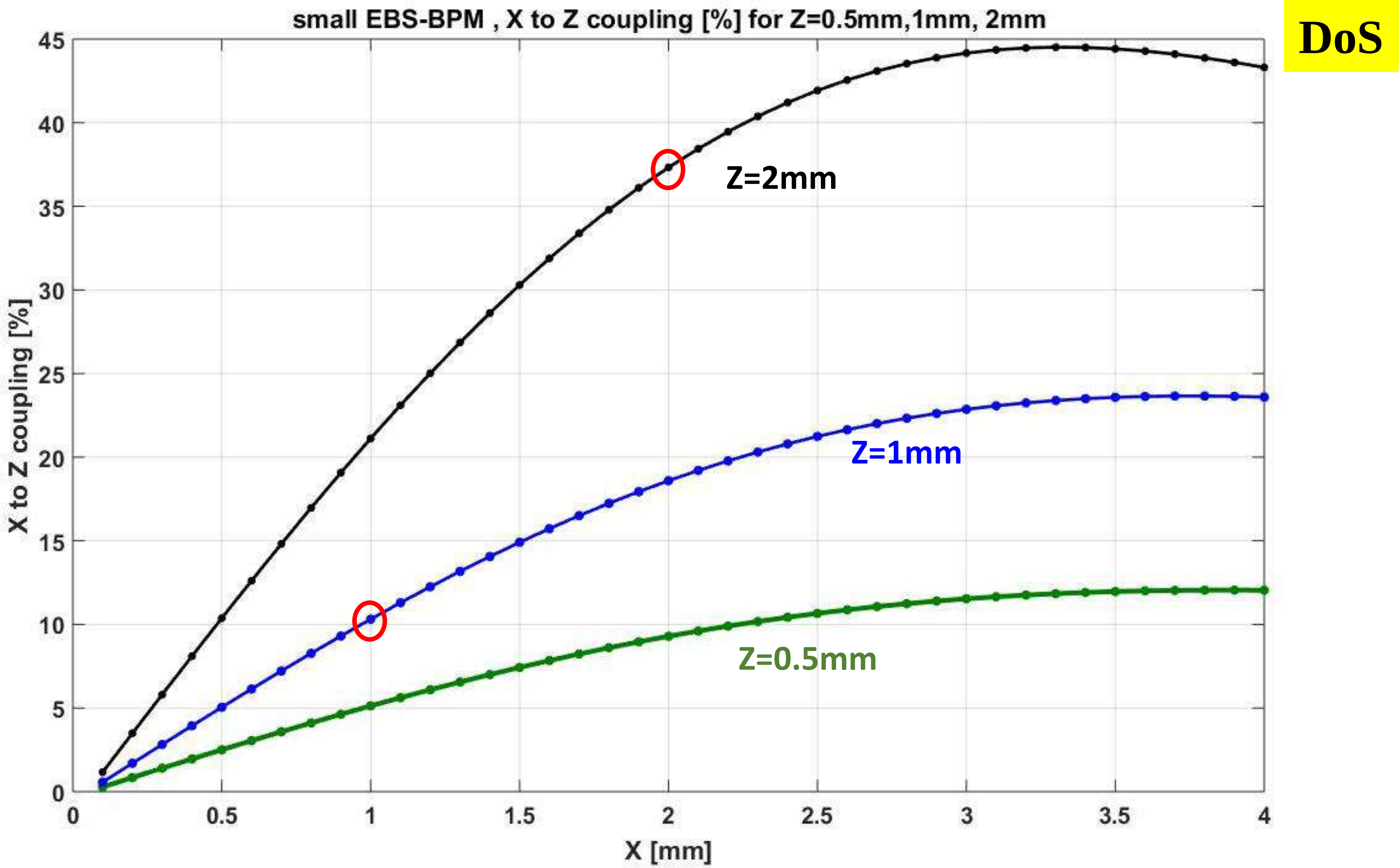
50% !

X → Z



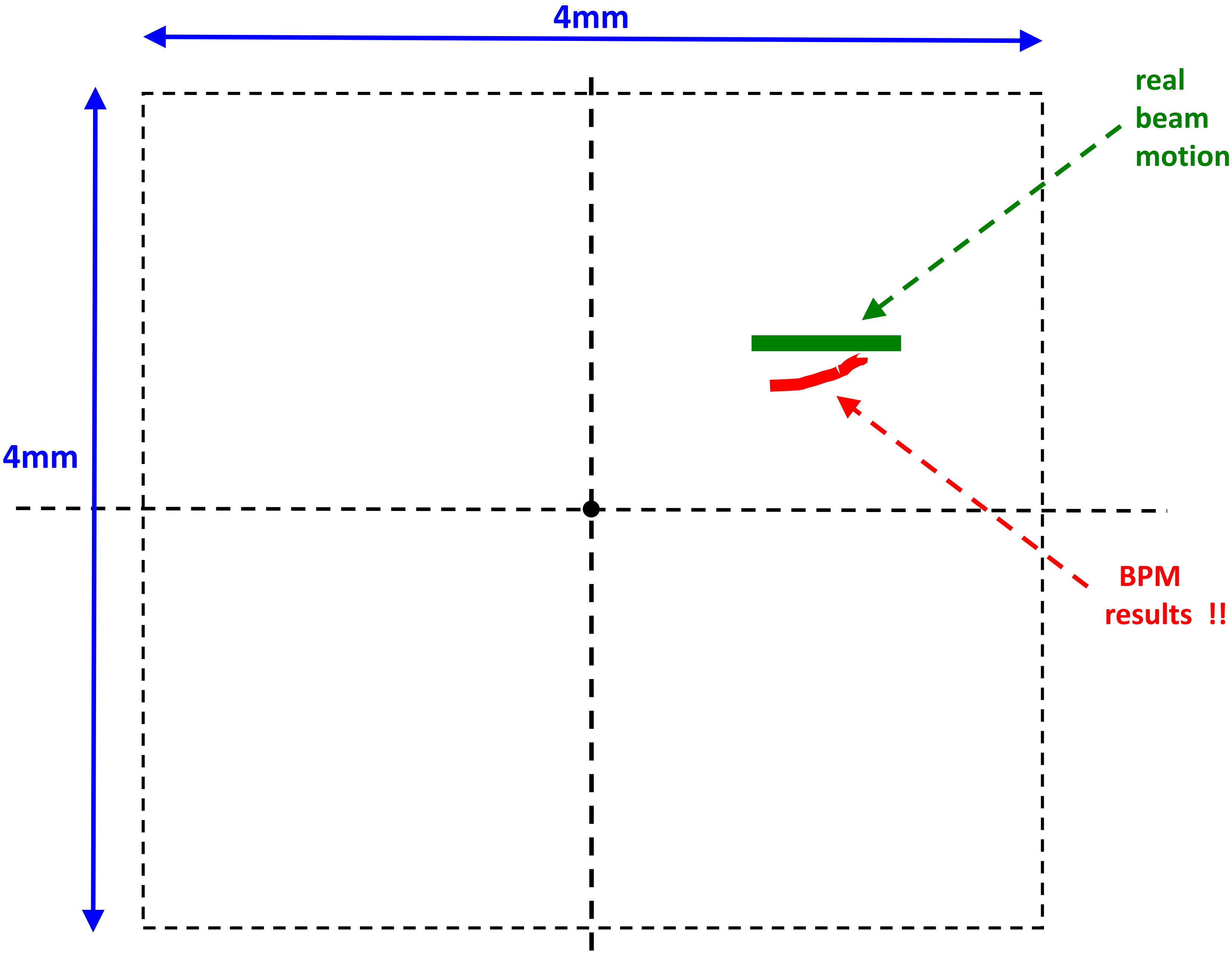
50% !

