

Calculation of corrected BPM data with polynomials obtained from BpmLab: ESRF and ALBA showcases

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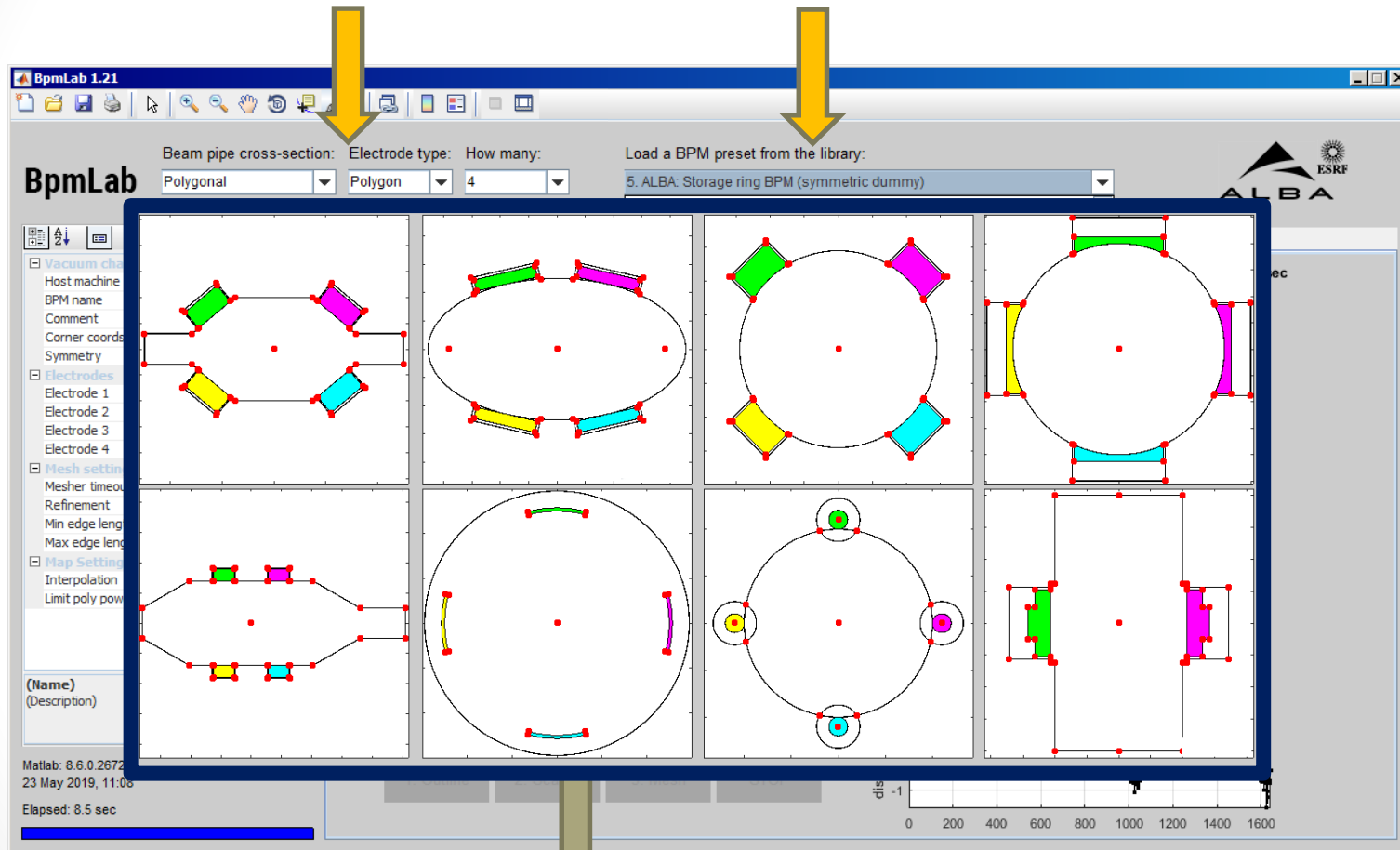


What is BpmLab?

a FEM-based Matlab tool for BPM response simulation and treatment

2D BPM slices are defined by combinations of simple shapes: circles, ellipses & polygons

Library of many real BPMs (34 and counting...)



Geometry, mesh & map settings

Geometry outlines

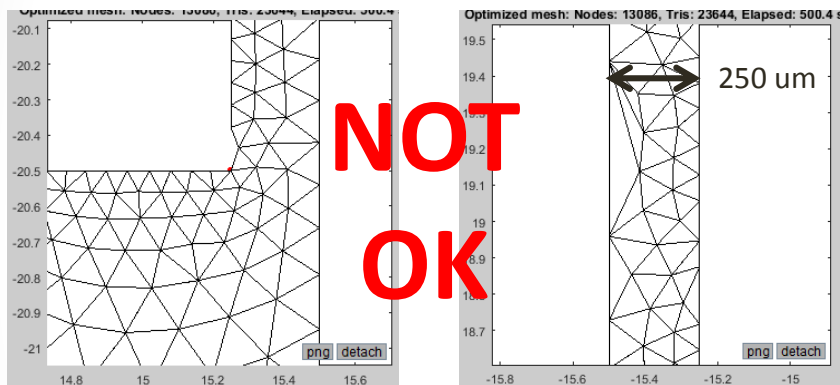
Final mesh & boundary nodes precision



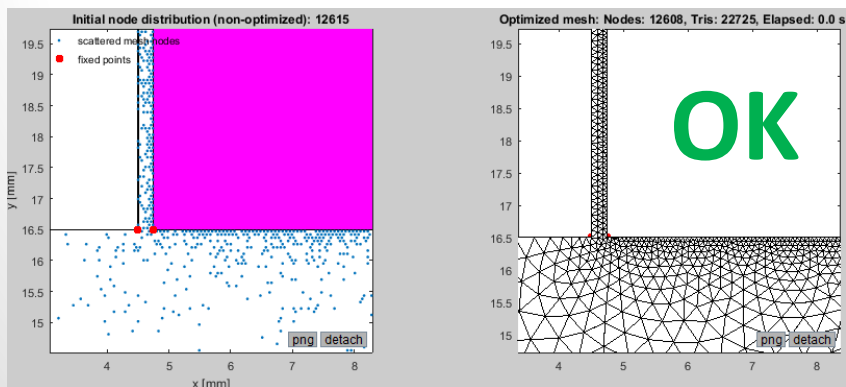
Meshing:

Open-source tetrahedral mesh generator based on metric functions (*DistMesh*).

- Uniform or non-uniform meshes
- User-defined min/max mesh size
- Extremely reliable inner mesh
- Boundary mesh QA: by eye. Always check!



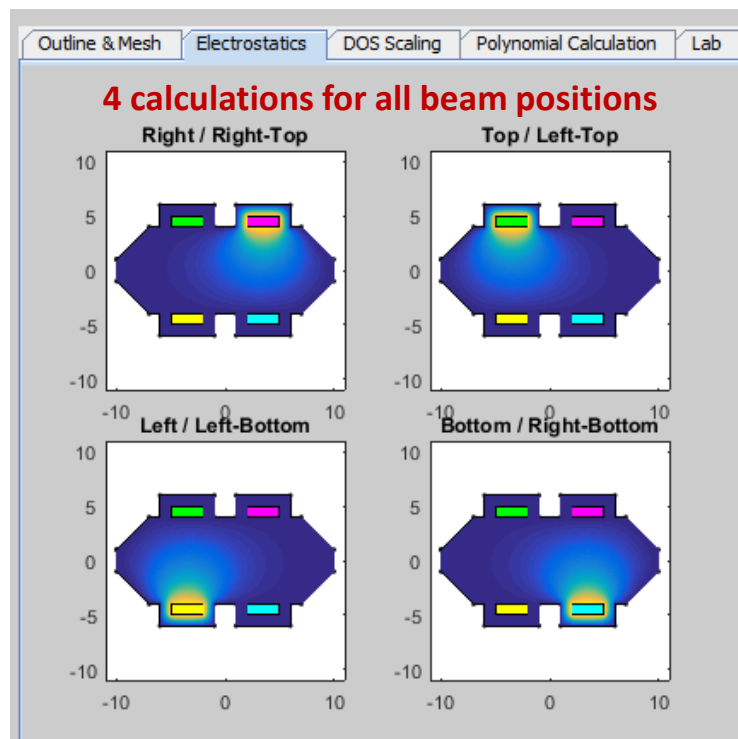
Examples of a badly converged mesh



Properly converged mesh

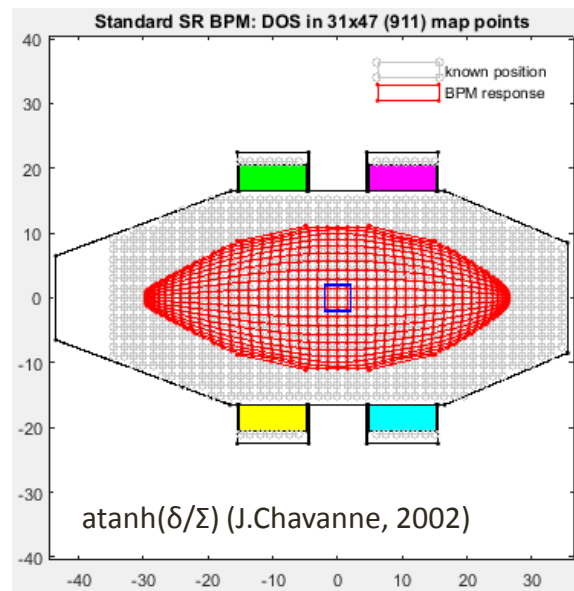
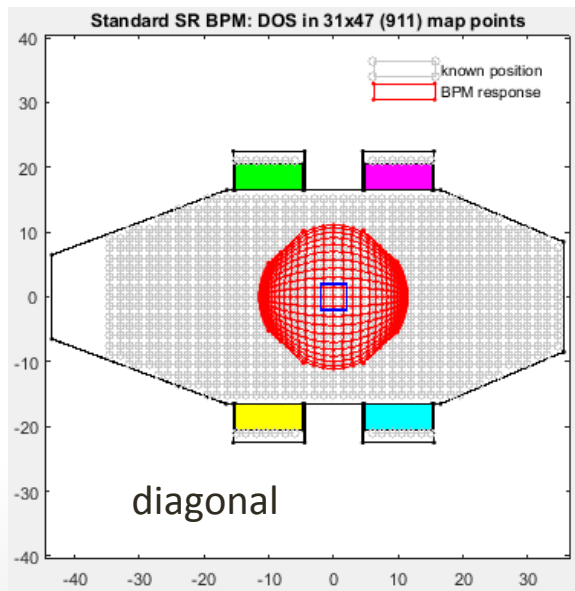
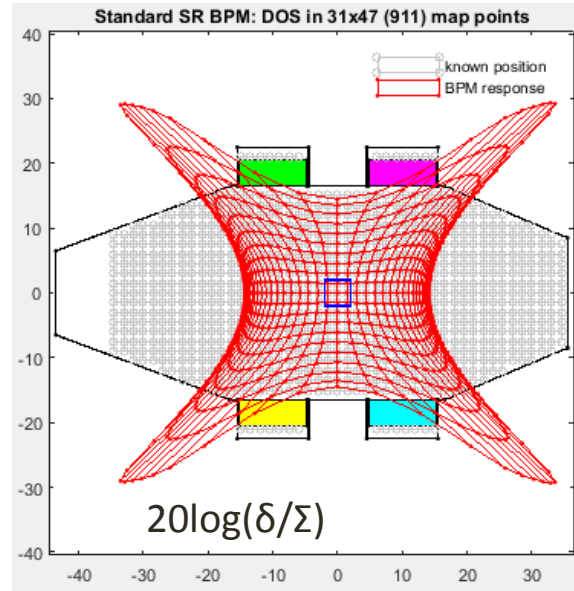
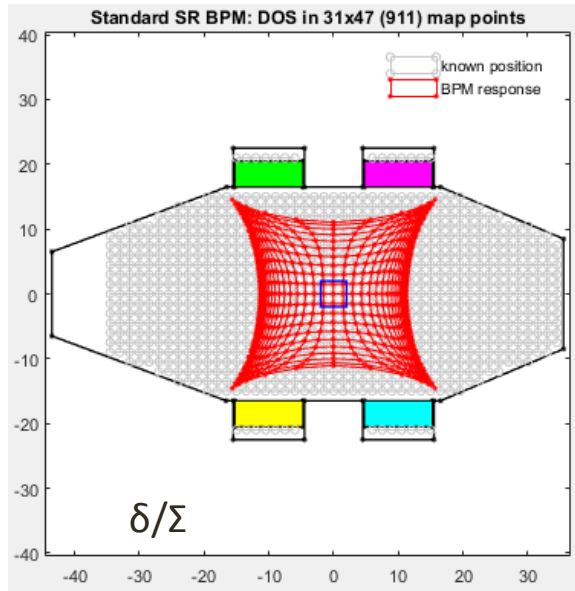
FEM Solver:

