Intensity-dependent effects at ATF2 using BPM measurements

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Outline

- **Analysis of BPM data taken in December 2017.**

- **BPM resolution calculation along the beamline.**

- **Using SVD technics to extrapolate charge-related physical effects along the beamline.**

BPM resolution calculation

$$\begin{pmatrix} d_{1k} \\ d_{2k} \\ \vdots \\ d_{Mk} \end{pmatrix} = \begin{pmatrix} d_{11} & d_{12} & \cdots & d_{i\neq k,1} & \cdots & d_{1N} \\ d_{21} & d_{22} & \cdots & d_{i\neq k,2} & \cdots & d_{2N} \\ \vdots & \vdots & & \vdots & & \vdots \\ d_{M1} & d_{M2} & \cdots & d_{i\neq k,1} & \cdots & d_{MN} \end{pmatrix} \cdot \begin{pmatrix} v_1 \\ v_2 \\ \vdots \\ v_N \end{pmatrix}$$

$$d_k \qquad\qquad D_k \qquad\qquad v$$

d_{ik} = measured displacement in BPM k for machine pulse i

M = number of machine pulses

N = number of BPMs

v = correlation coefficients between all BPMs and the one of interest

Ref:
Cavity beam position monitor system for the Accelerator Test Facility 2
Y. I. KIM *et al.*
DOI: 10.1103/PhysRevSTAB.15.042801

BPM resolution calculation

$$SVD(D_k) = USV^T$$

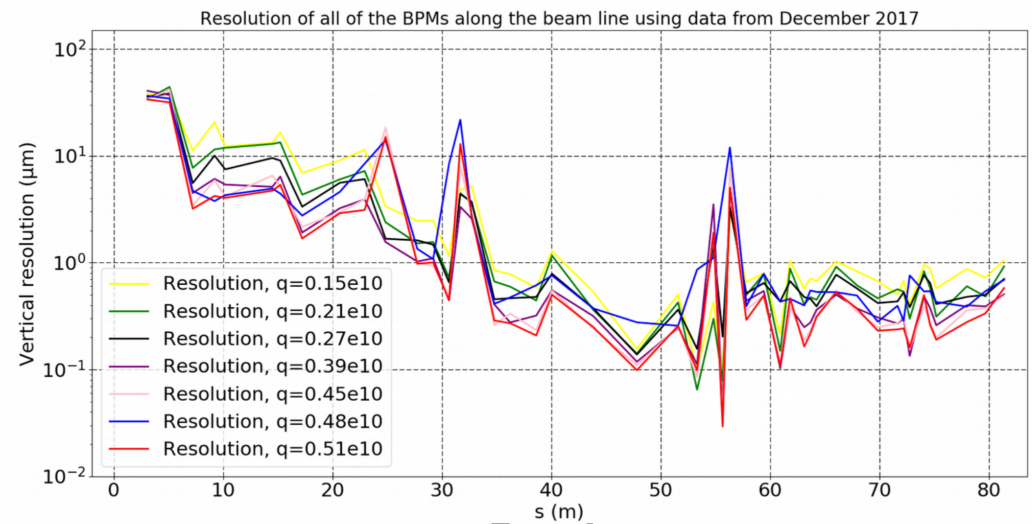
$$\Rightarrow \qquad D_k^{-1} = VS^{-1}U^T$$