Z → X

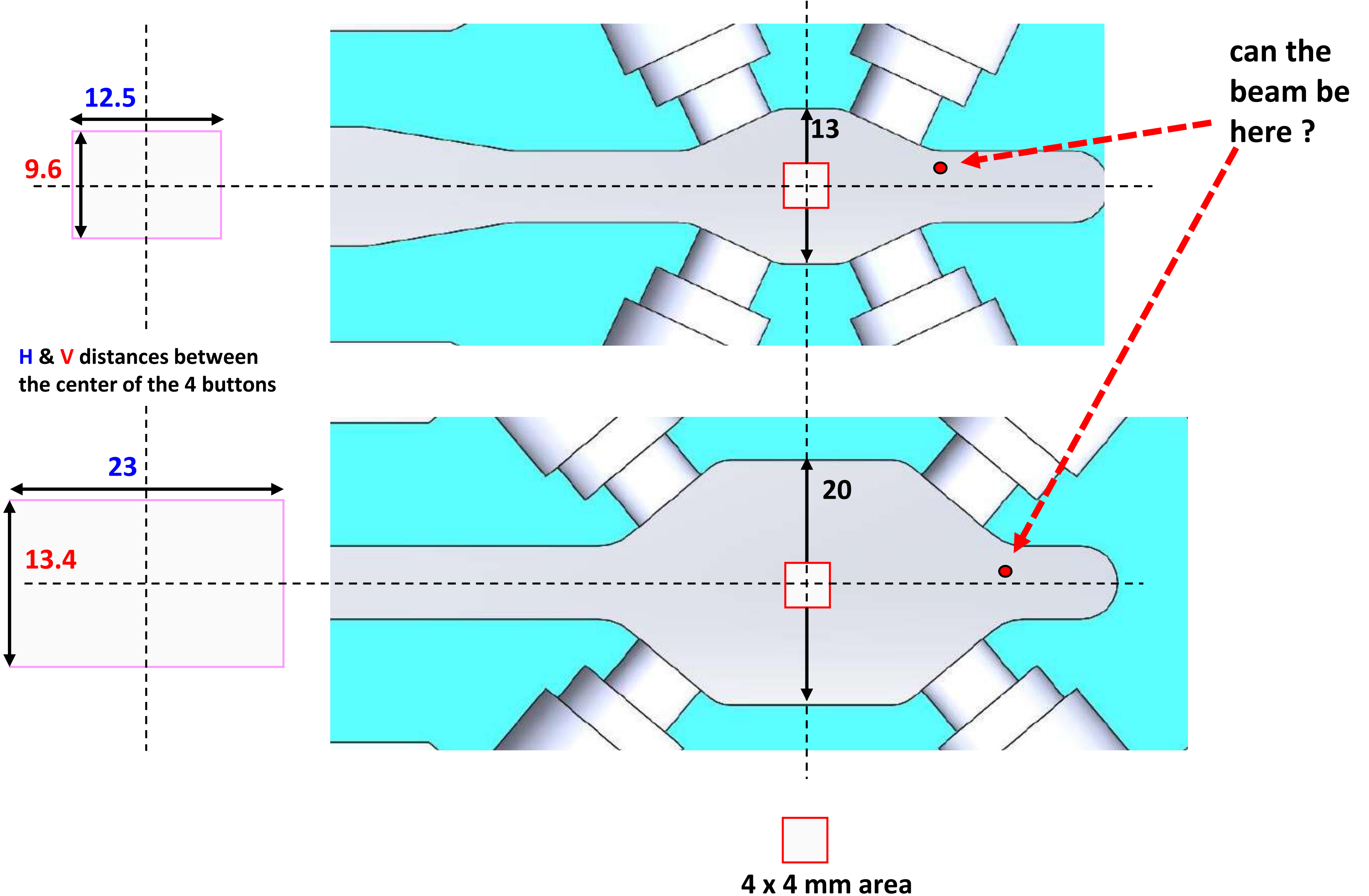


note : for **small EBS-BPM** : with beam at **X=Z=1mm** : coupling of X→Z =**10%**

at **X=Z=2mm** : coupling of X→Z =**37%**



NOT acceptable for beam dynamic studies



define **Zones** with what expectation of
dis-linearity error and **couplings**

why is it an issue now ?

1) it has been an issue since long, treated case-by-case by different people & labs

2) the (todays' trend towards) smaller geometries of the BPMs (smaller beam-pipes) amplify the dislinearity & coupling

3) once the beam is close to the center the problem is alleviated, perhaps even negligible but in new, "difficult" rings :

-a- the beam will often be far away from center (initial commissioning) and the DoS results may be too misleading to allow efficient orbit correction

-b- even later (after orbit correction) the beam may (in many BPMs) not be close enough to the center, and DoS coupling will corrupt lattice measurements like beta functions, phase-advance, response-matrix (steerer→ BPMs)

- T.Shintake, Sensitivity calculation of BPMs using boundary element method, 1987
- A.Stella, INFN, Frascati, Analysis of the Daphne BPM with boundary element method, Dec. 1997
- R.W.Helms, G.H.Hoffstaetter, Cornwell University, Orbit & optics improvement by evaluating the nonlinear BPM response, 2005
- G.Kube, DESY, Hamburg, Sensitivity estimation for PETRA-III BPMs based on a boundary element method, 2007
- G.Rehm, DLS, UK, Boundary Element Solver, Matlab script configurable for different BPM geometries
- N.Hubert, L.Nadolski, Soleil, France, BPM data correction at Soleil, 2008
- R.Bartolini, J.Rowland, DLS, UK, Geometric nonlinearities of a 4 buttons BPM, Feb. 2010
- A.Nosych, ALBA, Barcelona, Overview of the geometrical non-linear effects of buttons BPMs and methodology for their efficient suppression, 2014

dislinearity & **coupling** are 2 different issues

but **both** originate from the same problem → geometry of BPM-block & the **un-**suitable **DoS**

and **both** can be solved by same 2 (different) solutions :

- A : 2D cross-terms **polynomials**
possibly applicable **inside BPM electronics**,
if not then in the server (or higher level)

or

- B : "**Voltage Inversion**"
reiterative converging process,
more precise for some cases, more time consuming
not further treated in this presentation

example of a 2D cross-term polynomial of the 5th order :

$X=a+d-c-b/(a+b+c+d)$ $Y=a+b-c-d/(a+b+c+d)$

Xp $= + 6.752 \cdot X \; -8.701 \cdot X \cdot Y^2 \; -2.503 \cdot X \cdot Y^4 \; +0.597\, X^3 \; +7.737\, X^3 \cdot Y^2 \; +5.225\, X^5$

Yp $= + 15.761 \cdot Y \; -19.858 \cdot Y \cdot X^2 \; +8.718 \cdot Y \cdot X^4 \; +19.585\, Y^3 \; -25.002\, Y^3 \cdot X^2 \; +8.8895\, Y^5$

in comparison, the **DoS** :

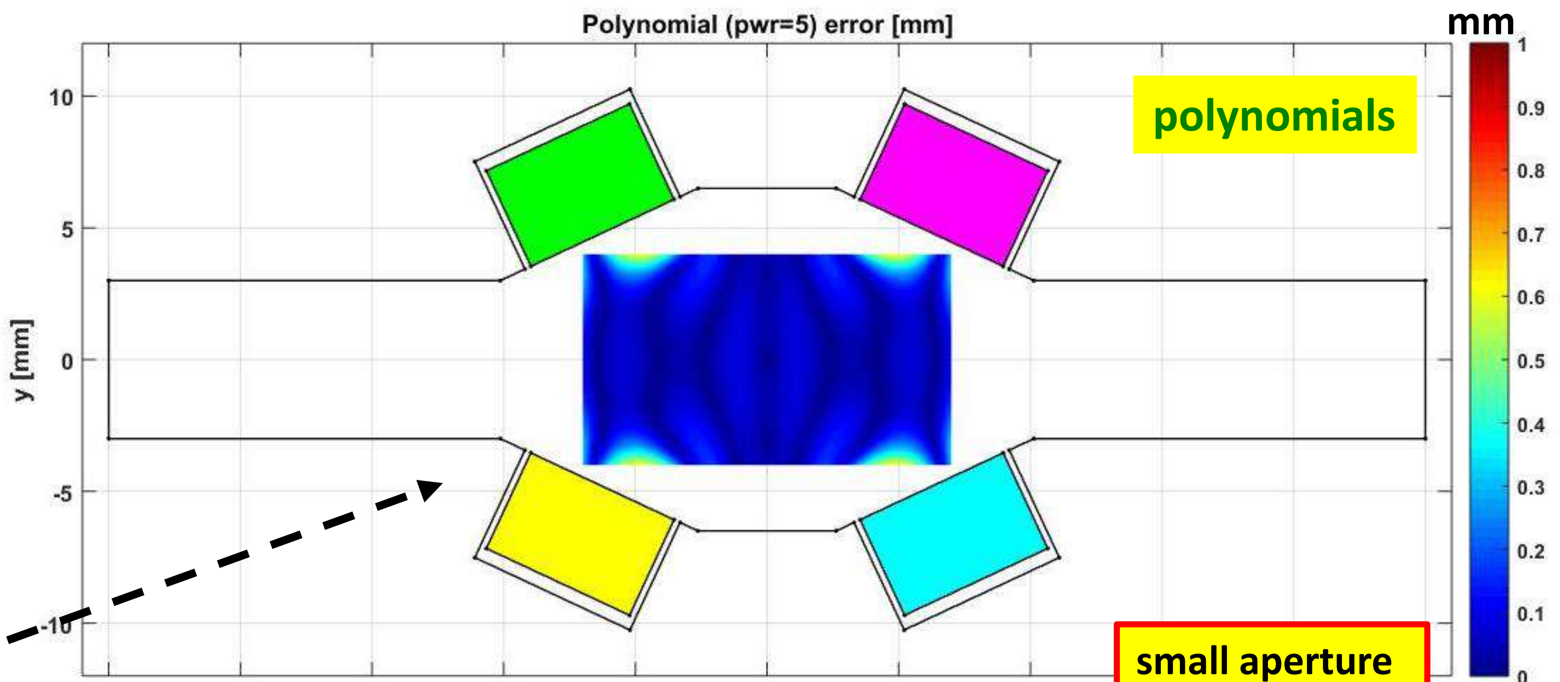
$X=a+d-c-b/(a+b+c+d)$ $Y=a+b-c-d/(a+b+c+d)$