2D electrostatic Poisson solver with linear basis functions and boundary electric potential excitation (Diriclet boundary conditions):

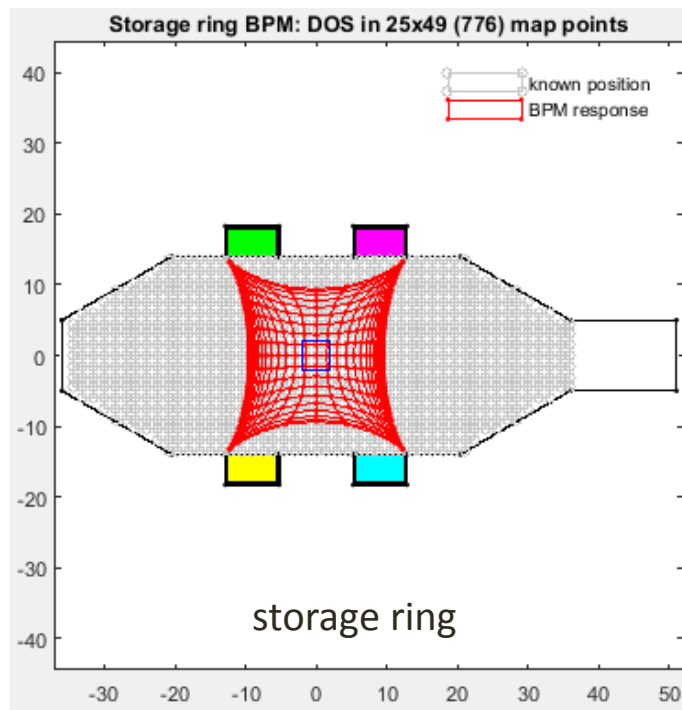
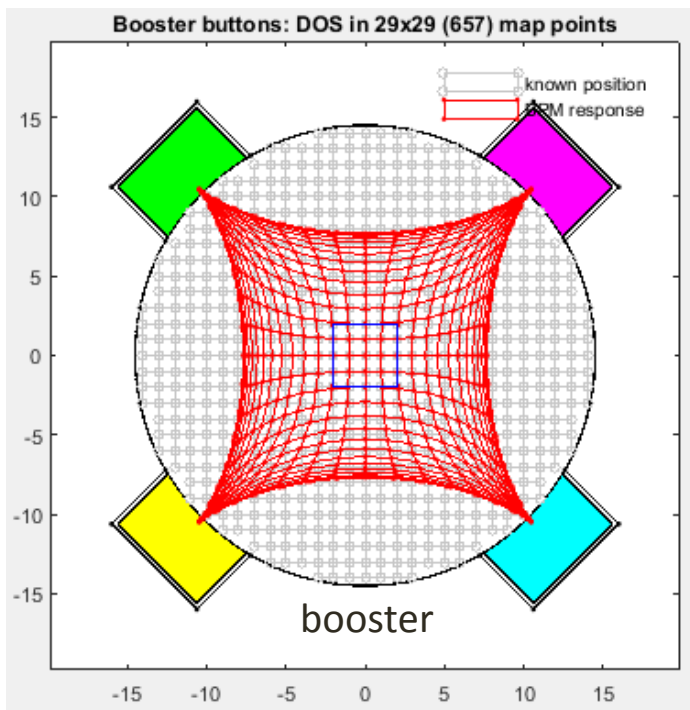


Green's reciprocity theorem: the surface charge induced on an electrode due to a test charge at (x,y) is proportional to the potential at that same position when the test charge is absent and the electrode is excited by a potential V .

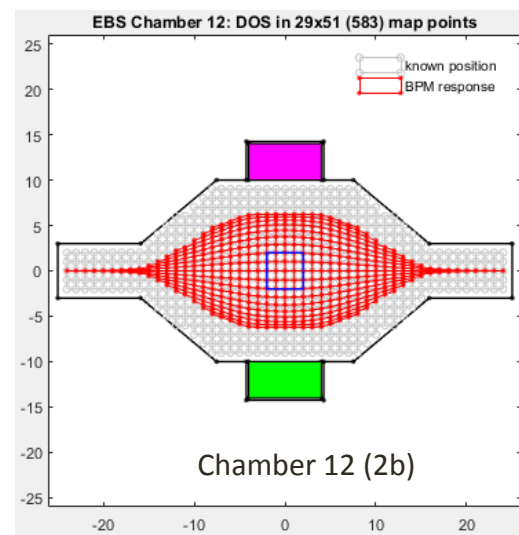
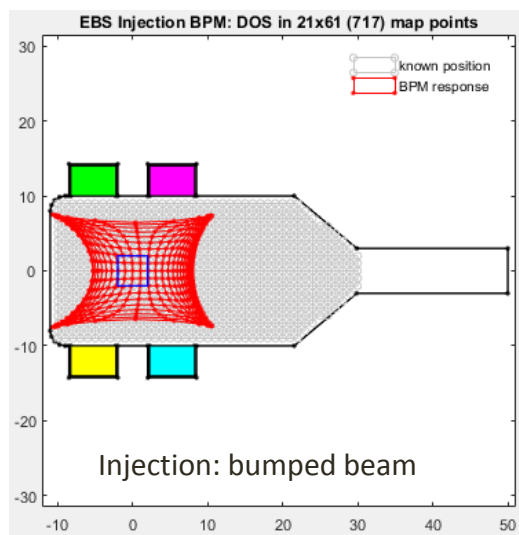
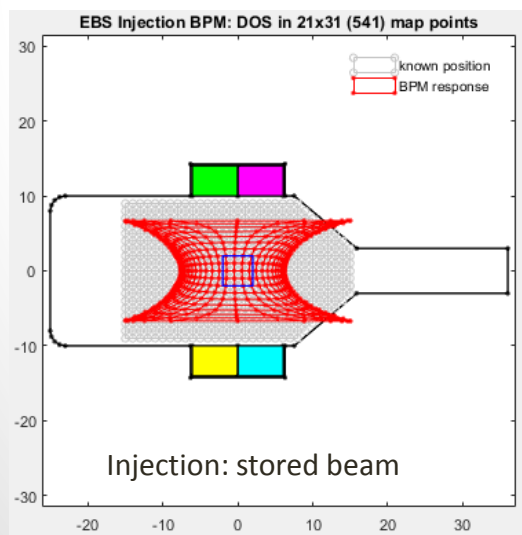
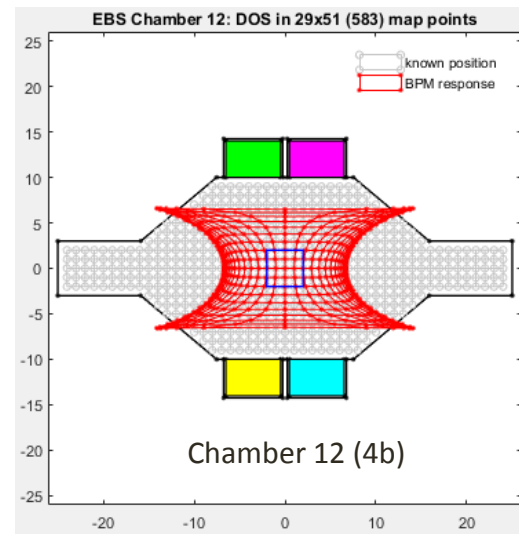
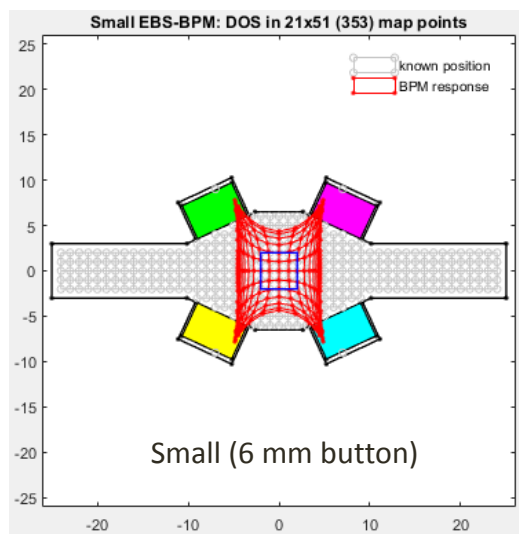
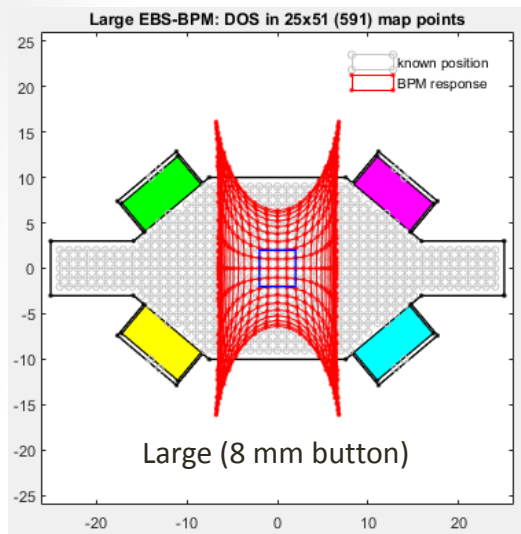
ESRF standard SR BPM

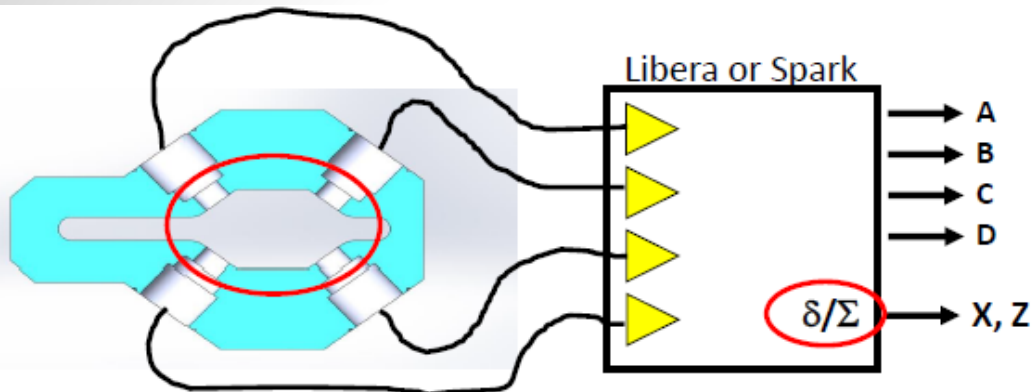


ALBA BPM family



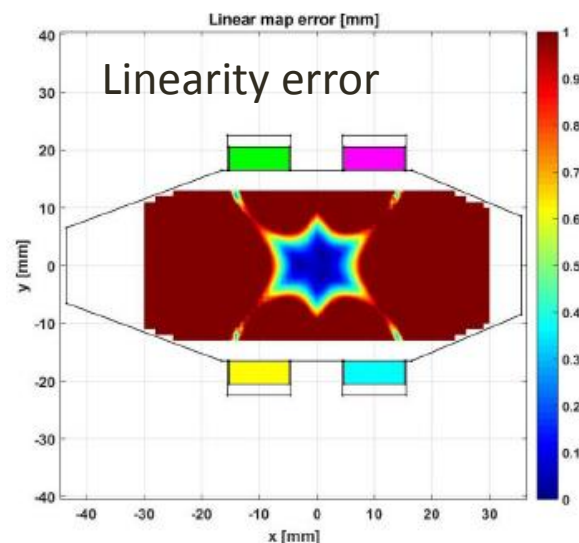
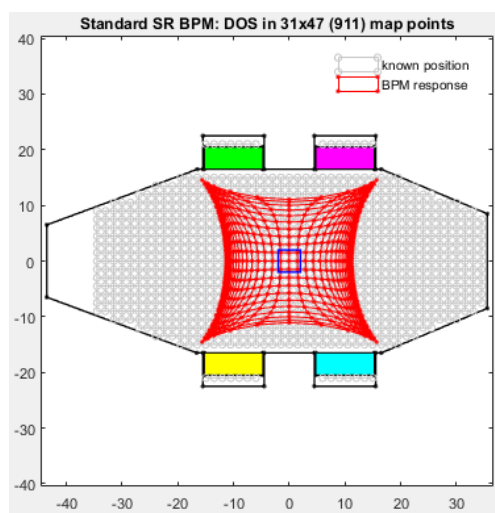
Upcoming EBS BPM family





Perfect BPM & low noise
stable electronics are still
imperfect:

dislinearity !
coupling !