$$d_k = D_k \cdot v \quad \Leftrightarrow \quad v = D_k^{-1} \cdot d_k$$

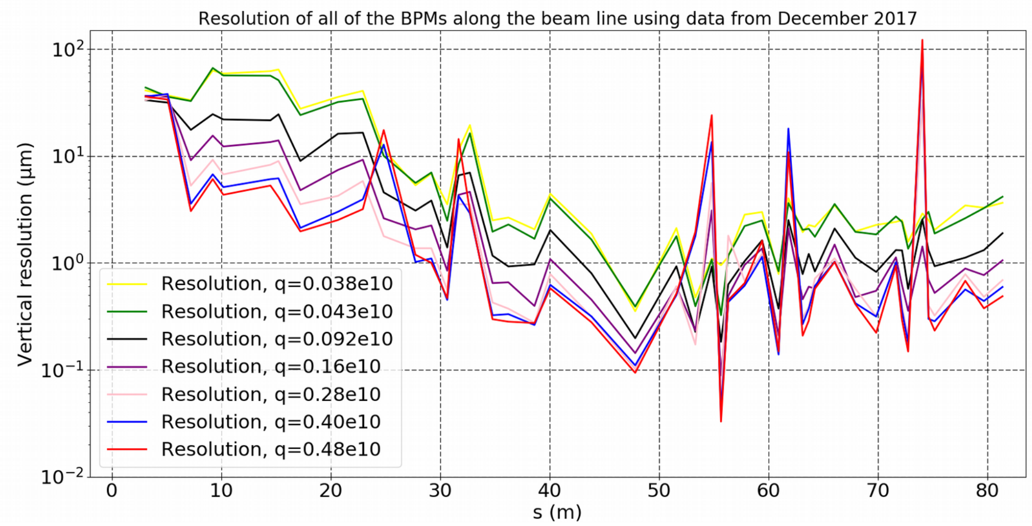
Position residuals vector: $R_k = d_k - D_k \cdot v$