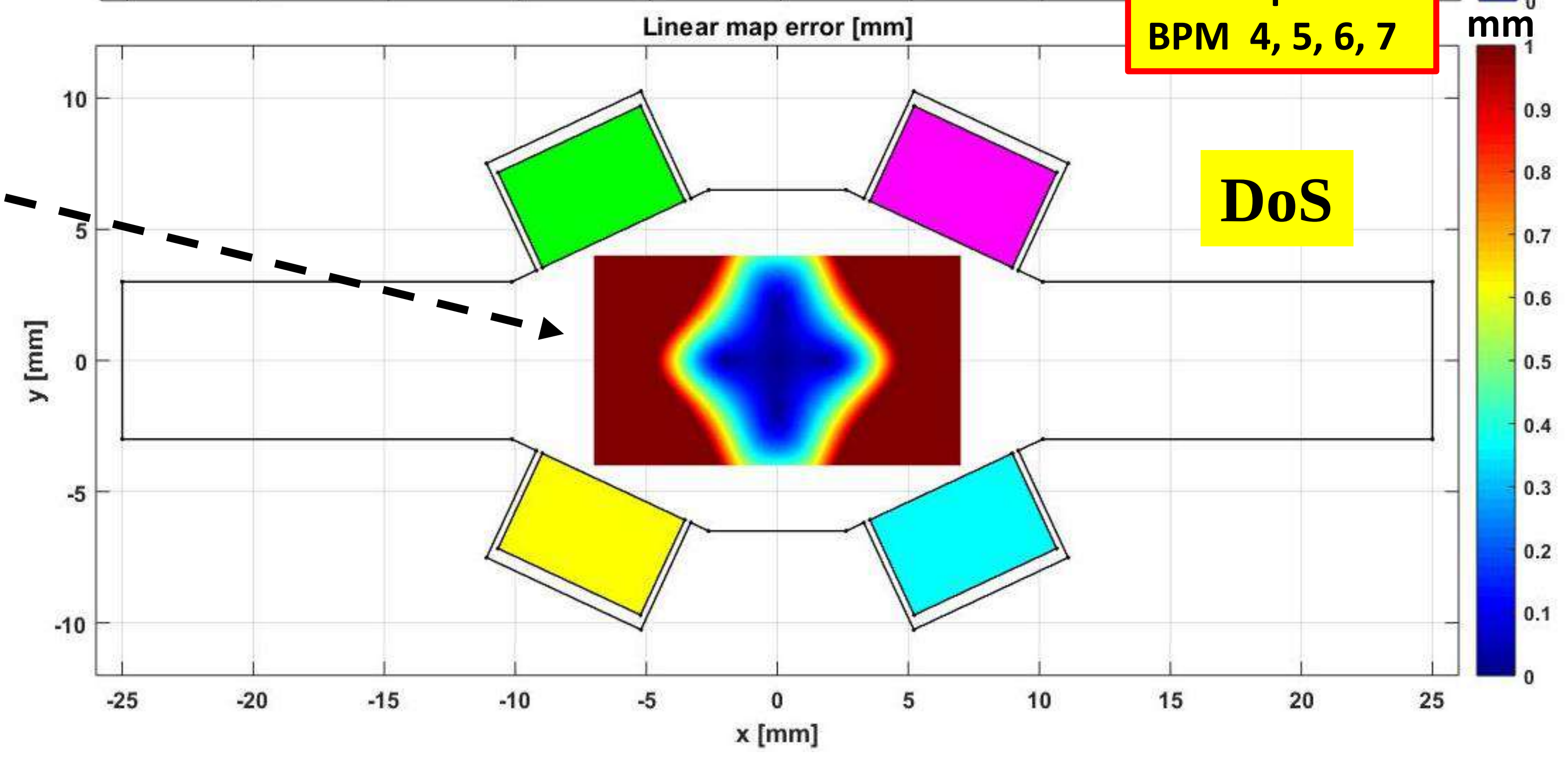
Xd $= + 6.752 \cdot X$

Yd $= + 15.761 \cdot Y$

solution :

using 2D cross-terms polynomials to correct the dislinear response from the DoS





solution :

using 2D cross-terms polynomials

However :

1) computing time :
this correction has to be applied on <u>each sample</u> of BPM data ...

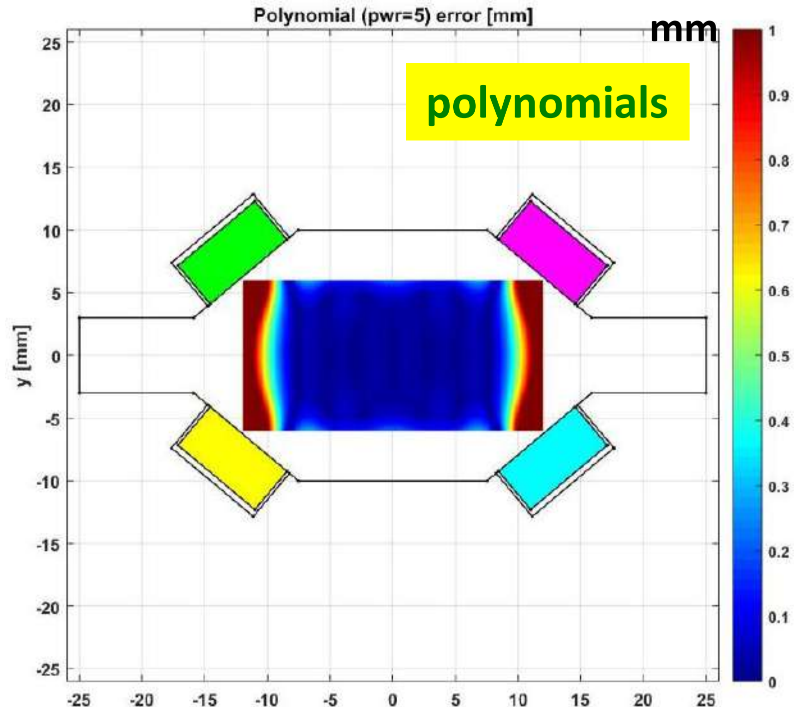
40Hz SA-data should be feasible

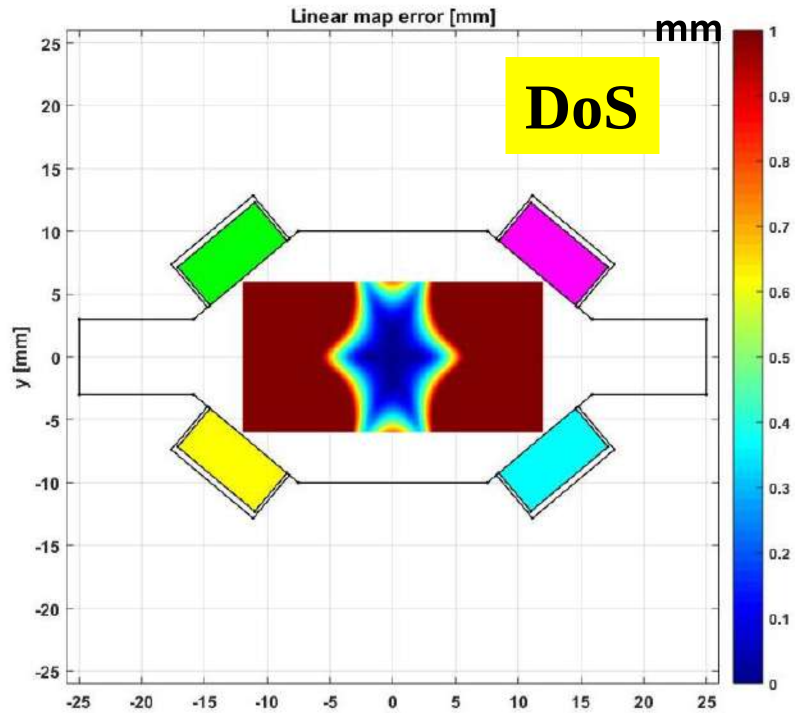
2) what happens with unknown electric offsets ?

a) We measure & compensate these as good as possible
b) The effect of un-correct units will be simulated

3) even these polynomials do not to fully correct the dislinearity

Voltage Inversion can be used for very large displacements,
but at low data-rates, yet OK for first-turn(s) commissioning





big aperture BPM
1, 2, 3,   8, 9, 10

examples from **Bpmlab**

Bpmlab is written & maintained by Andriy Nosych, at ALBA, Barcelona
in principle available free of charge, contact Andriy on : anosych@cells.es

the ESRF is collaborating with him and ALBA to get in 2018
a more evolved & upgraded & specific version of it
to more systematically deal with our needs & concerns on BPM-blocks