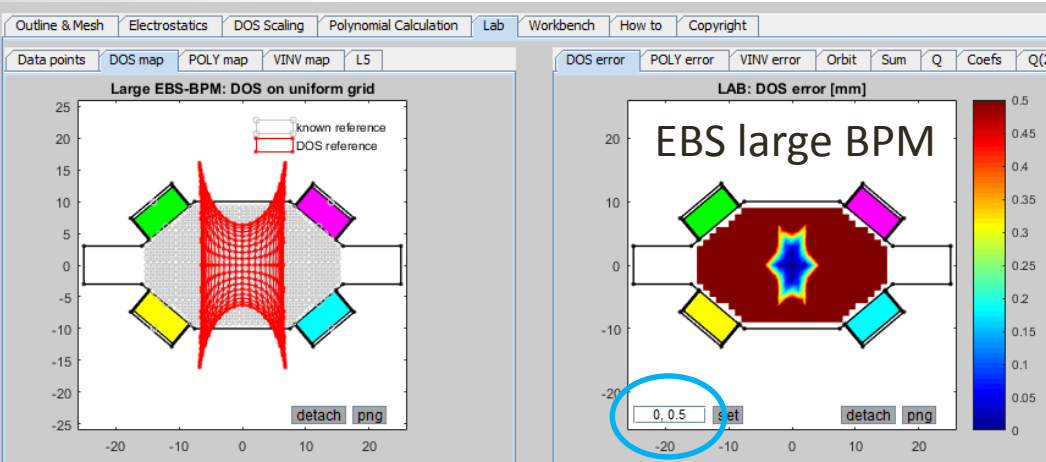
How to correct?

- Linear coefficient (real-time)
- Polynomial families (real-time)
- Specific formulae (real-time)
- Lookup tables (post-process)
- Voltage inversion (iterative optimization, so post-process)

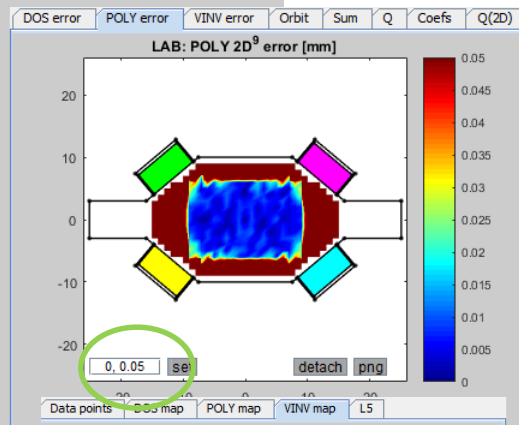
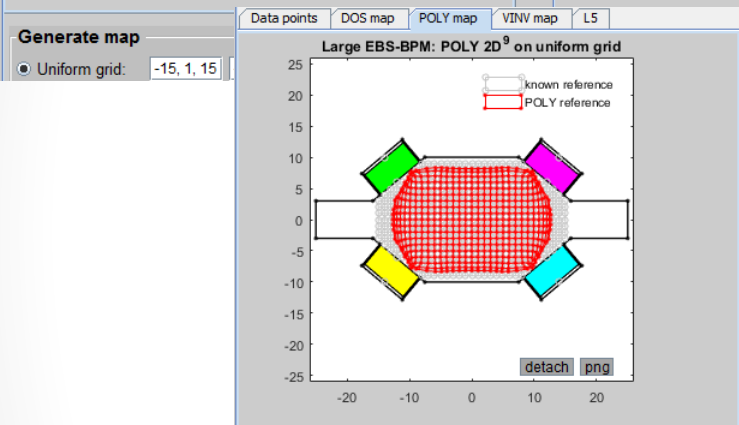
At what level? (by DS/Libera? by end-user?)

How fast? (TbT 100x kHz, FA 10x kHz, SA 10x Hz)

Linear correction by DOS



Polynomial correction



Generate map

Uniform grid: -15, 1, 15

Scattered points: 100

Channel mods

Add noise [%]: 0,0,0,0

Ampl/att coef: 1,1,1,1

Generate map

Uniform grid: -15, 1, 15 -10, 1, 10

Scattered points: 100

Import signals: select file

Channel mods

Add noise [%]: 0,0,0,0

Ampl/att coef: 1,1,1,1

show positions update

Corrections

DOS: POLY: VOLTAGE INVERSION:

kx 6.762 - 9 + Algorithm: newton0 (minFunc)

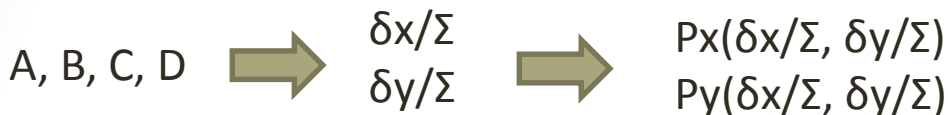
ky 16.103 Q adv Search around: Nearest Mesh Node

update update background mode Go Stop

Inverted voltages

Polynomial correction seems to be the straight-forward solution if you want to have large beam drifts, and have fast real-time position nonlinearity suppression.

2 polynomials need to be applied to each data sample:



Large EBS-BPM: POLY 2D⁹ on uniform grid

LAB: POLY 2D⁹ error

known reference
POLY reference

Polynomials are coupled 2D type.

Higher power = more coefficients, e.g.:

- Max pwr 7: 36 terms
- Max pwr 13: 105 terms
- etc.

Generate map

- Uniform grid: [-15, 1, 15] [-10, 1, 10]
- Scattered points: 100

Channel mods

Add noise [%]: 0,0,0,0

Ampl/att coef: 1,1,1,1

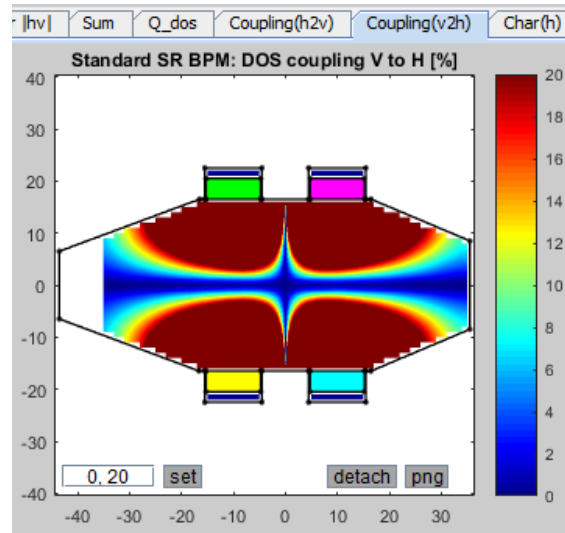
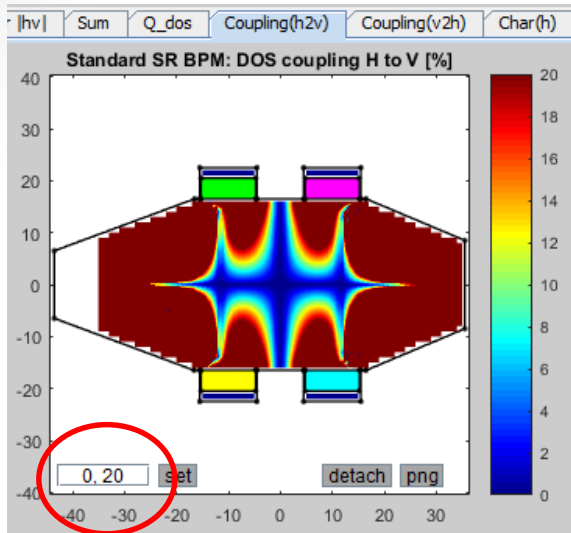
Corrections

DOS: []

POLY: 9

Horizontal polynomial		Vertical polynomial	
x15y0	42.447,588	x15y0	332,85
x14y1	69,241	x14y1	30.832,228
x14y0	1.586,775	x14y0	-91,782
x13y2	-147.300,086	x13y2	-1.013,609
x13y1	-30,787	x13y1	649,664
x13y0	-38.002,923	x13y0	-356,605
x12y3	-268,15	x12y3	-128.135,023
x12y2	-5.824,034	x12y2	266,235
x12y1	-23,161	x12y1	-5.875,599
x12y0	-680,907	x12y0	74,861
x11y4	192.923,913	x11y4	806,502
x11y3	108,826	x11y3	-2.499,222
x11y2	135.707,181	x11y2	1.363,088
x11y1	11,446	x11y1	21,457
x11y0	2.415,753	x11y0	21,769
x10y5	264,206	x10y5	178.343,616
x10y4	7.159,382	x10y4	-139,257
x10y3	251,661	x10y3	75.137,916
x10y2	3.999,233	x10y2	-346,509
x10y1	-53,746	x10y1	-20.805,545
x10y0	-613,595	x10y0	23,971
x9y6	-119.217,304	x9y6	-26,609
x9y5	-89,889	x9y5	3.033,505
x9y4	-165.912,163	x9y4	-1.229,843
x9y3	-102,727	x9y3	979,278
x9y2	-30.718,33	x9y2	-562,911
x9y1	20,02	x9y1	-383,234
x9y0	6.998,334	x9y0	100,256
x8y7	26,581	x8y7	-100.888,026
x8y6	-3.322,619	x8y6	-83,2
x8y5	-408,769	x8y5	-128.358,48
x8y4	-5.465,52	x8y4	264,434
x8y3	12,264	x8y3	14.514,828
x8y2	-90,818	x8y2	128,623
x8y1	33,628	x8y1	11.464,579
x8y0	446,532	x8y0	-39,127
x7y8	35.815,842	x7y8	207,817
x7y7	-22,577	x7y7	-1.361,804
x7y6	85.849,102	x7y6	-280,47
x7y5	140,898	x7y5	-1.672,073

Coupling (DOS positions)

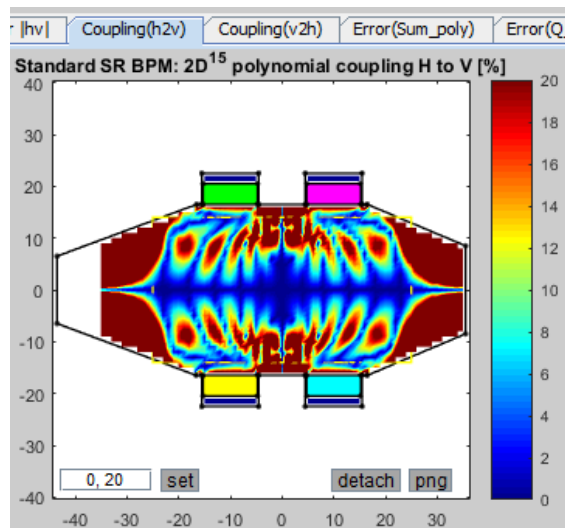
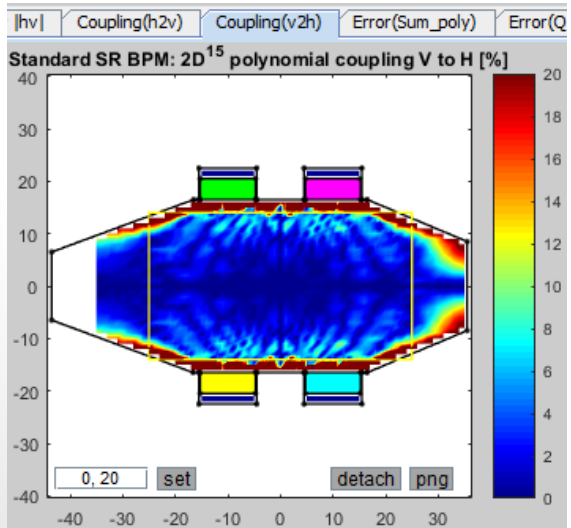


Coupling:

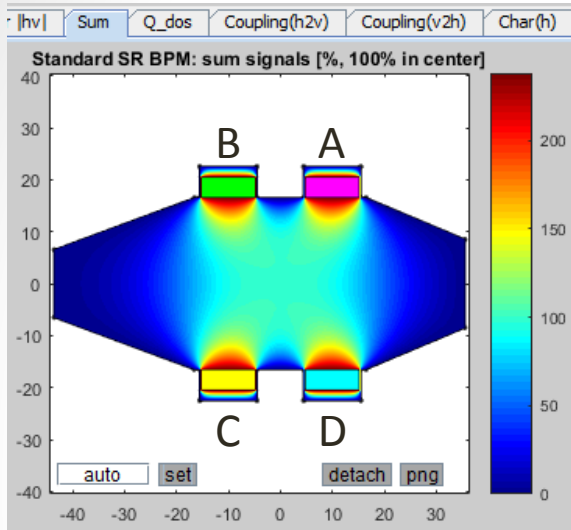
Ratio of how much the position change in one dimension affect its change in the other dimension.

Using the polynomial corrected positions can minimize the coupling effect.