Resolution of BPM *k*: $\sigma_k = \sqrt{\frac{\Sigma_i^M R_{ki}^2}{M}}$

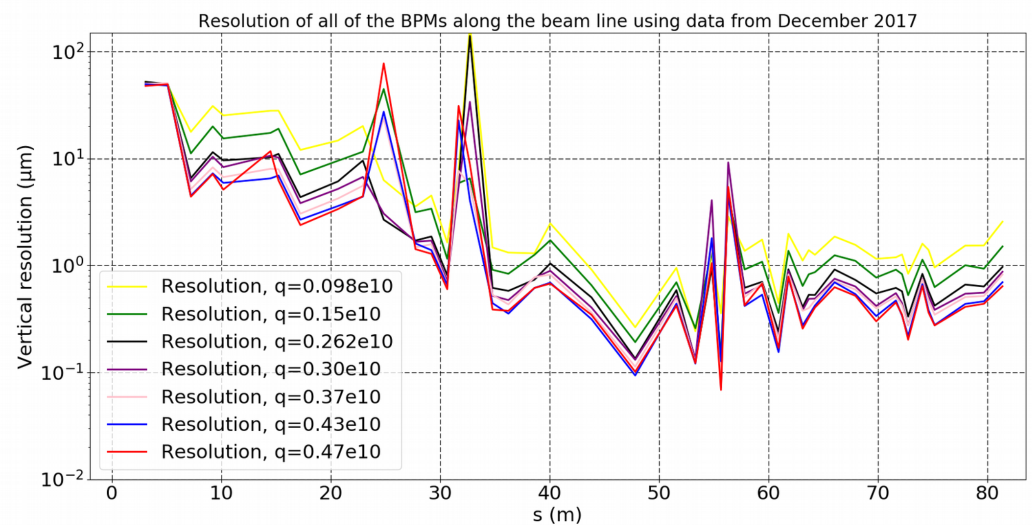
BPM resolution calculation



Run1

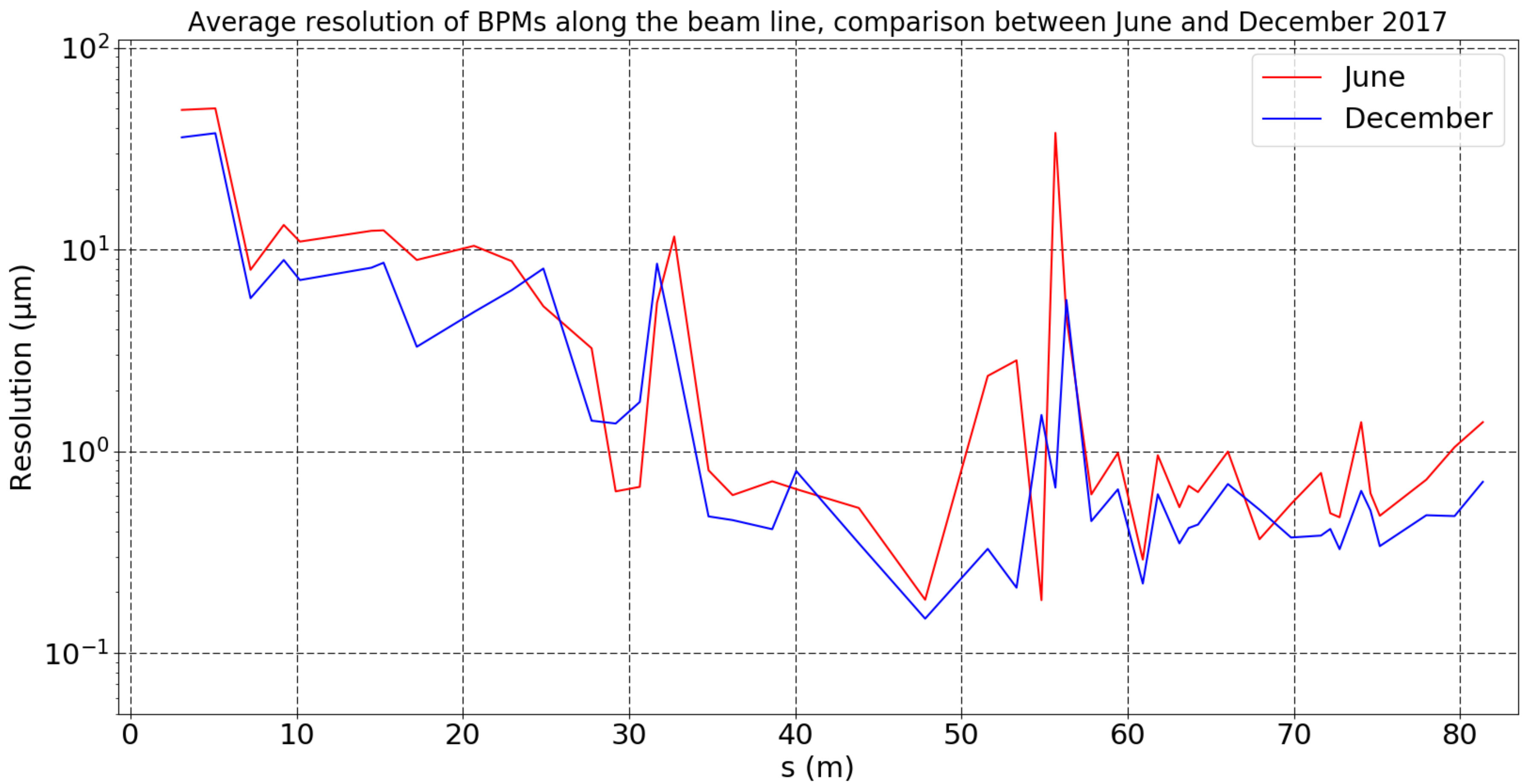


Run2



Run3

BPM resolution along the beam line – vertical plane

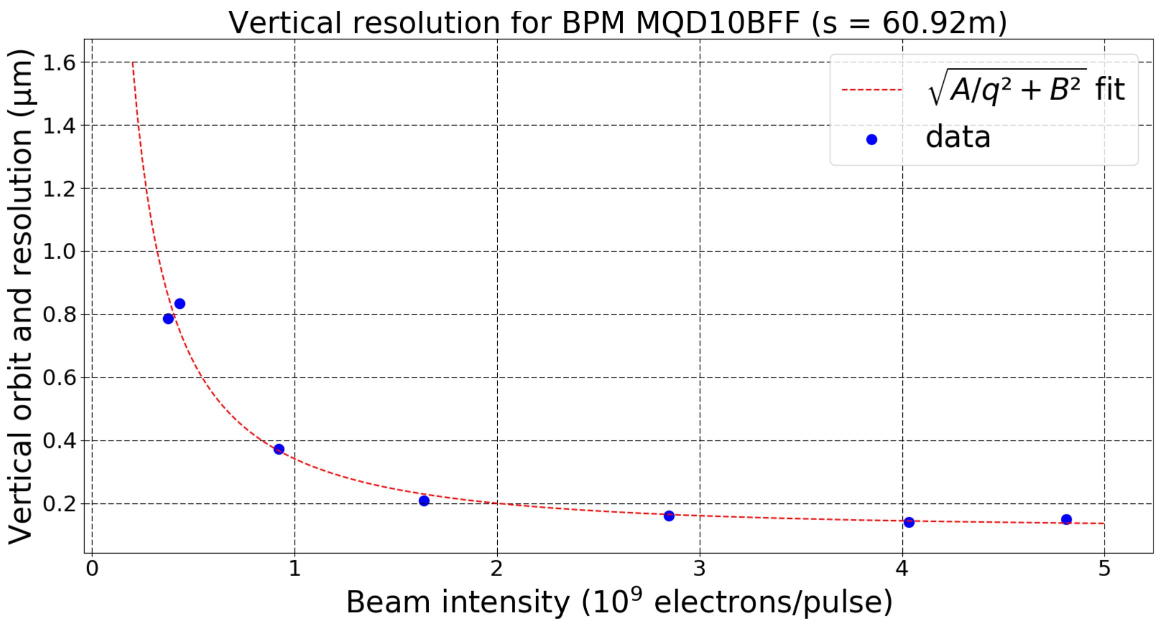


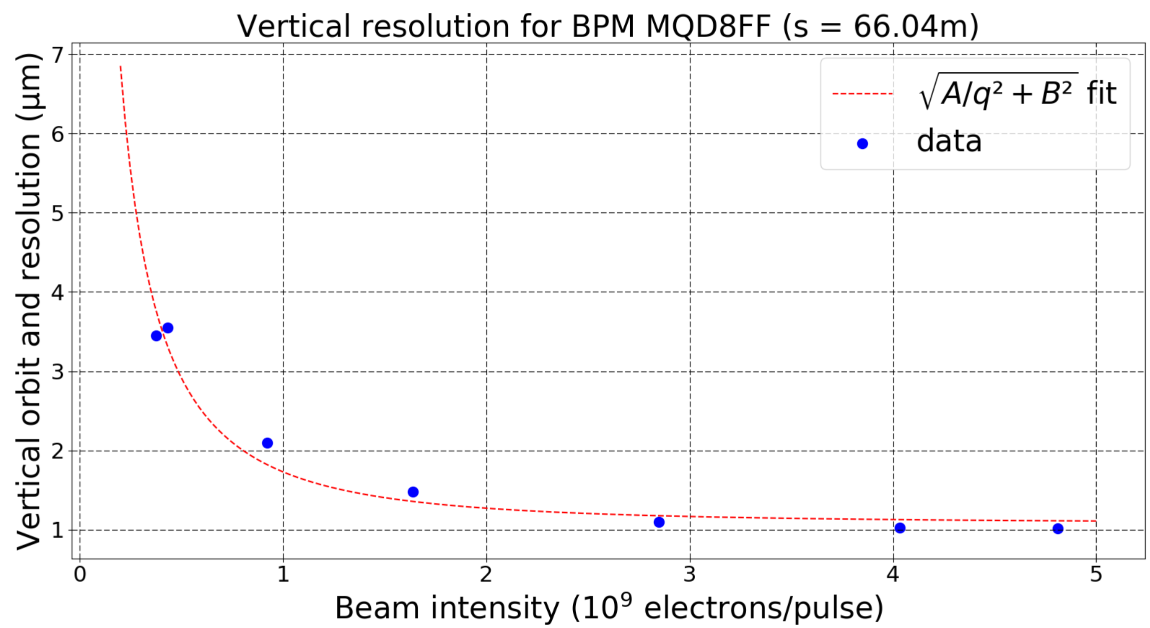
Improvement of the average BPM resolution.

BPM resolution dependence with charge – vertical plane

BPM resolution depends on the charge following: $\sqrt{\left(\frac{A}{q^2}+B^2\right)}$

BPM name	s(m)	A	B
MQD16X	34.781	0.815	0.293
MQF17X	36.231	0.958	0.178
MQD18X	38.614	0.574	0.137
MQF19X	40.058	2.846	0.491
MQD20X	43.824	0.490	0.224
MQF21X	47.816	0.020	0.105
MQM16FF	51.582	0.573	0.468
MQM15FF	53.316	-0.034	0.624
MQM14FF	54.816	...	...
MFB2FF	55.654	0.063	0.000
MQM13FF	56.316	0.087	0.834
MQM12FF	57.816	0.958	0.577
MQM11FF	59.416	1.006	1.164
MQD10BFF	60.916	0.102	0.112
MQD10AFF	61.816	...	...
MQF9BFF	63.116	0.612	0.137
MSF6FF	63.676	0.769	0.315
MQF9AFF	64.236	0.563	0.526
MQD8FF	66.036	1.813	1.112
MQF7FF	67.936	0.600	0.418
MQD6FF	69.836	0.668	0.189
...	...	...	...