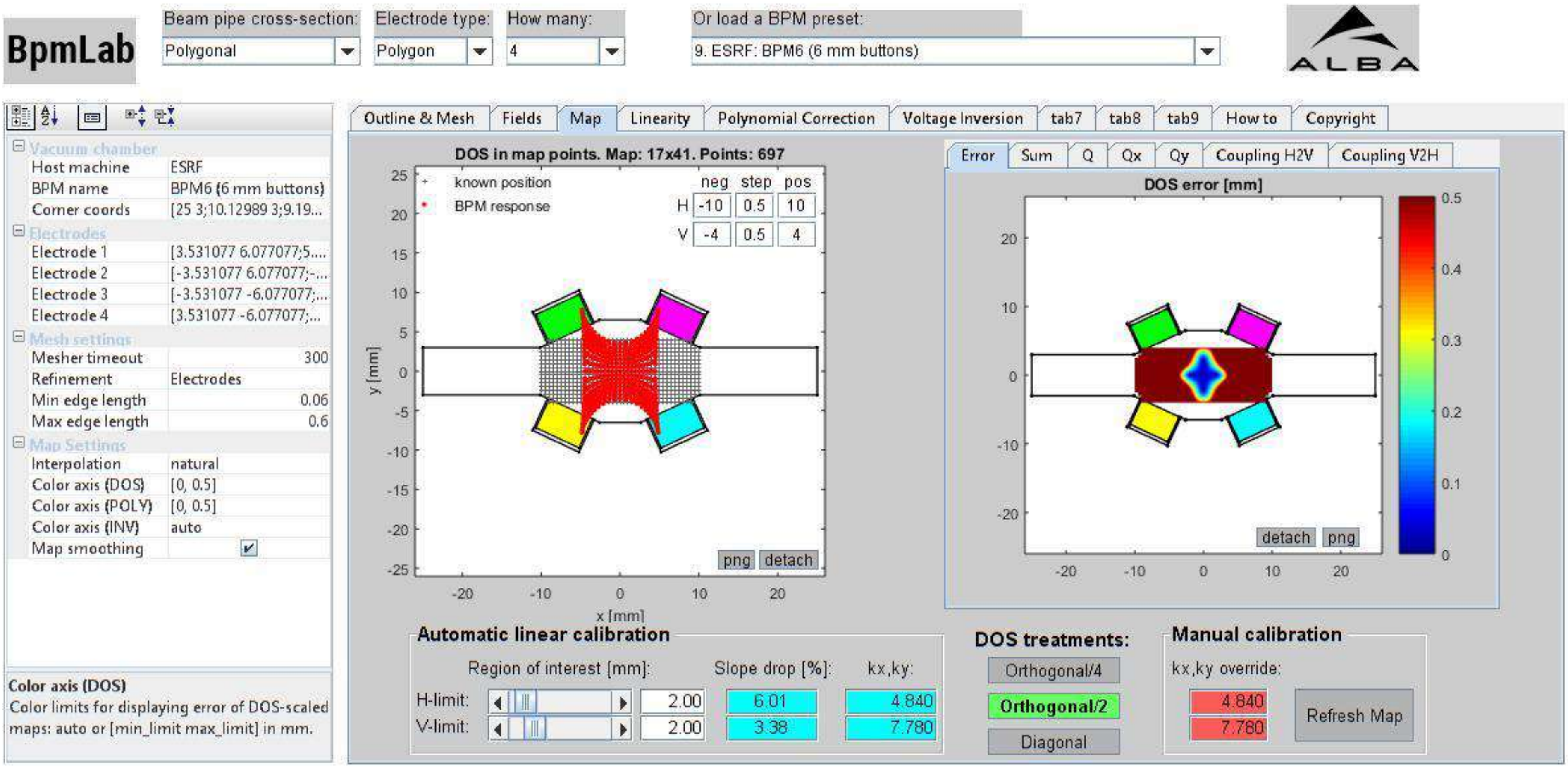
so in addition to the visualization of the BPM, the errors, the mapping,
the calculation of polynomials etc.

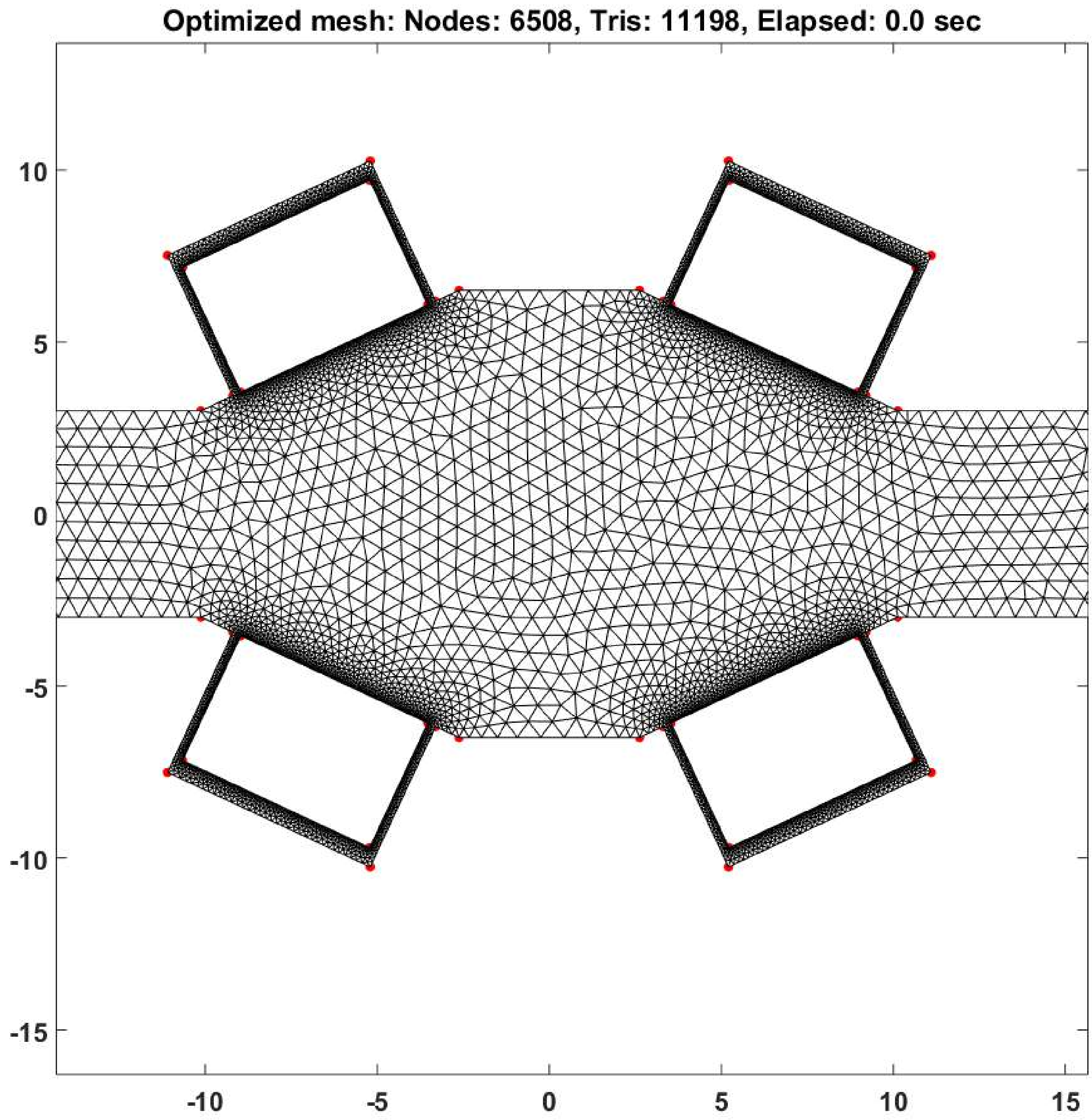
this specific ESRF version will also calculate : - the Sum and Q (incoherence) values
- the H→V and V→H coupling values

and determine the best polynomials that correct : - both the beam's H & V coordinates
- and Sum and Q