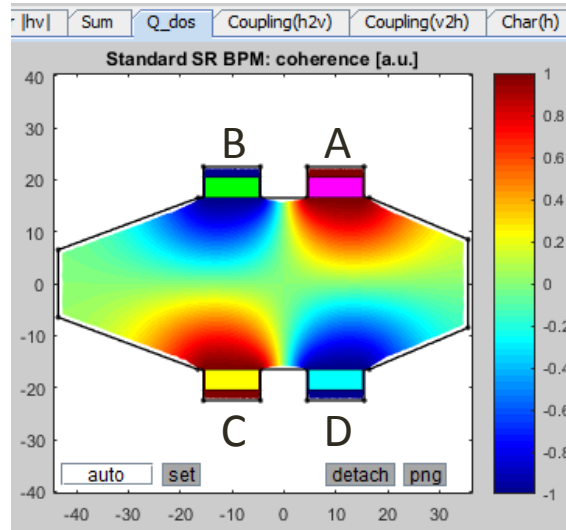
Coupling improved (Poly correction)



Sum signal

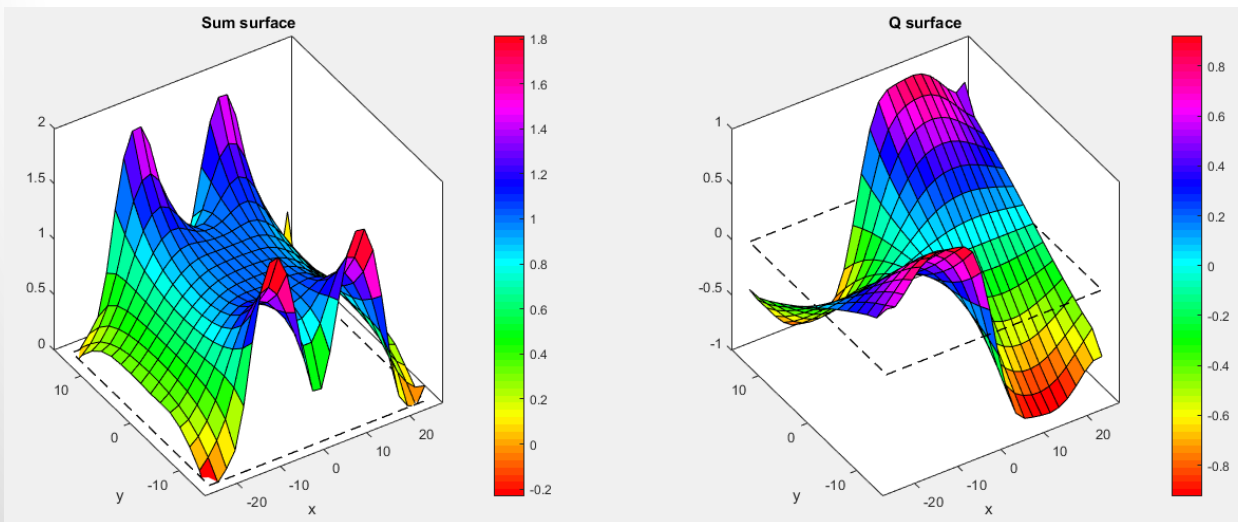


Signal Coherence



$$\Sigma = A+B+C+D$$

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



Sum & Coherence:
Strongly nonlinear.

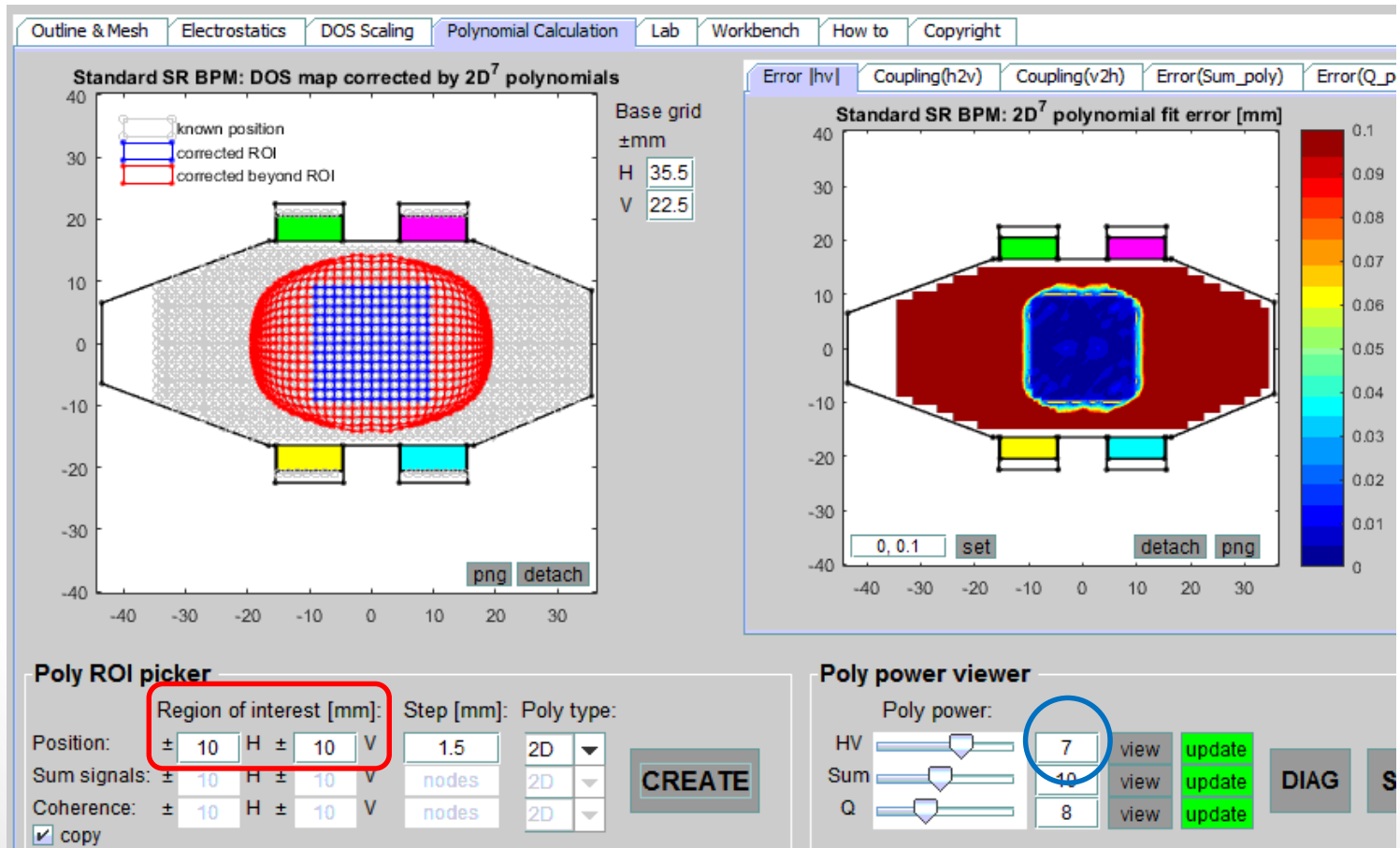
Can be linearized with
higher-order polynomials.

BpmLab: Polynomial ROI fitness

A polynomial is defined by its effective ROI and max power. Ho can we pick them?

Step 1) Fix max polynomial power (here: x^7y^7) and scan the ROI dimensions.

Accuracy starts to deteriorates as the poly needs to fit a more curvy surface:



BpmLab: Polynomial power fitness

Step 2) Fix the ROI (here ± 20 mm x ± 10 mm) and scan the poly power.

Step 3) Choose the power/ROI combination that fits your needs

Beware: speed of calculation can increase for higher power polynomials.

The screenshot displays the BpmLab software interface with the following components:

- Top Menu:** Outline & Mesh, Electrostatics, DOS Scaling, Polynomial Calculation, Lab, Workbench, How to, Copyright.
- Left Panel: Standard SR BPM: DOS map corrected by 2D³ polynomials**
 - Legend: known position (white), corrected ROI (blue), corrected beyond ROI (red).
 - Base grid \pm mm: H 35.5, V 22.5.
 - Buttons: png, detach.
- Right Panel: Standard SR BPM: 2D³ polynomial fit error [mm]**
 - Color scale: 0 to 0.1 mm.
 - Buttons: 0, 0.1, set, detach, png.
- Poly ROI picker**

Region of interest [mm]:	Step [mm]:	Poly type:
Position: \pm 20 H \pm 10 V	1.5	2D
Sum signals: \pm 20 H \pm 10 V	nodes	2D
Coherence: \pm 20 H \pm 10 V	nodes	2D

copy **CREATE**
- Poly power viewer**

	Poly power:	
HV	3	view update
Sum	14	view update
Q	12	view update

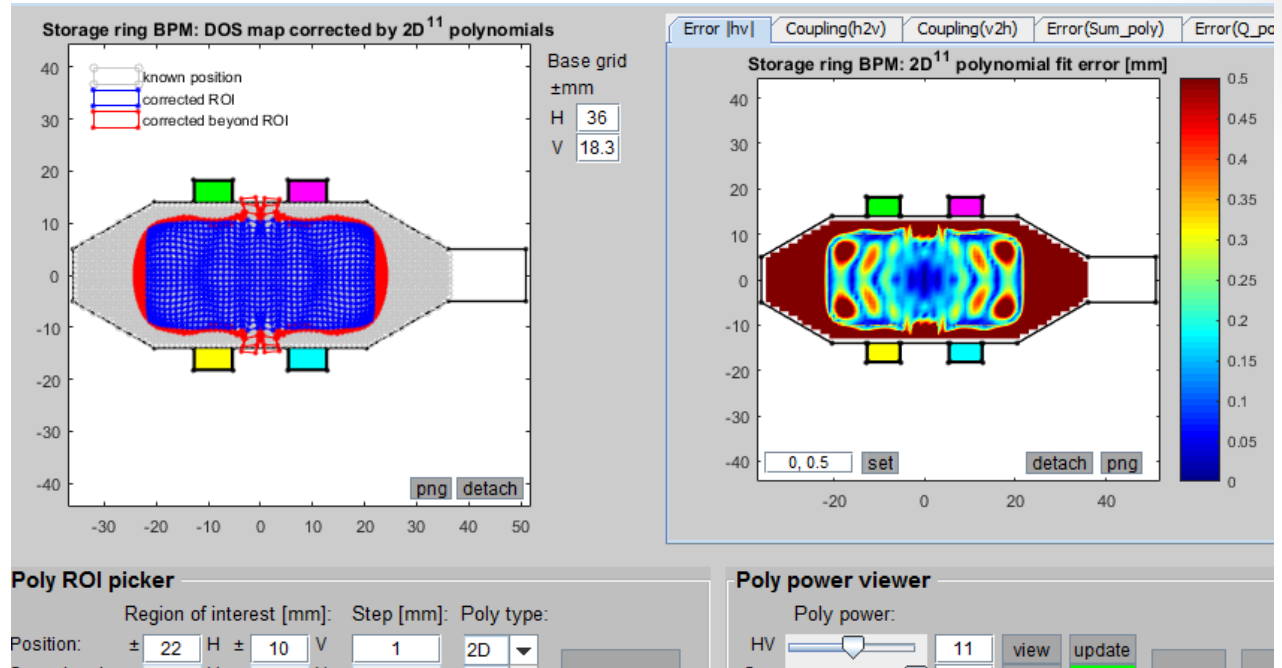
DIAG **S**

BpmLab: Polynomial fitness

Finally we have to stop somewhere, e.g.:

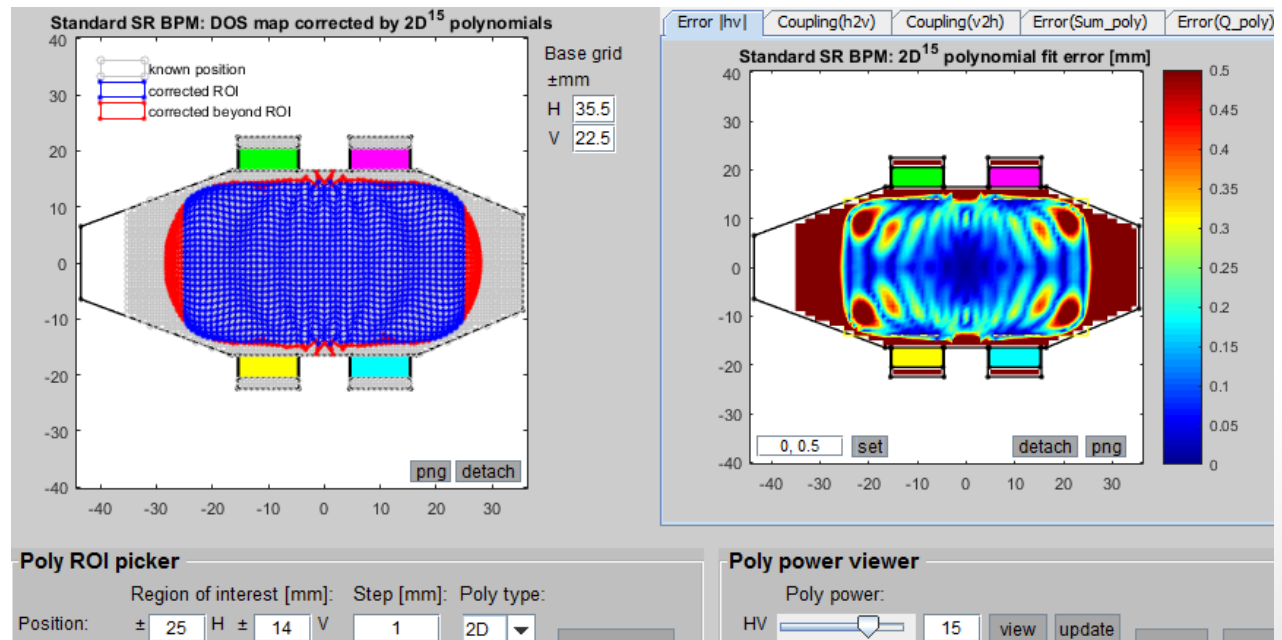
ALBA SR BPM

ROI = $\pm[22, 10]$ mm
max pwr = 11



ESRF SR BPM

ROI = $\pm[25, 14]$ mm
max pwr = 15



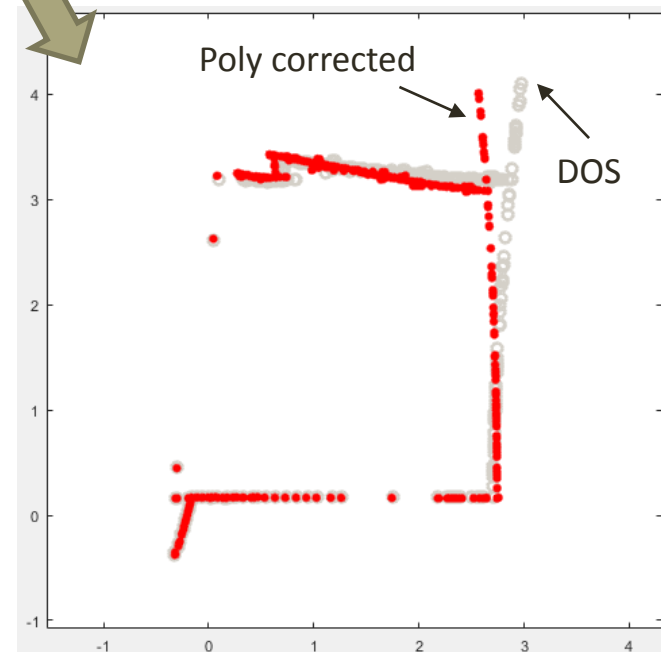
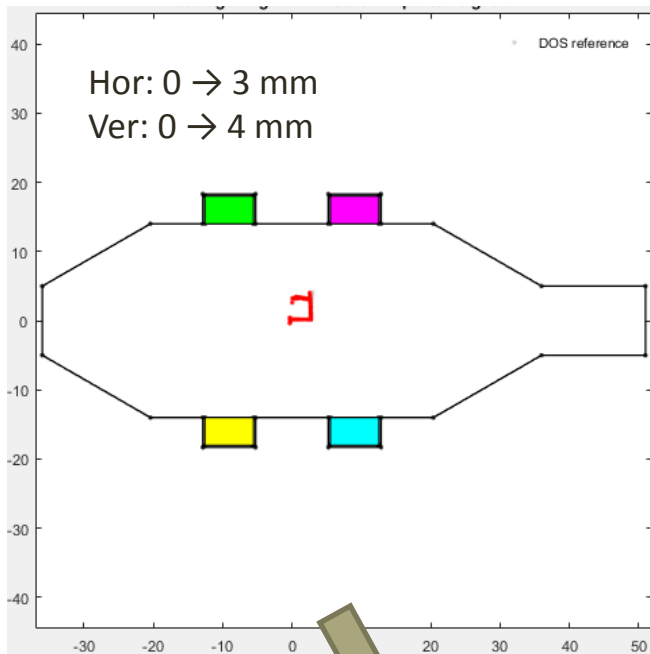
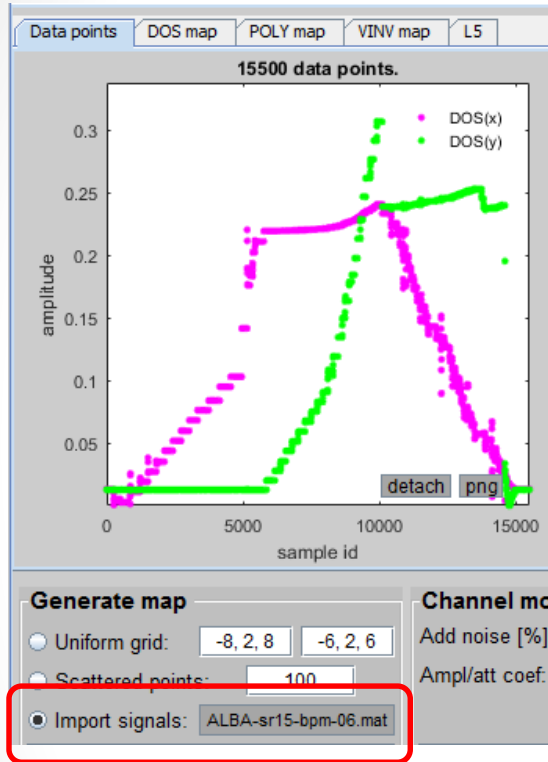
EBS BPM

Several Poly families
selectable in Libera DS.
max pwr = ??

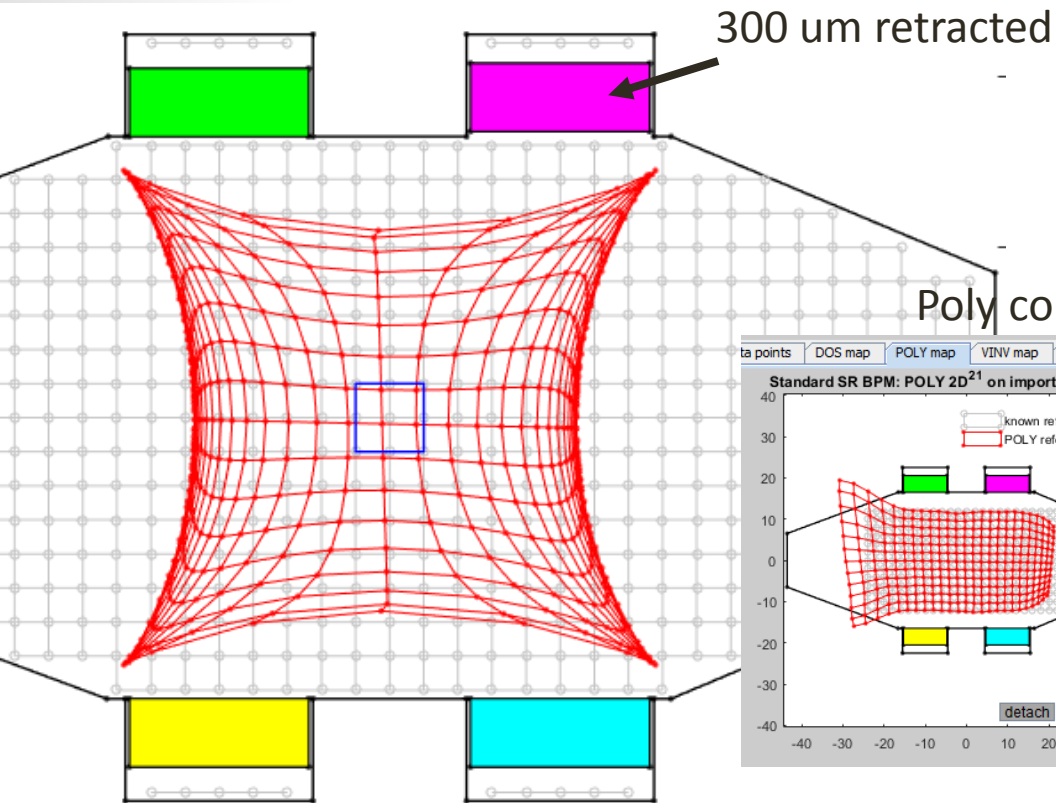
BpmLab: Post-processing real signals

ALBA SR

Local bump, 4 orbit-correctors

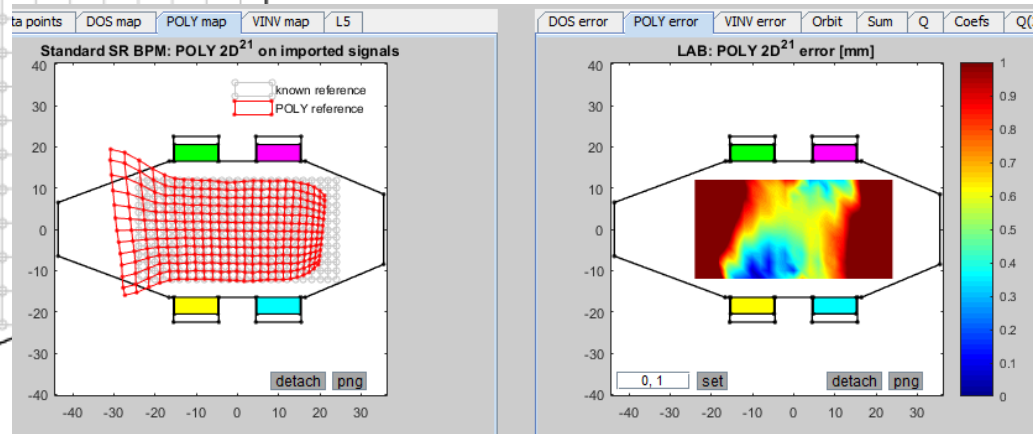


BpmLab: Button imperfections (retraction/protrusion)