Singular Value Decomposition

$$D = \begin{pmatrix} d_{11} & d_{12} & \cdots & d_{1N} & q_1 \\ d_{21} & d_{22} & \cdots & d_{2N} & q_2 \\ \vdots & \vdots & & \vdots & \vdots \\ d_{M1} & d_{M2} & \cdots & d_{MN} & q_M \end{pmatrix}$$

d_{ik} = measured displacement in BPM k for machine pulse i
M = number of machine pulses
N = number of BPMs
q_i = charge of pulse i

SVD – Adding charge information

$$D=\begin{pmatrix} d_{11} & d_{12} & \cdots & d_{1N} & q_1 \\ d_{21} & d_{22} & \cdots & d_{2N} & q_2 \\ \vdots & \vdots & & \vdots & \vdots \\ d_{M1} & d_{M2} & \cdots & d_{MN} & q_M \end{pmatrix}$$

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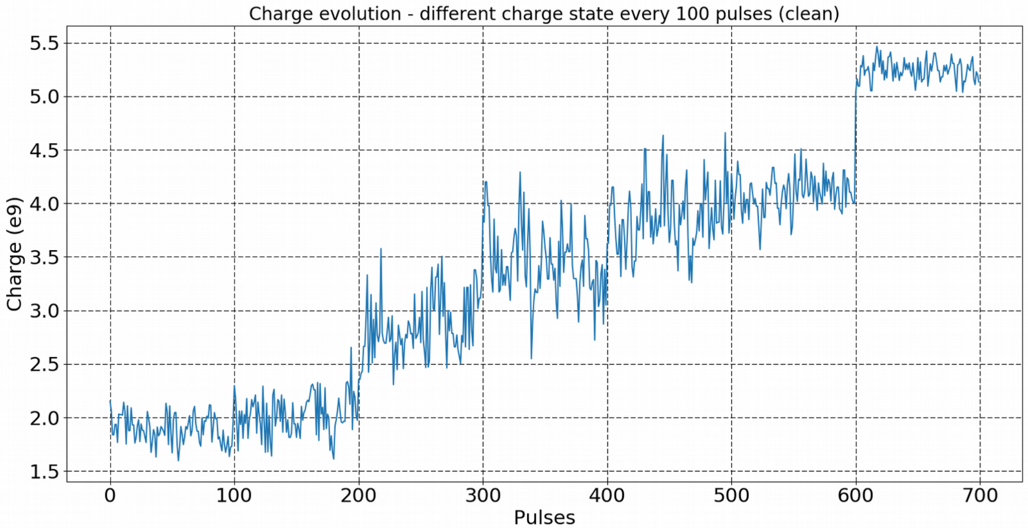
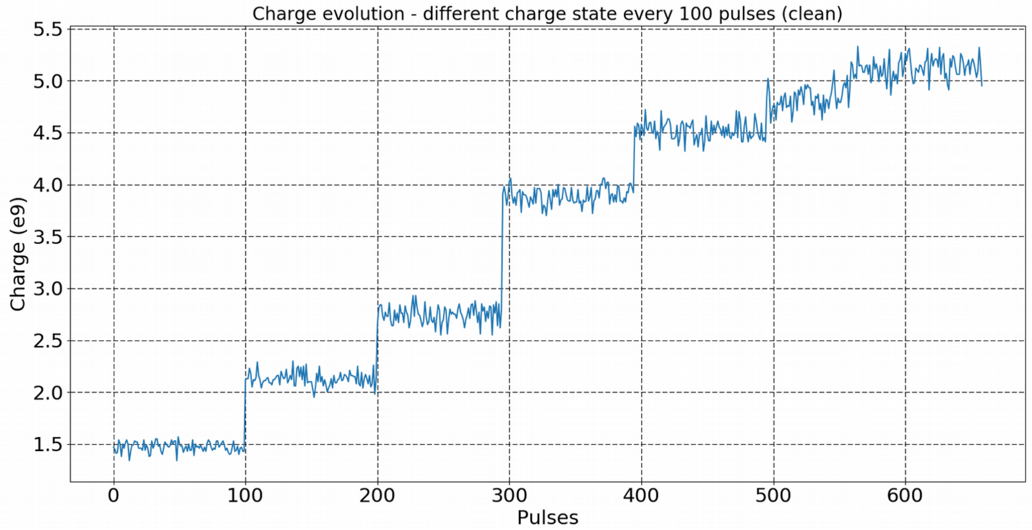
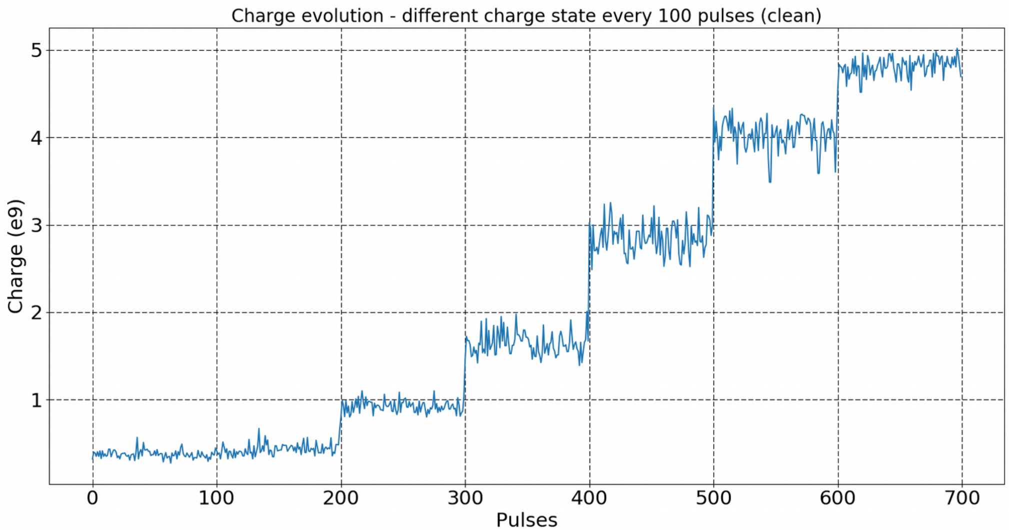
Charge