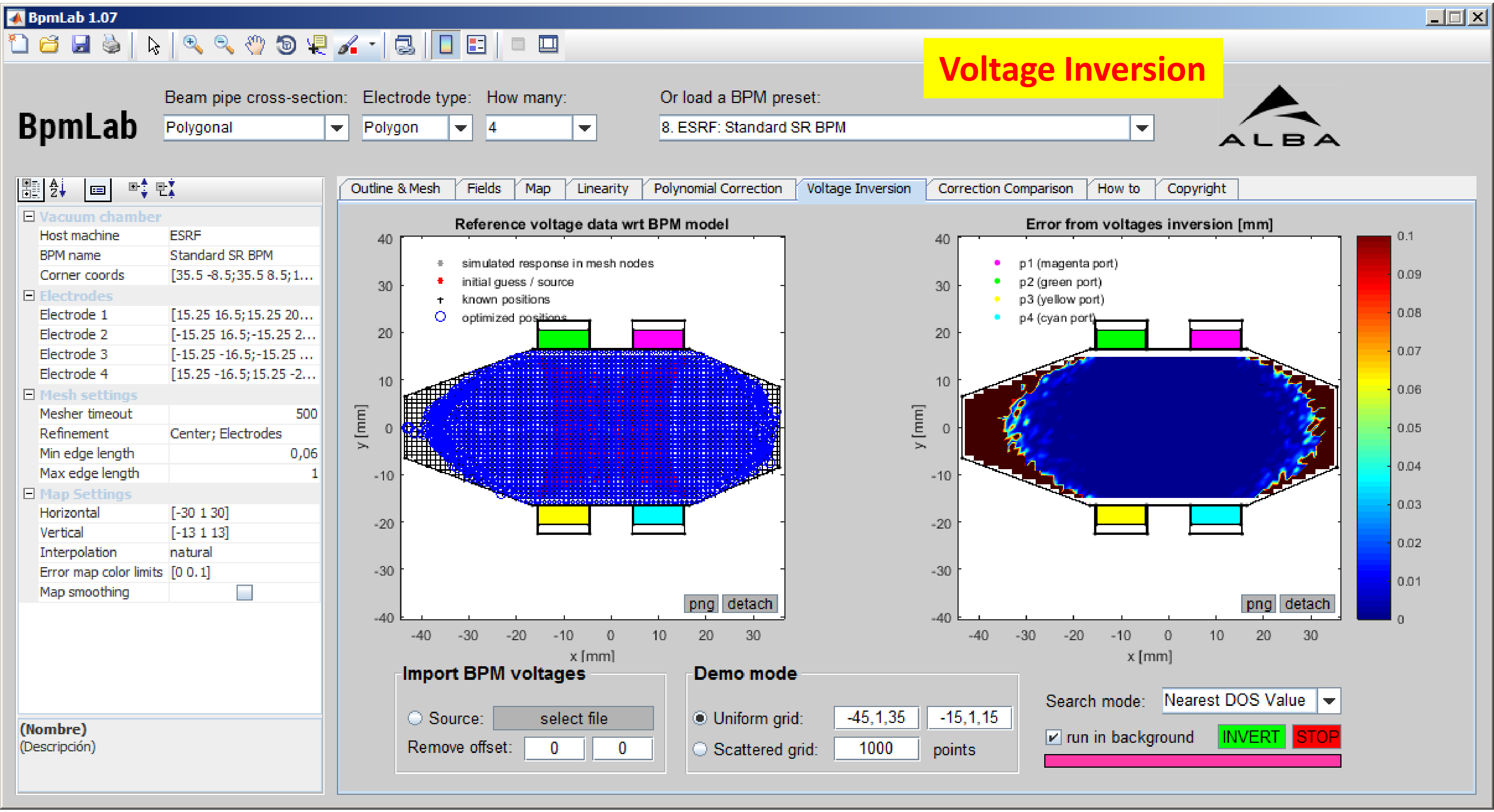
provide a parallel solution using Voltage Inversion for extreme cases

and also allow an assessment of "wry" BPMs and their most appropriate correction

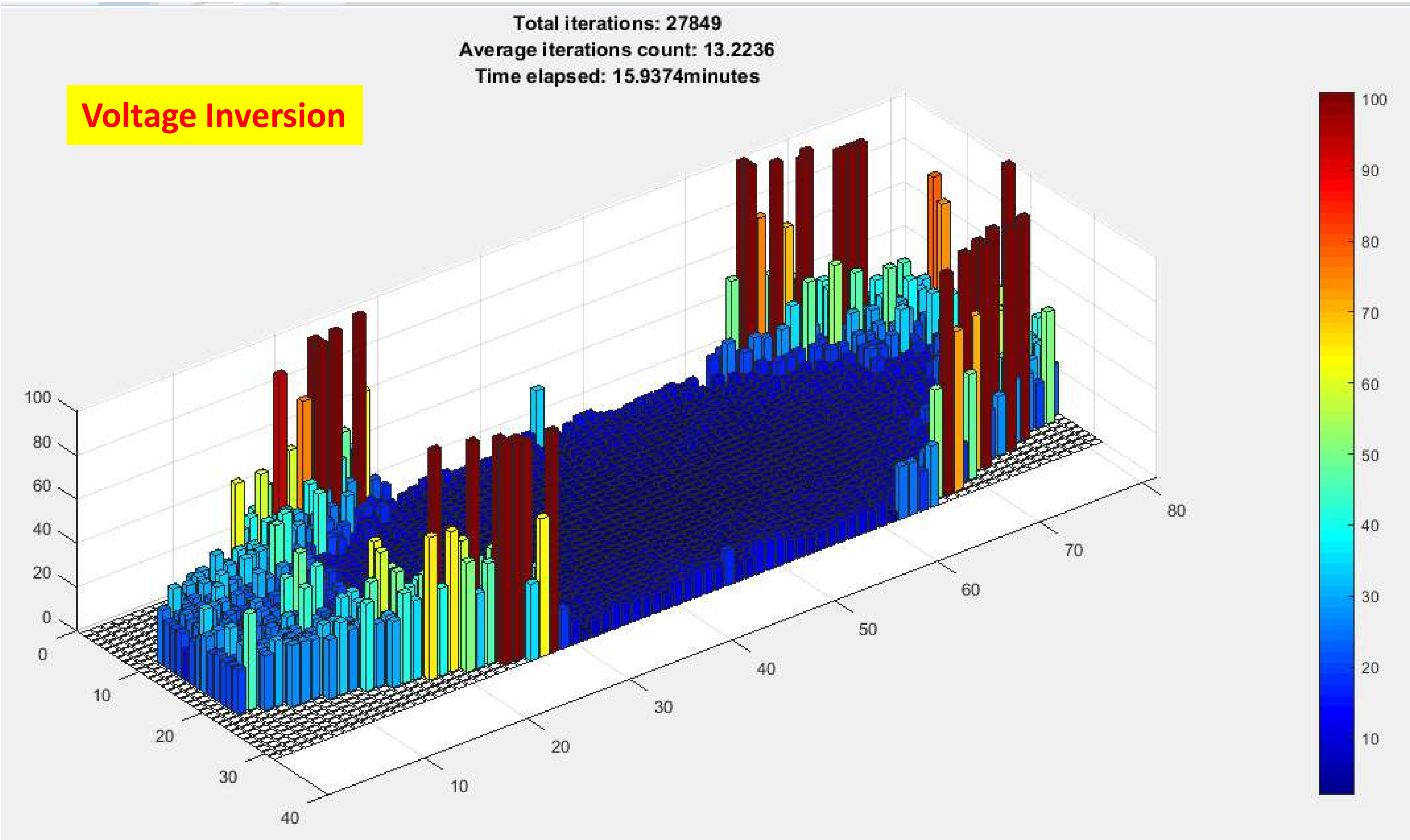

BpmLab
Beam pipe cross-section:
Polygonal
Electrode type:
Polygon
How many:
4
Or load a BPM preset:
9. ESRF: BPM6 (6 mm buttons)
ALBA
Vacuum chamber
Host machine
ESRF
BPM name
BPM6 (6 mm buttons)
Corner coords
[25 3;10.12989 3;9.19...
Electrodes
Electrode 1
[3.531077 6.077077;5....
Electrode 2
[-3.531077 6.077077;-...
Electrode 3
[-3.531077 -6.077077;...
Electrode 4
[3.531077 -6.077077;...
Mesh settings
Mesher timeout
300
Refinement
Electrodes
Min edge length
0.06
Max edge length
0.6
Map Settings
Interpolation
natural
Color axis (DOS)
[0, 0.5]
Color axis (POLY)
[0, 0.5]
Color axis (INV)
auto
Map smoothing
Color axis (DOS)
Color limits for displaying error of DOS-scaled maps: auto or [min_limit max_limit] in mm.
Outline & Mesh
Fields
Map
Linearity
Polynomial Correction
Voltage Inversion
tab7
tab8
tab9
How to
Copyright
DOS in map points. Map: 17x41. Points: 697
known position
BPM response
neg
step
pos
H
-10
0.5
10
V
-4
0.5
4
y [mm]
x [mm]
png
detach
Error
Sum
Q
Qx
Qy
Coupling H2V
Coupling V2H
DOS error [mm]
detach
png
Automatic linear calibration
Region of interest [mm]:
Slope drop [%]:
kx,ky:
H-limit:
2.00
6.01
4.840
V-limit:
2.00
3.38
7.780
DOS treatments:
Orthogonal/4
Orthogonal/2
Diagonal
Manual calibration
kx,ky override:
4.840
7.780
Refresh Map



Optimized mesh: Nodes: 6508, Tris: 11198, Elapsed: 0.0 sec
10
5
0
-5
-10
-15
-10
-5
0
5
10
15