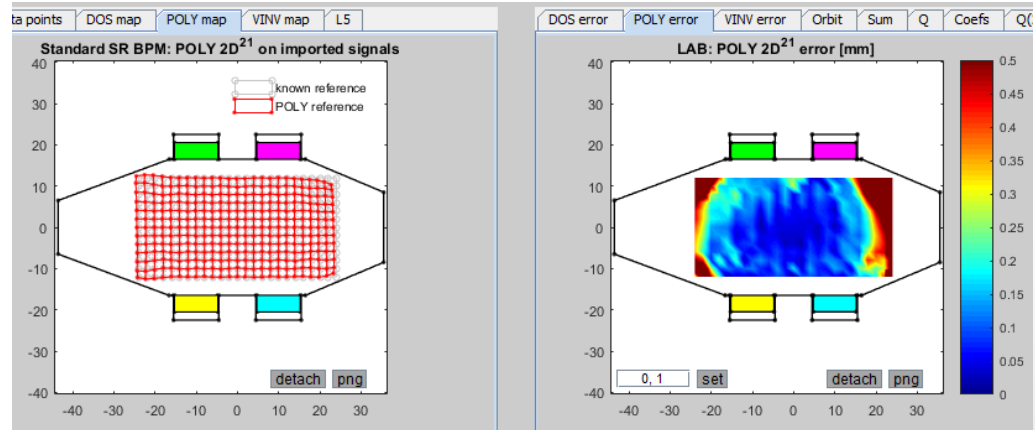


Use "perfect Poly" to correct this distortion

Poly correction: channel A as is

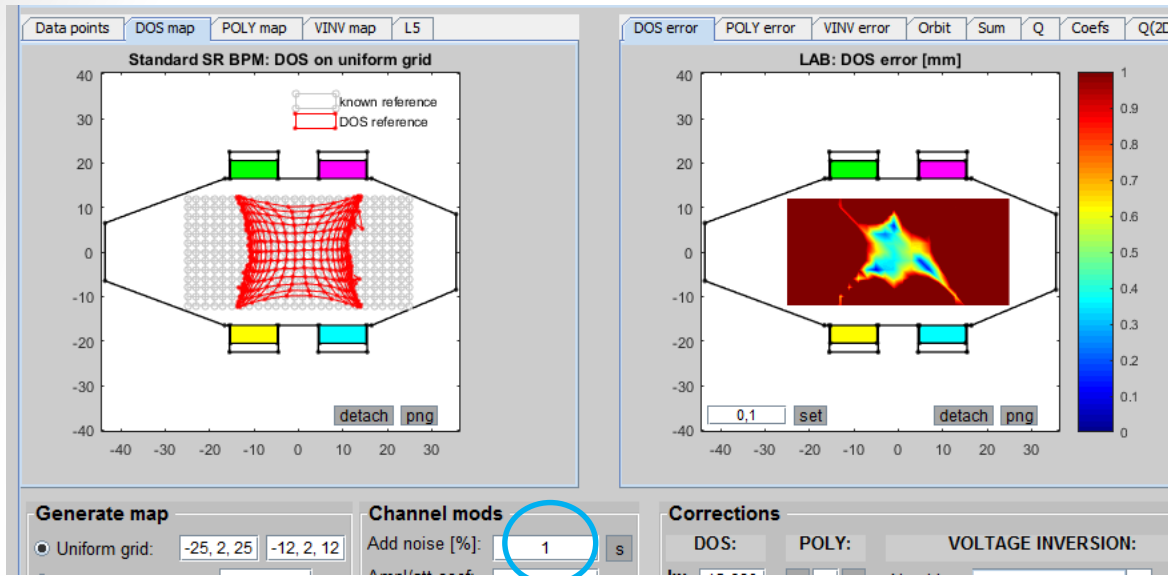


Poly correction: channel A compensated

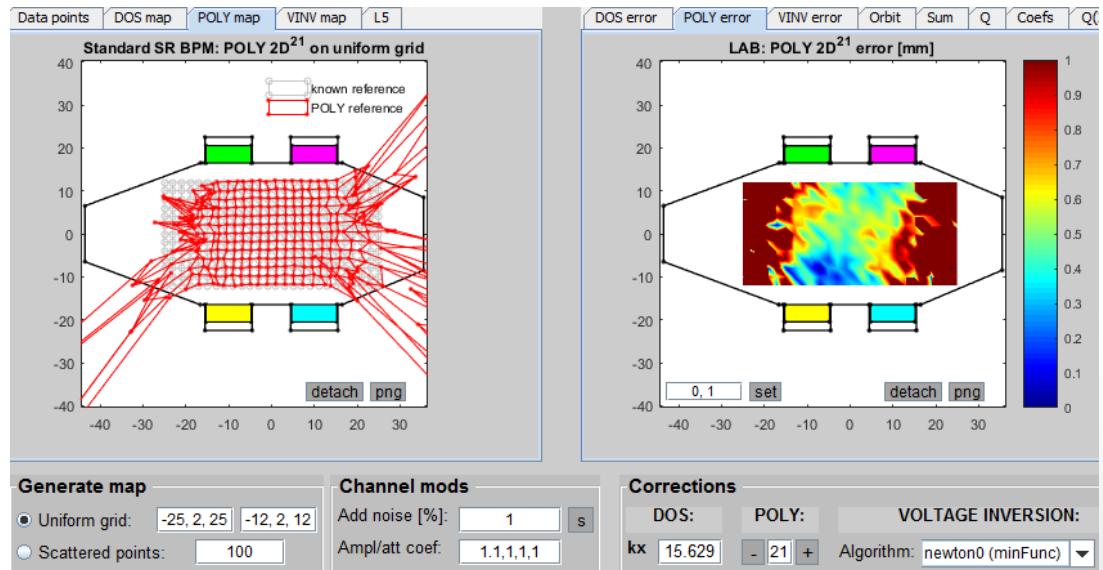


Add noise (1%) to all channels:

DOS treatment



Poly correction



BpmLab summary

Requires Matlab toolbox-free installation (versions range 2014b-2017)

Instruments:

- meshing (DistMesh)
- short 50-line 2D electrostatic FEM solver
- optimization (minFunc)

Features:

- Easy arbitrary geometry input & many presets
- BPM response map calculation in 2D
- Correction polynomial calculation (within ROI)
- Direct voltage-to-position inversion (post-processing)
- Introduce geometry imperfections
- Signal manipulation (channel distortion, attenuation, amplification)
- Import real BPM signals for studies and post-processing

Download from here:

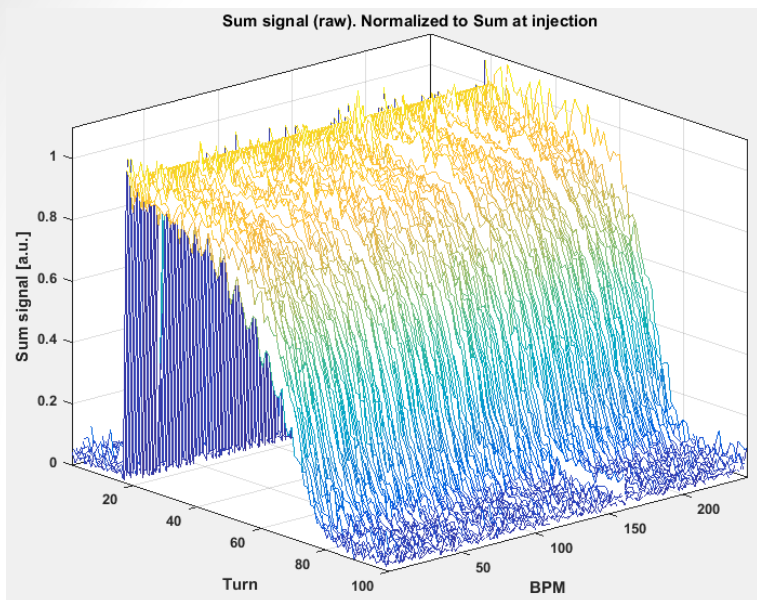
https://intranet.cells.es/Divisions/Accelerators/RF_Diagnostics/Diagnostics/Orbit Position/Tools/bpmlab

Now the interesting stuff...

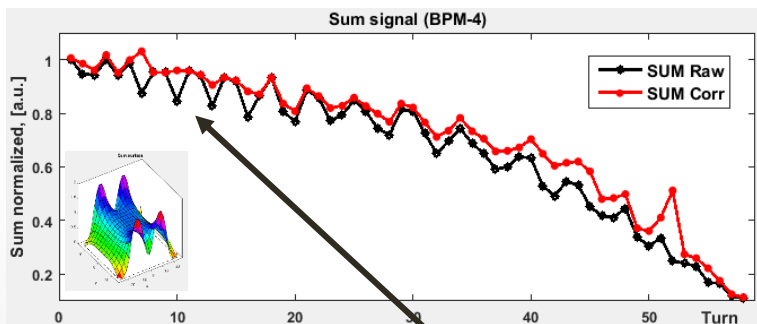
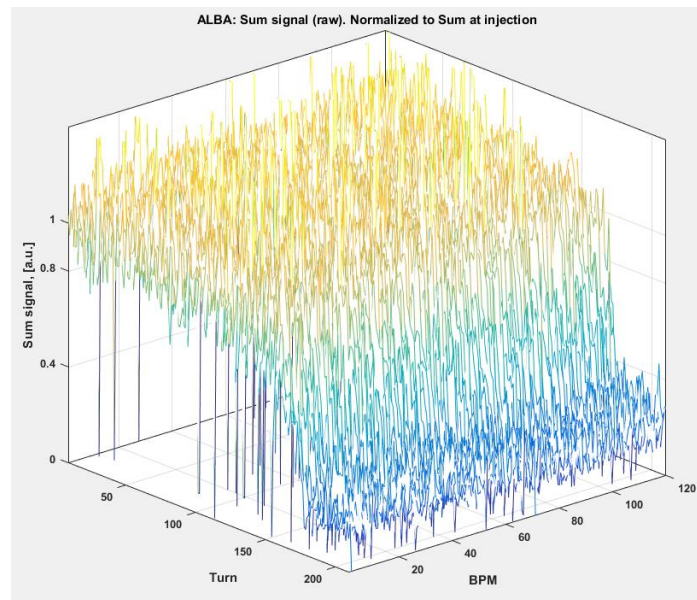
Experiments!

Injecting with RF off: Signal SUM & COHERENCE

ESRF (Nov 26, 2018)

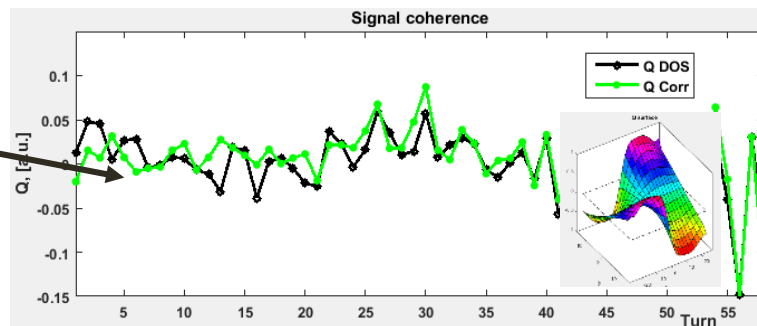


ALBA (May 2019)



$$\text{Corrected Sum} = \text{SUM}_{\text{RAW}} / (\text{norm_coef} * \text{SUM}_{\text{model}}) \rightarrow 1$$

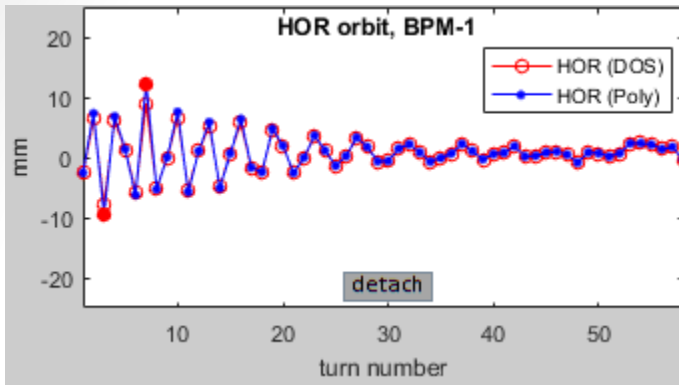
$$Q \text{ Corrected} = Q_{\text{DOS}} - Q_{\text{model}} \rightarrow 0$$



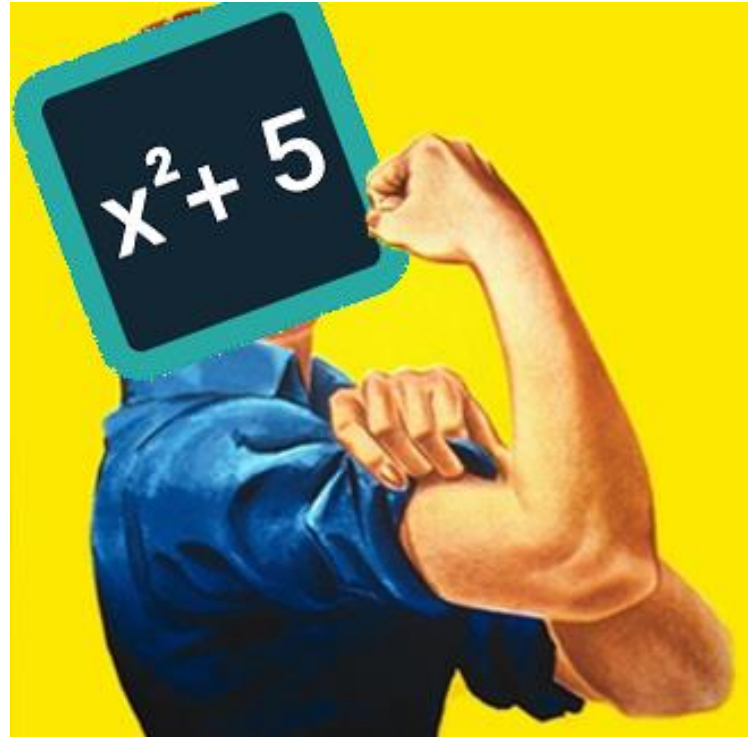
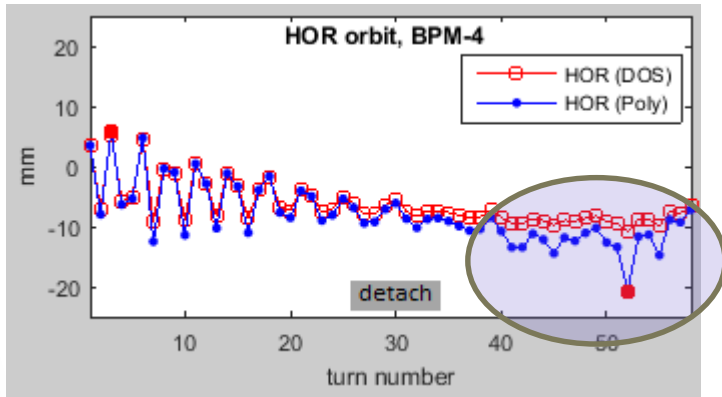
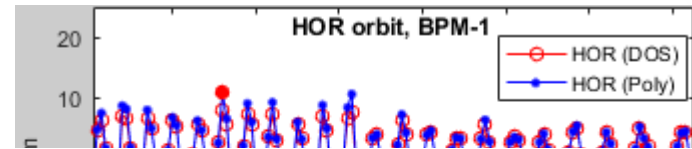
Compensation in the first turns.
Then becomes very noisy, why? Sum and Q are sensitive to beam size. It deteriorates without RF (blows up, bunch charge decrease, path & energy change).

Injecting with RF off: Polynomials vs. DOS

ESRF



ALBA



RF off \rightarrow beam spirals inward
Linear formula underestimates
Polynomial can see farther (

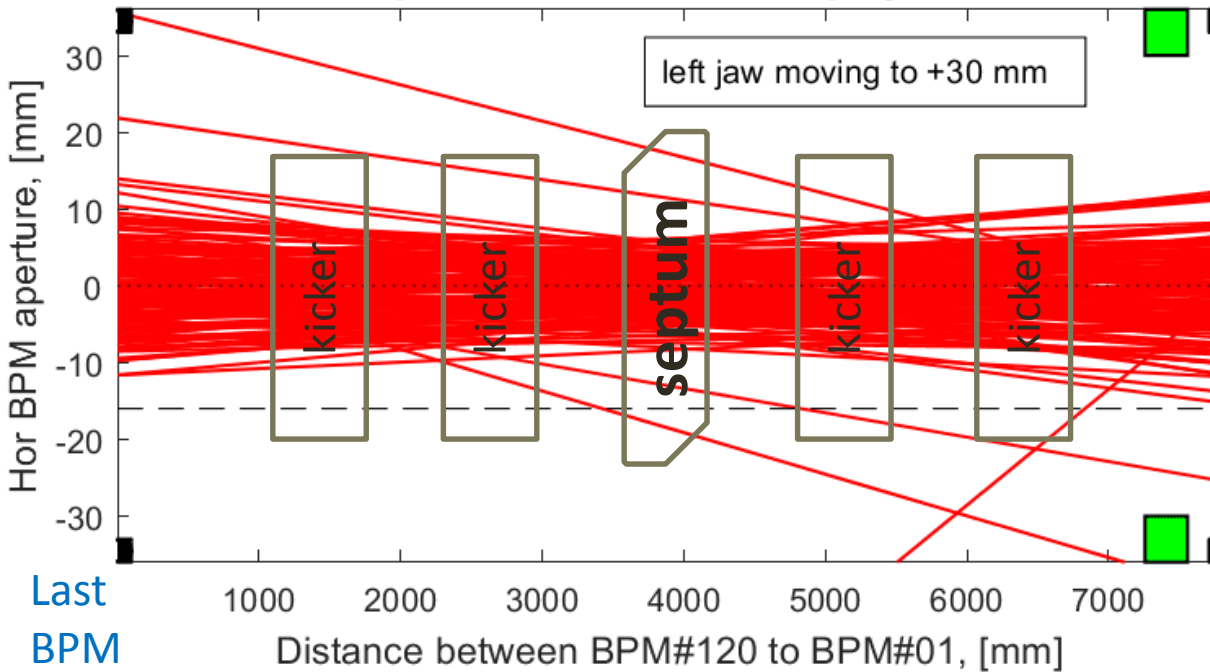
Polynomial power!!!

So finally, polynomials or DOS?

Injecting with RF off: Scraper test

ALBA SR injection straight, PSA May2019

Beam trajectory evolution vs. closing scraper.
Injections with RF off, all usable 145 turns.
Beam position corrected with polynomials.

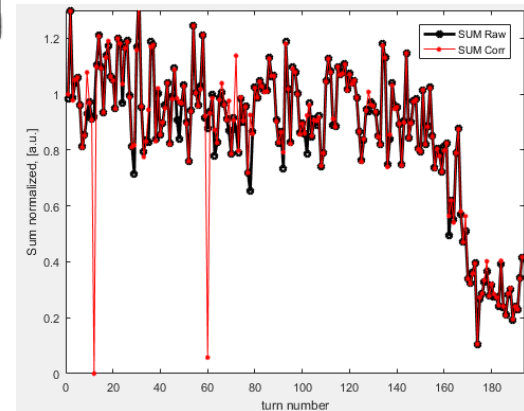


first
BPM

Each jaw kills beam at ± 7 mm
DOS error ≤ 2.5 mm
Poly error ≤ 0.16 mm

← Septum blade

Last
BPM

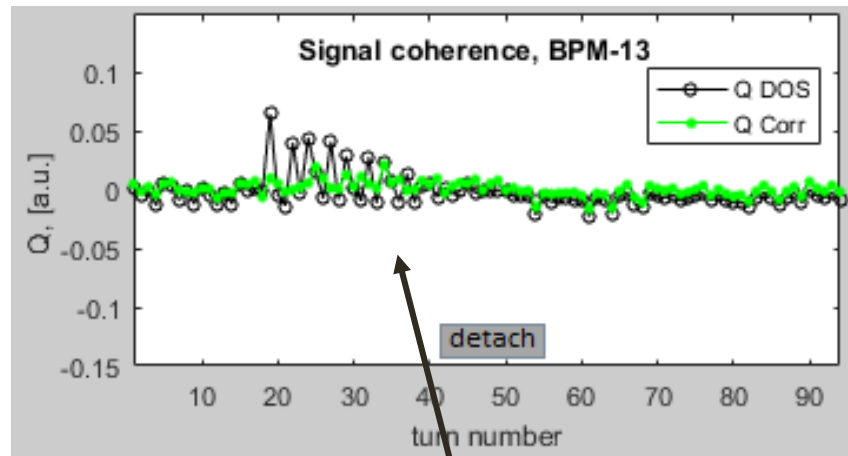
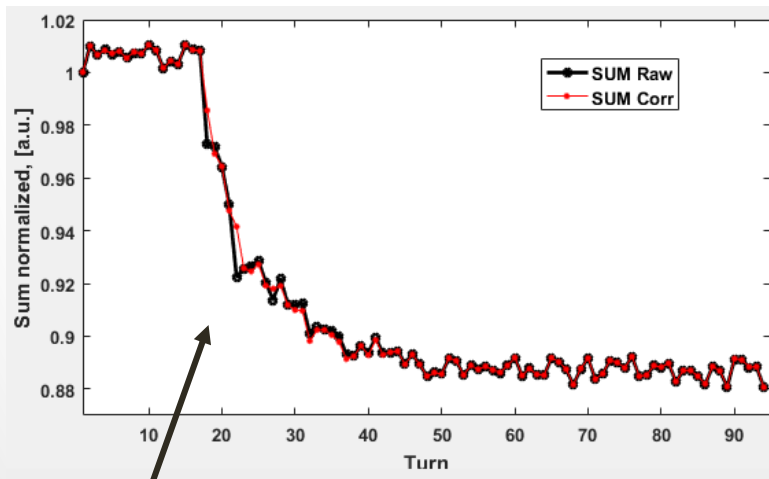
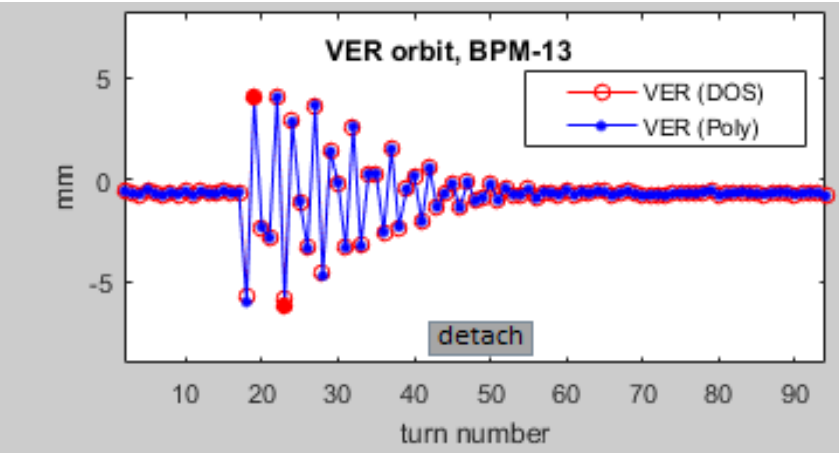
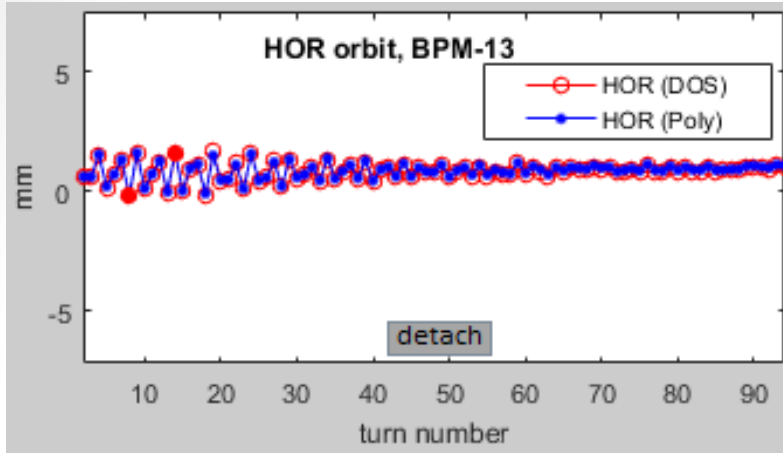


← ~8 meters →

Beam kicks: vertical plane kick

ESRF MDT Nov27: big V-kick, partial loss

MAF off
Anti-smearing on

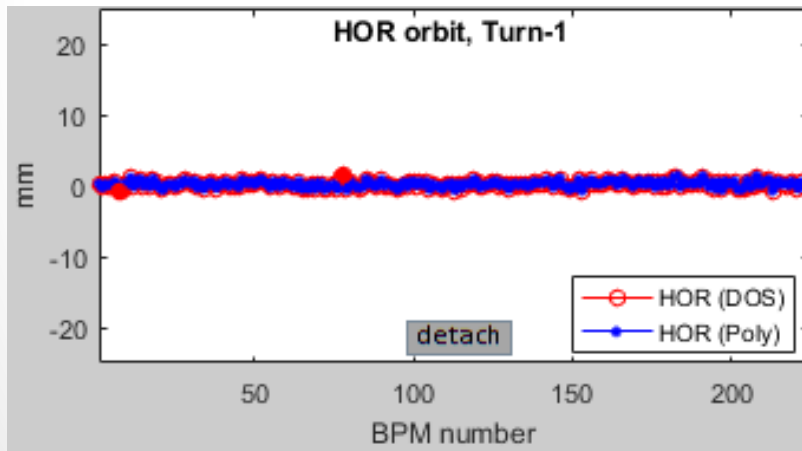
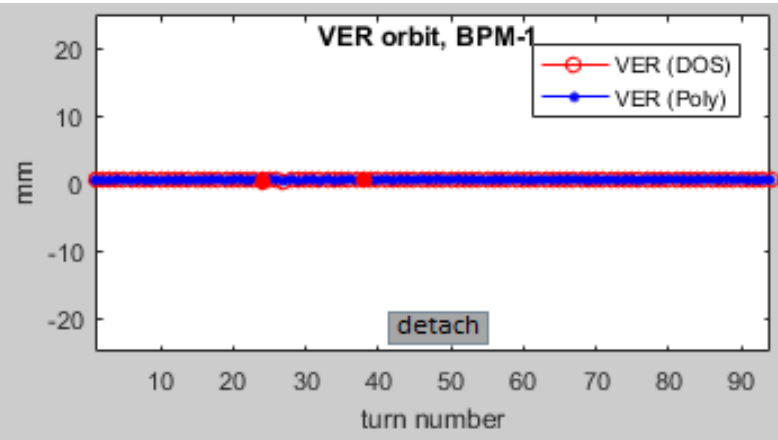
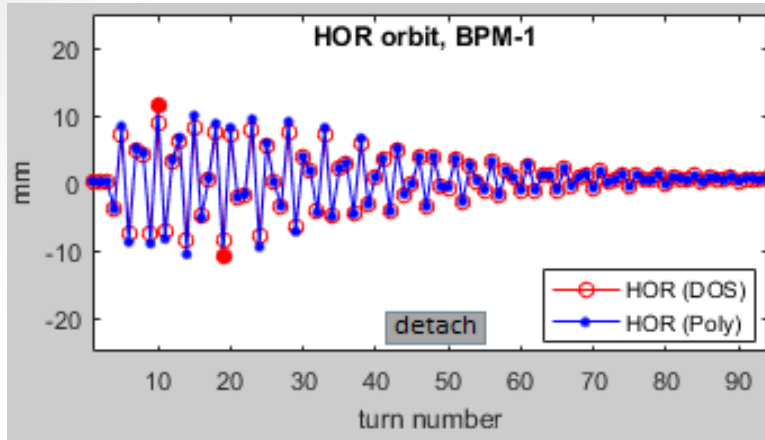


Note the behavior of the Sum during the V-kick (bunch length doesn't change?)