Voltage Inversion
BpmLab 1.07
BpmLab
Beam pipe cross-section:
Polygonal
Electrode type:
Polygon
How many:
4
Or load a BPM preset:
8. ESRF: Standard SR BPM
ALBA
Vacuum chamber
Host machine ESRF
BPM name Standard SR BPM
Corner coords [35.5 -8.5;35.5 8.5;1...
Electrodes
Electrode 1 [15.25 16.5;15.25 20...
Electrode 2 [-15.25 16.5;-15.25 2...
Electrode 3 [-15.25 -16.5;-15.25 ...
Electrode 4 [15.25 -16.5;15.25 -2...
Mesh settings
Mesher timeout 500
Refinement Center; Electrodes
Min edge length 0,06
Max edge length 1
Map Settings
Horizontal [-30 1 30]
Vertical [-13 1 13]
Interpolation natural
Error map color limits [0 0.1]
Map smoothing
(Nombre)
(Descripción)
Outline & Mesh
Fields
Map
Linearity
Polynomial Correction
Voltage Inversion
Correction Comparison
How to
Copyright
Reference voltage data wrt BPM model
simulated response in mesh nodes
initial guess / source
known positions
optimized positions
y [mm]
x [mm]
png
detach
Error from voltages inversion [mm]
p1 (magenta port)
p2 (green port)
p3 (yellow port)
p4 (cyan port)
Import BPM voltages
Source:
select file
Remove offset:
Demo mode
Uniform grid:
-45,1,35
-15,1,15
Scattered grid:
1000
points
Search mode:
Nearest DOS Value
run in background
INVERT
STOP



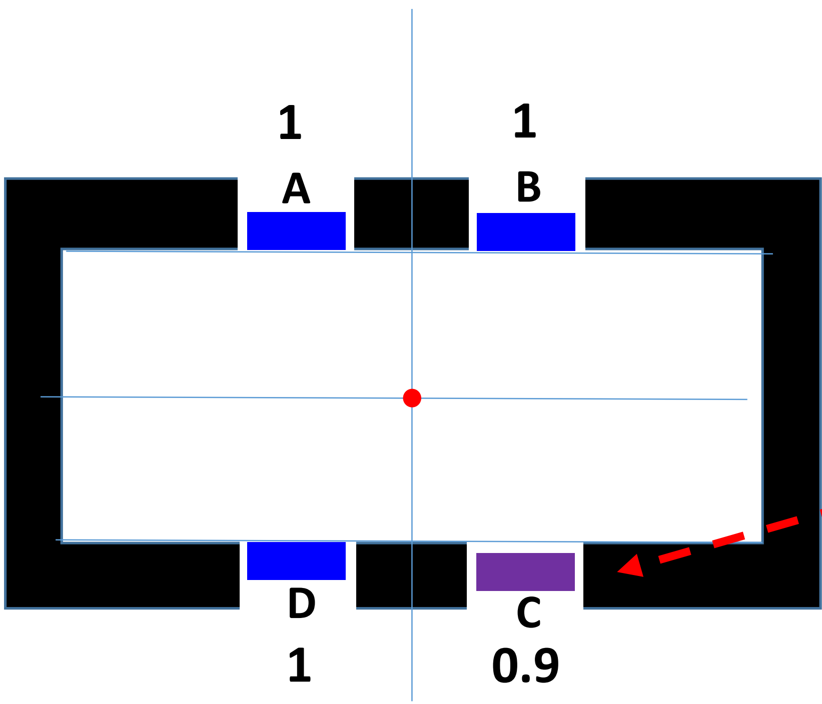
status : contract in process ESRF-ALBA

delivery : end 2018

What is the **electric** offset of a BPM-block ?

3 kinds of offsets :
- **electric offset BPM-block → non-equal sensitivity of the 4 buttons**
- alignment/mechanical offset of the BPM-block
- offset due to electronics / RF-cabling

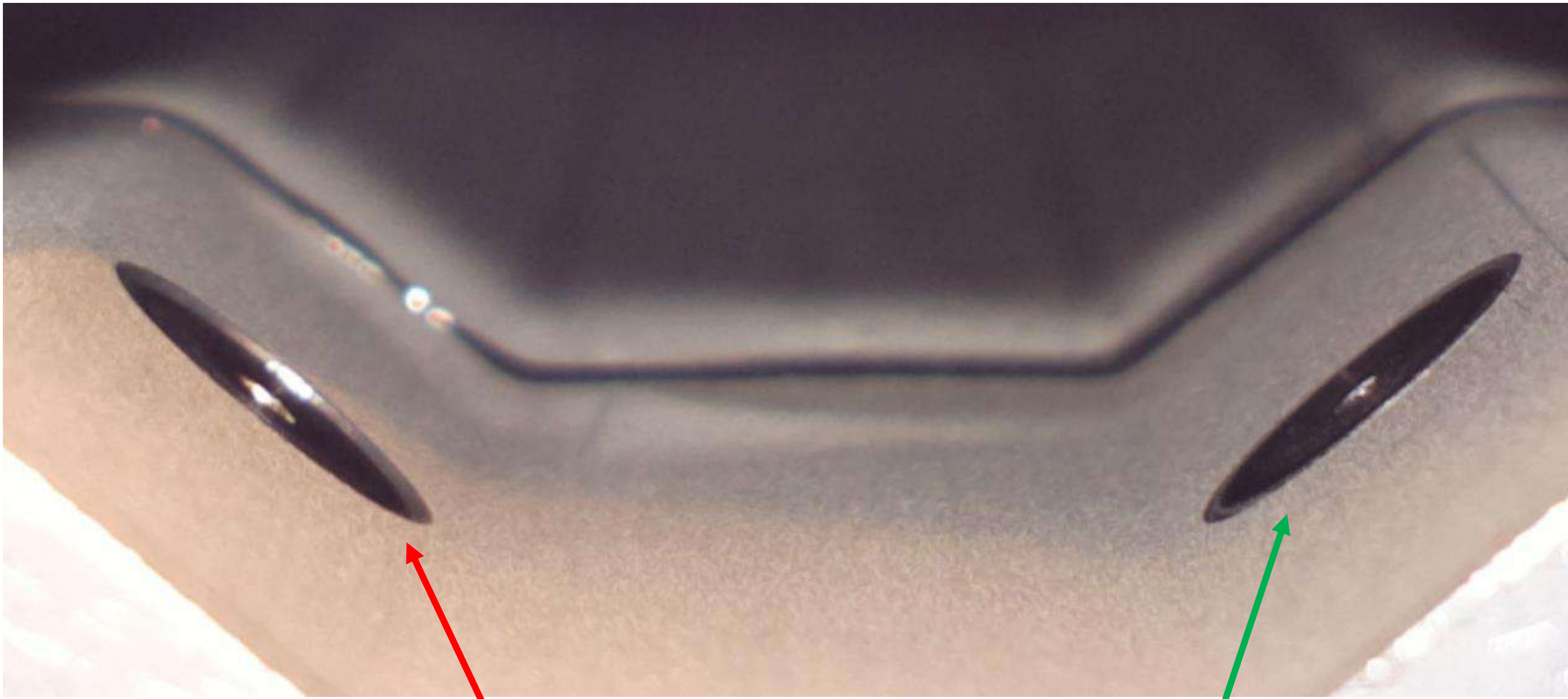
other offset causes not considered here (tilts, distorted geometry block/buttons)



electric offset BPM-block :
non-equal sensitivity of the 4 buttons
due to non-equal positioning