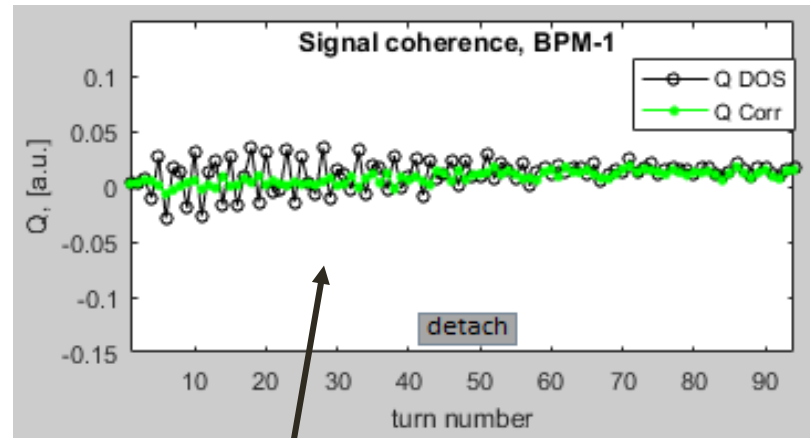
Very nice Q suppression!

Beam kicks: horizontal plane kick

ESRF MDT Nov27: moderate H-kick, small loss



View of all BPMs



Again a very nice Q suppression

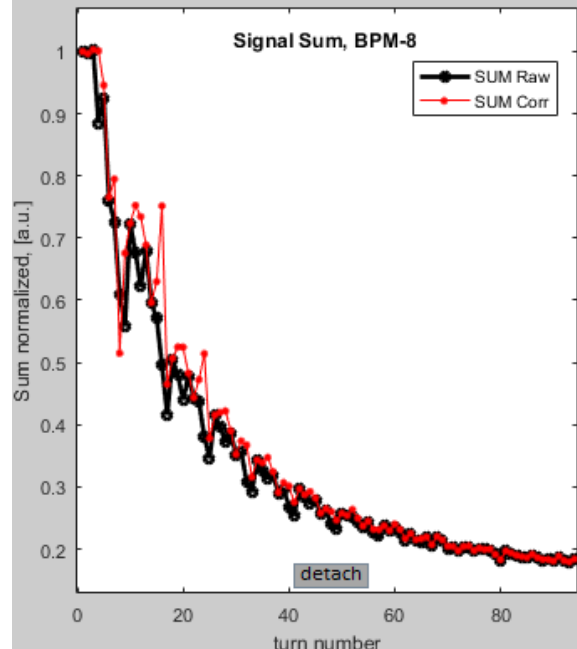
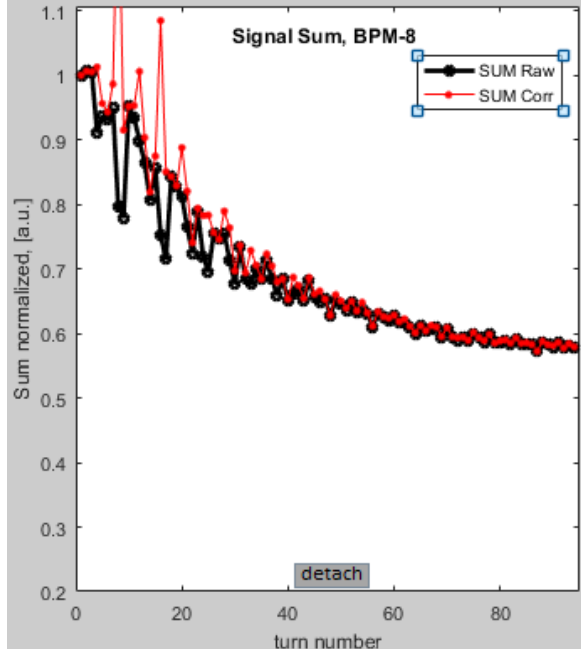
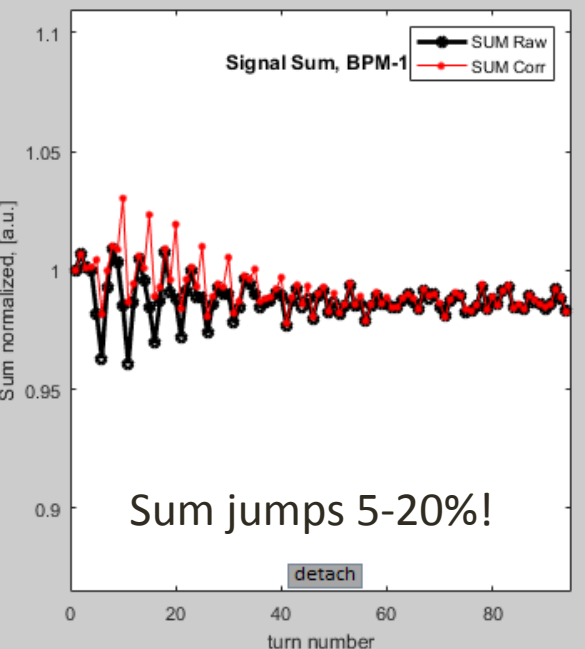
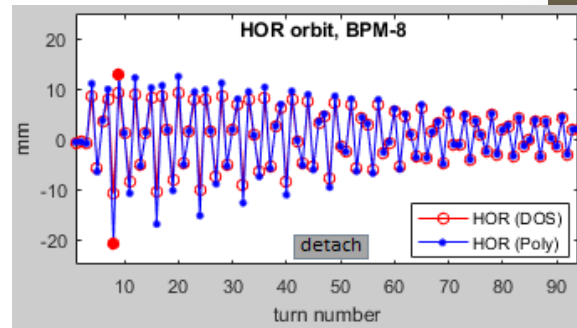
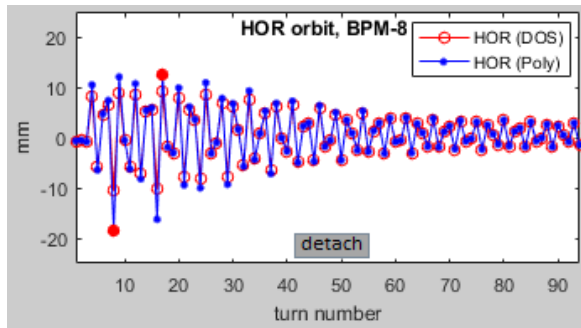
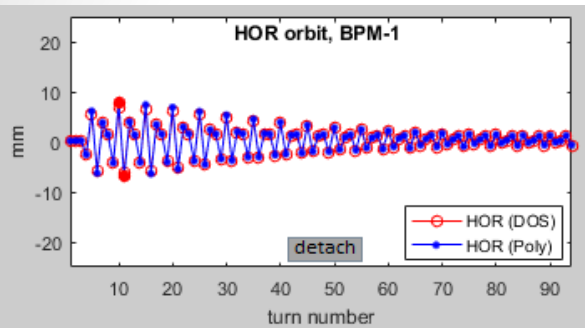
Beam kicks: horizontal plane kicks

ESRF MDT Nov27: H-kicks, loss variation

3 mA \rightarrow \sim 3 mA

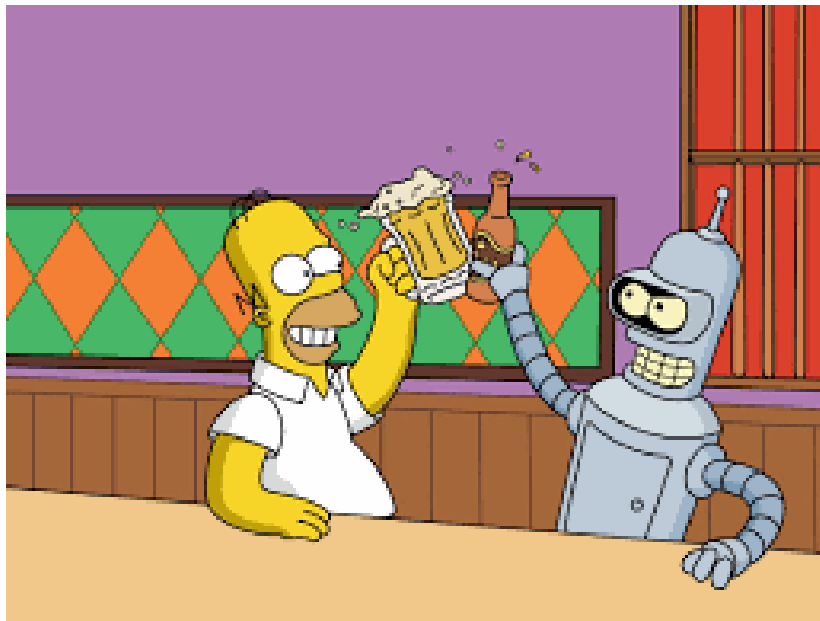
3 mA \rightarrow 1.5 mA

3 mA \rightarrow 0.5 mA



Sum oscillates only during H-kicks! Why?
Gets under/over compensated by SumPoly correction.

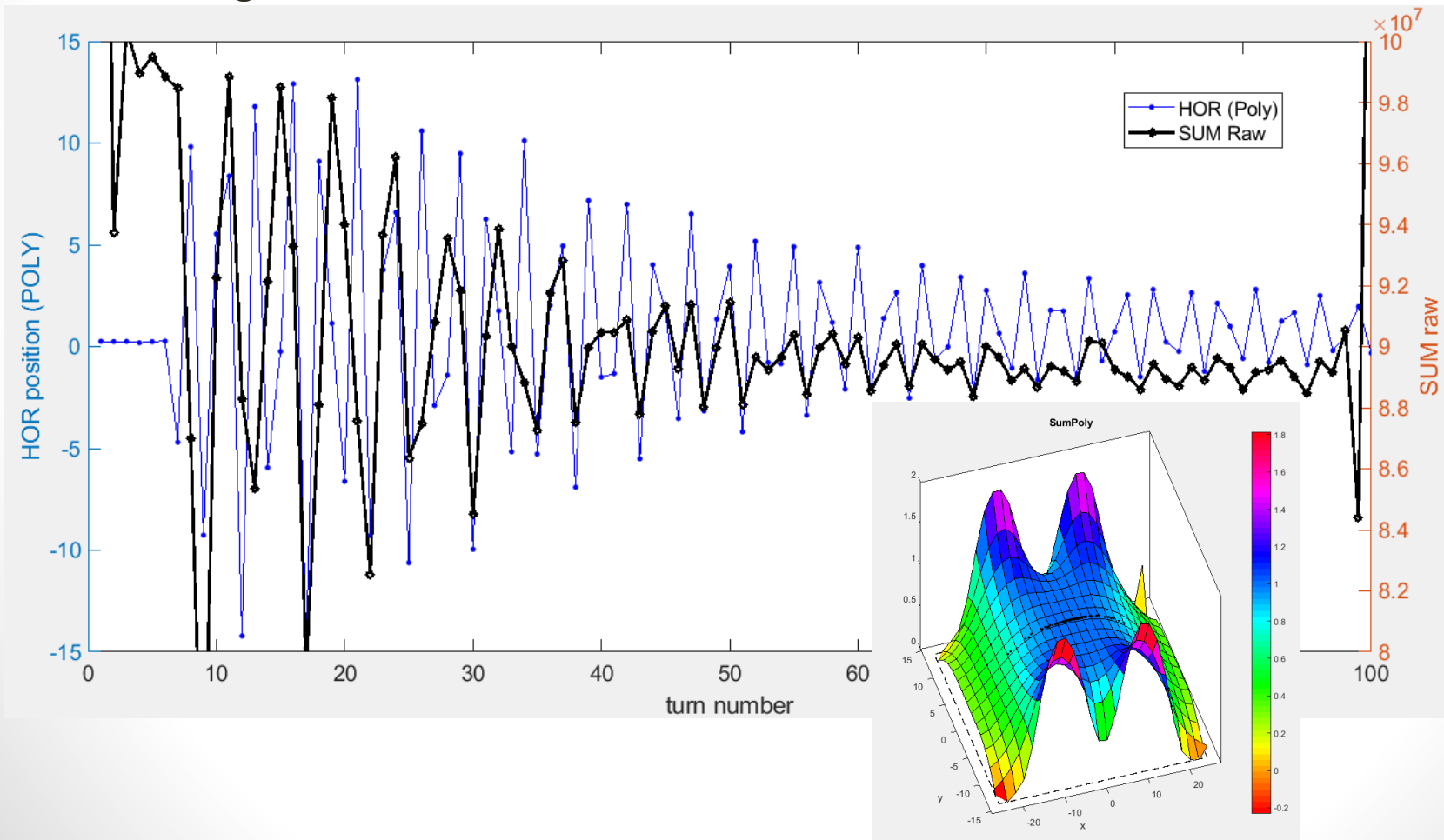
Thank you for your attention!



extras

Overlaying the measured Sum with the horizontal position -> no expected correlation:

- 1) **black dots** = simulated sum, so the sum does not get higher than 1 from beam moving left and right from the center.
- 2) beam goes right -> sum goes up, beam goes left -> sum goes down. **How is this possible. The sum is supposed to behave symmetrically, going down in both cases after crossing zero?**



Experimental application: ESRF (Nov 2018) kicks

MDT Nov27: H-kicks, loss variation