CH14-SR0413

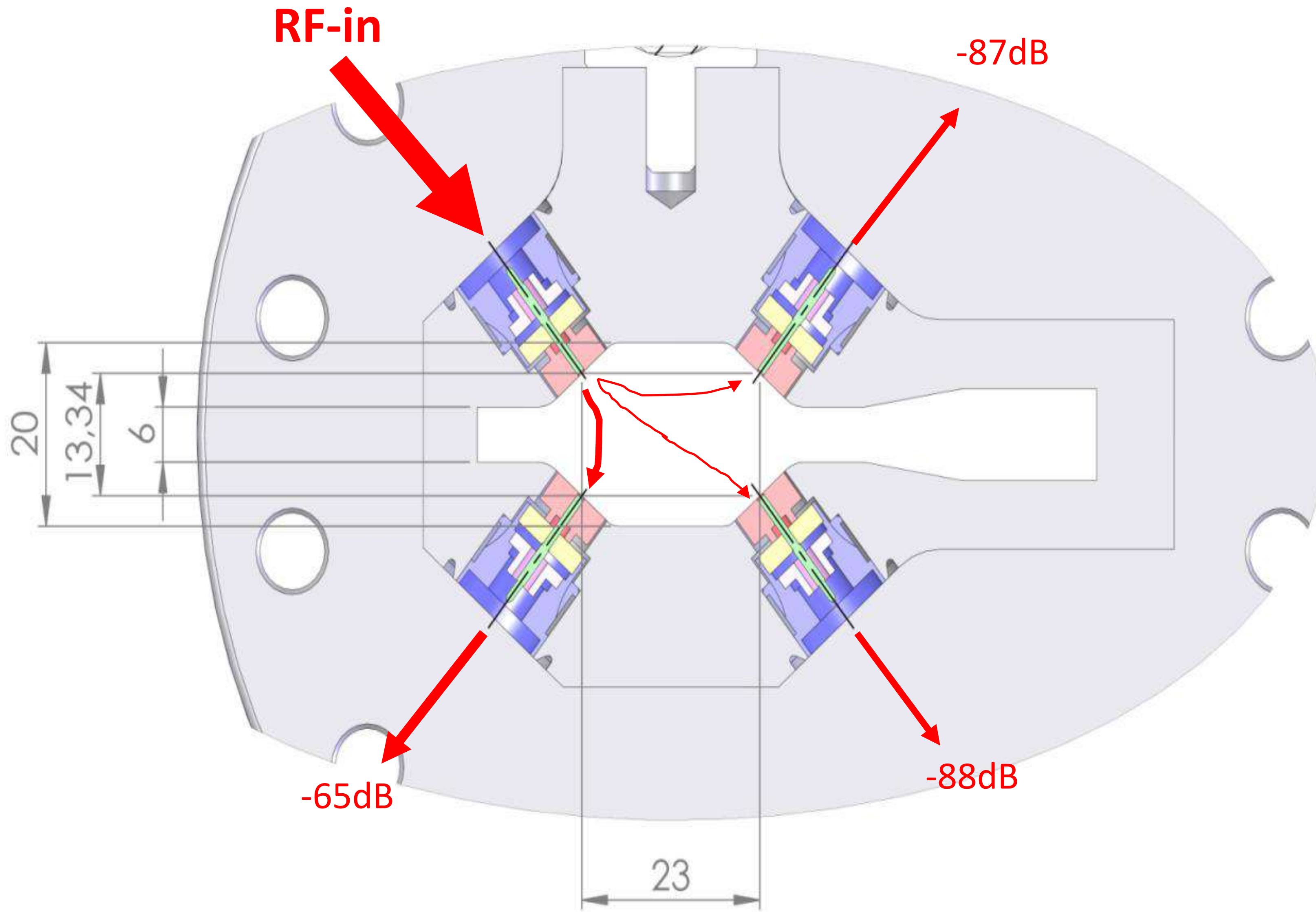
picture taken 23/02/2018, ESRF



C-button strongly retracted

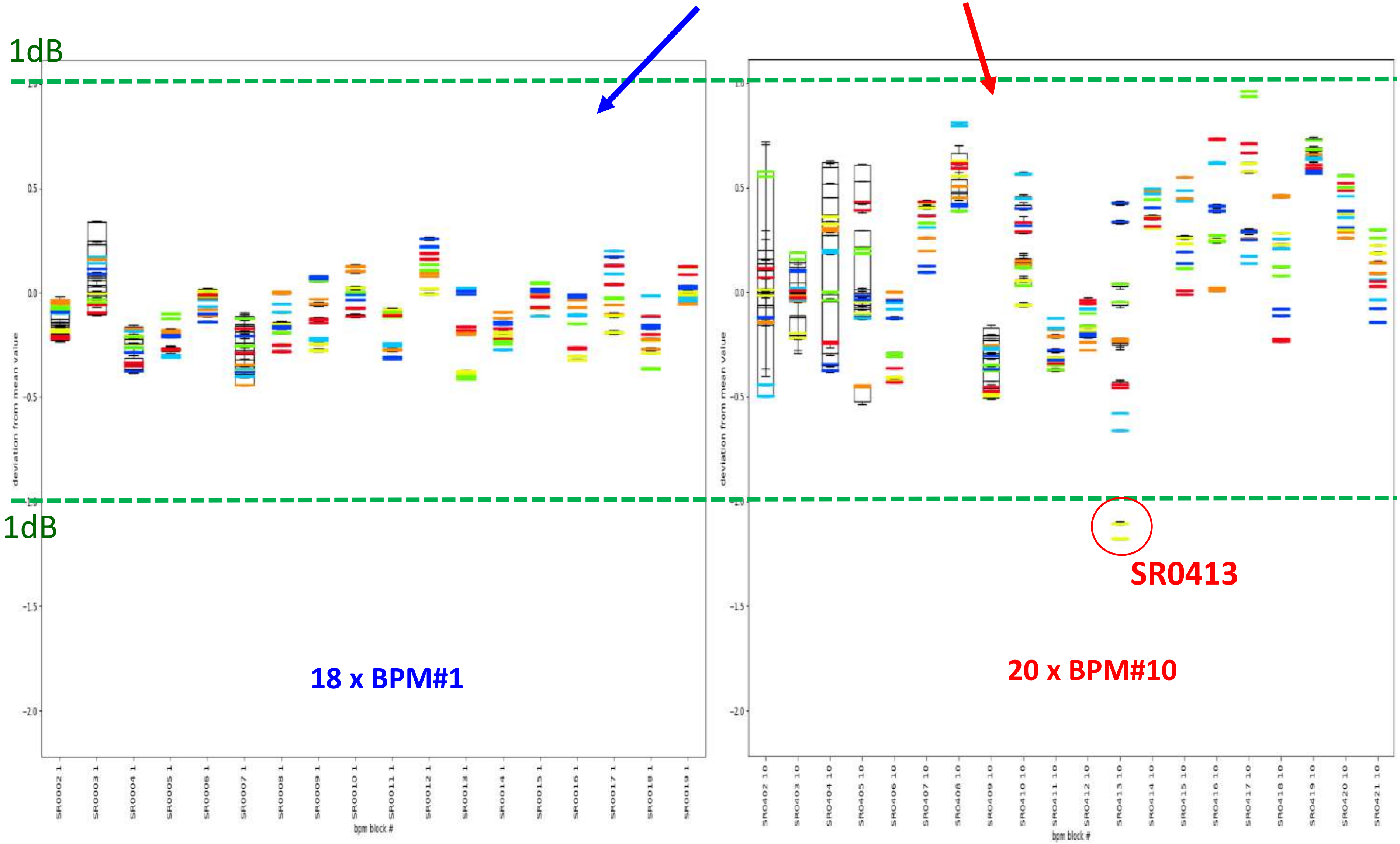
perfect

Measurements of "cross-RF-transmission" in BPM-blocks



4 x 3 measurements → sensitivity of each of the 4 buttons

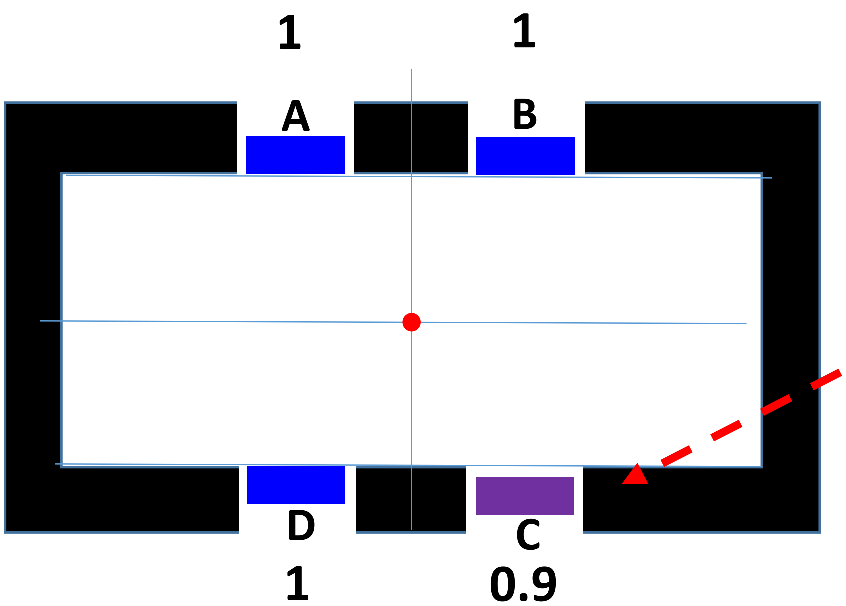
results of RF-cross-transmission measurements on numerous EBS-BPMs,
here below only of BPM #1 and BPM #10



manufacturer : FMB Berlin,
Ch#1=BPM#1

manufacturer : PINK Germany,
Ch#14=BPM#10

detection of incoherent electric offsets (possible with beam) : the incoherency (or Q) values of a set of A-B-C-D values



Q=Kq · (A+C-B-D) / (A+B+C+D)

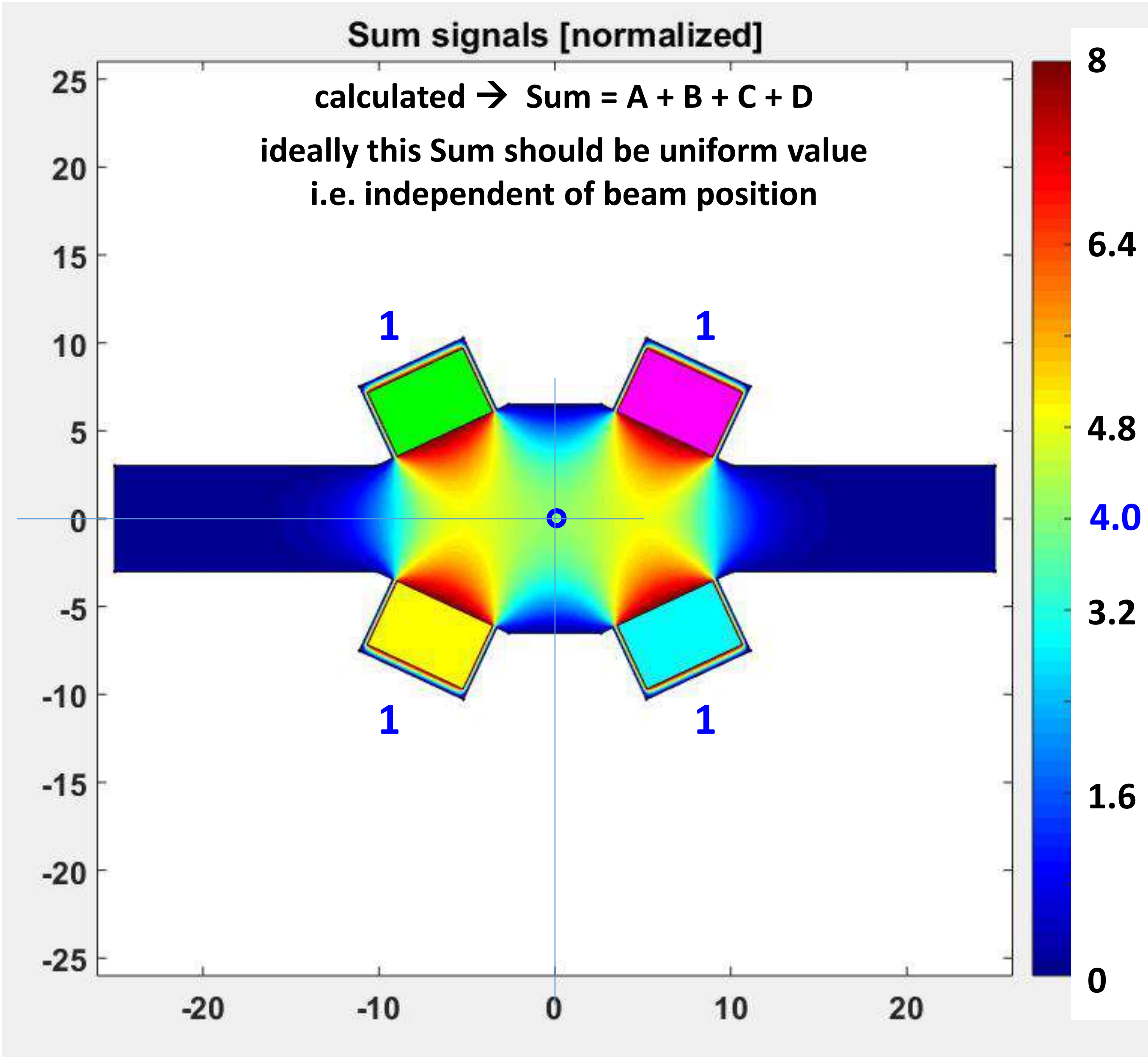
in this case of todays BPM (Kx=Kz=Kq=15):
Q=15 · 0.1 / 3.9 = **0.385mm**

important note :
the Q value indicates how (in-)coherent the 4 signals are
but does NOT tell which button is causing that incoherence (Q)

this Q is a very useful value :
1) to indicate the error-margin of the BPM results
2) but also to detect any the <u>drift or jumps of that Q-value</u>

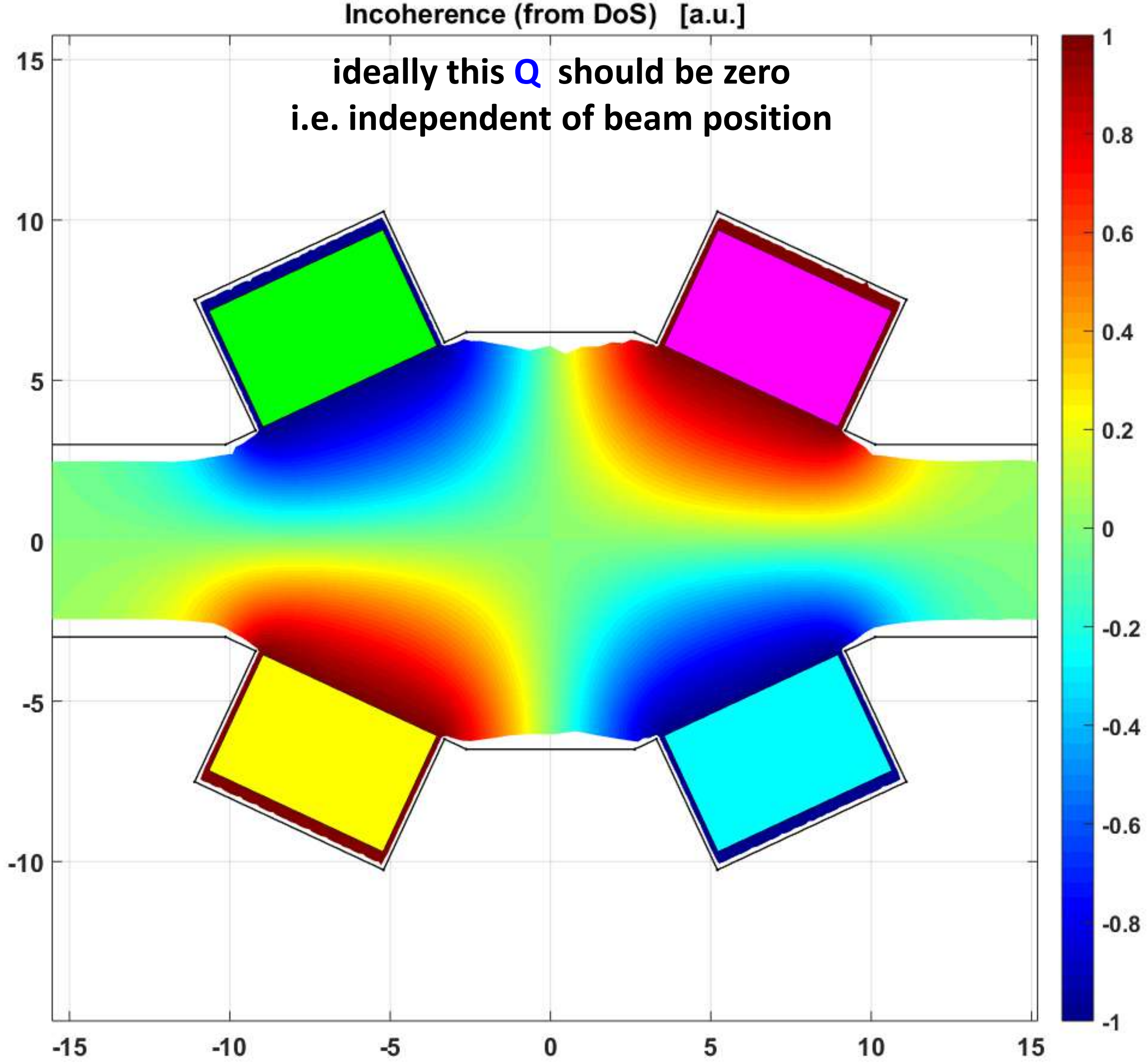
however with the simple DoS formula that only works in a small central area of the BPM

so, the same tool (Bpmlab from ALBA) that calculates linear & un-coupled BPM results will also calculate the correct Q value (over a large region)



this will also be dealt with by **Bpmlab_v_ESRF**

$Q = A+C-B-D / (A+B+C+D)$



this will also be dealt with by **Bpmlab_v_ESRF** consequence for BPM-Spark software :

in addition to :
the existing **H and V offsets**
4 button-sensitivity constants to be added

DoS :

X=a+d-c-b/(a+b+c+d)   Y=a+b-c-d/(a+b+c+d)

$\mathbf{X = Kx \cdot X + Xoff}$
$\mathbf{Y = Ky \cdot Y + Yoff}$

$X=a \cdot Ka + d \cdot Kd - c \cdot Kc - b \cdot Kb \,/\, (a \cdot Ka + b \cdot Kb + c \cdot Kc + d \cdot Kd)$

$Y=a \cdot Ka + b \cdot Kb - c \cdot Kc - d \cdot Kd \,/\, (a \cdot Ka + b \cdot Kb + c \cdot Kc + d \cdot Kd)$

$\mathbf{Xp = +\ 6.752 \cdot X\ -8.701 \cdot X \cdot Y^2\ -2.503 \cdot X \cdot Y^4\ +0.597\ X^3\ +7.737\ X^3 \cdot Y^2\ +5.225\ X^5\ +\ Xoff}$

$\mathbf{Yp = +\ 15.761 \cdot Y\ -19.858 \cdot Y \cdot X^2\ +8.718 \cdot Y \cdot X^4\ +19.585\ Y^3\ -25.002\ Y^3 \cdot X^2\ +8.8895\ Y^5\ +\ Yoff}$

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and dealing with other inevitable dyssymmetries

Thank you for your attention

Kees Scheidt

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