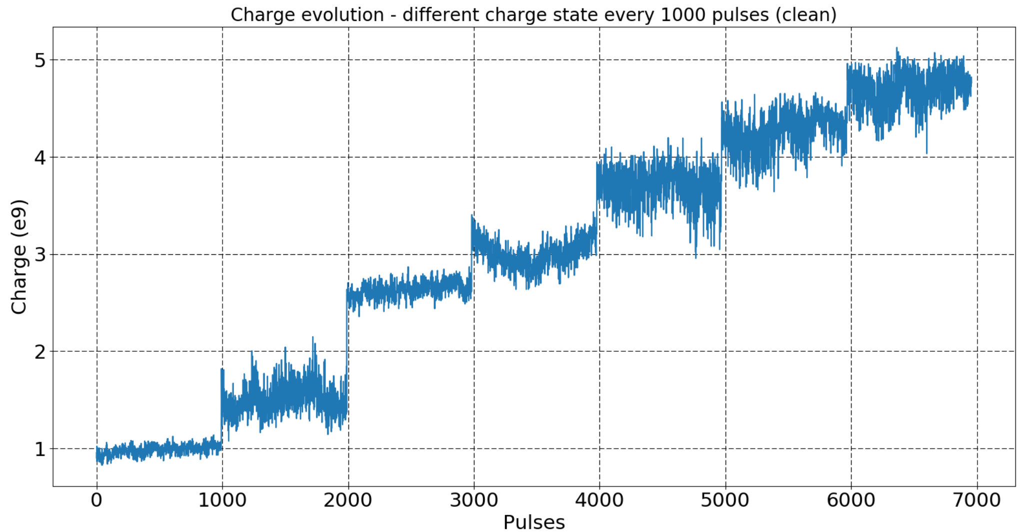
June 2017



December 2017 Run1



December 2017 Run2



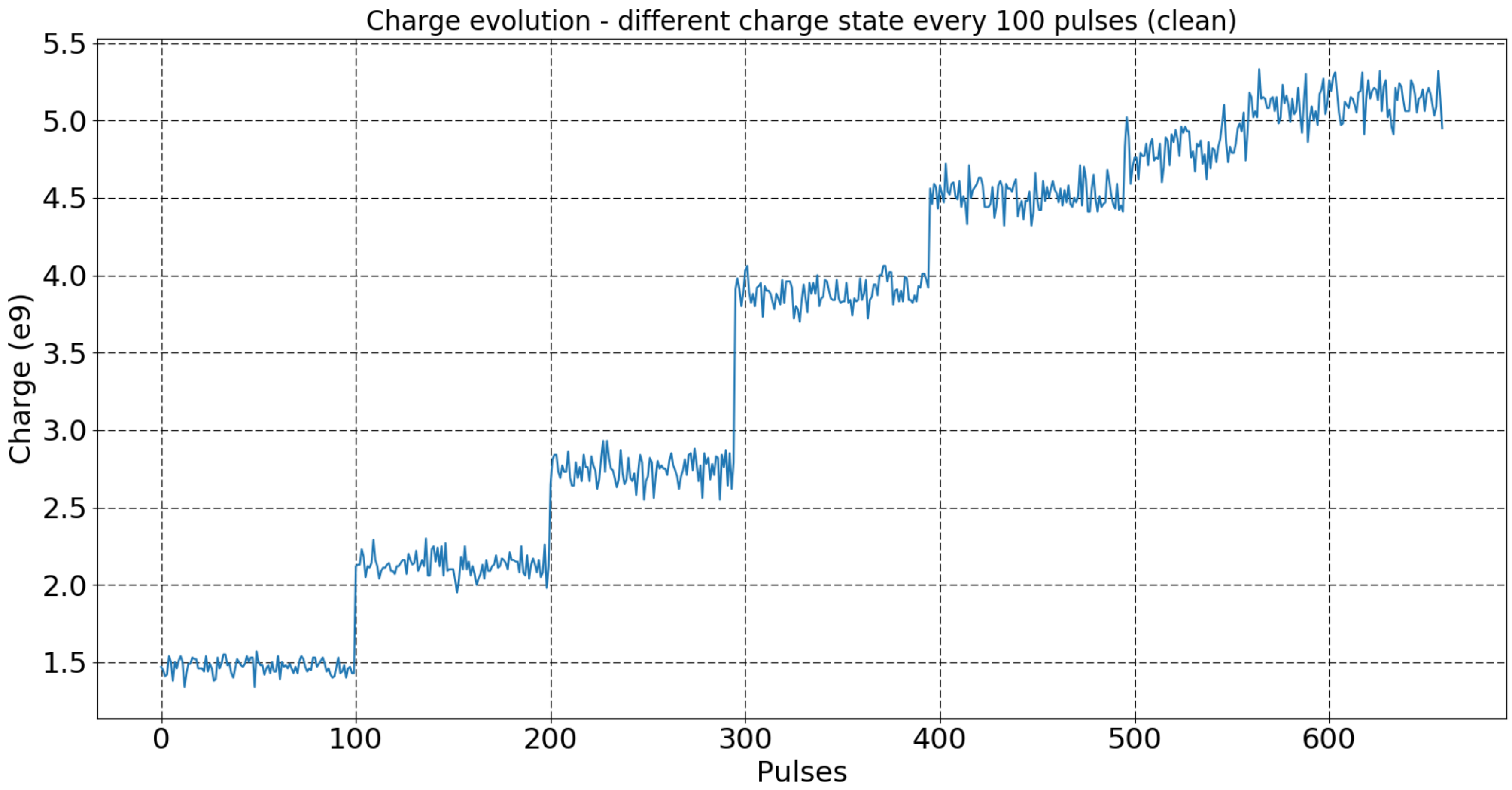
December 2017 Run3

SVD – Details

$$SVD\begin{pmatrix} d_{11} & d_{12} & \cdots & d_{1N} & q_1 \\ d_{21} & d_{22} & \cdots & d_{2N} & q_2 \\ \vdots & \vdots & & \vdots & \vdots \\ d_{M1} & d_{M2} & \cdots & d_{MN} & q_M \end{pmatrix}$$

$$= \underbrace{\begin{pmatrix} u_{11} & \cdots & u_{1M} \\ u_{21} & \cdots & u_{2M} \\ \vdots & & \vdots \\ u_{M1} & \cdots & u_{MM} \end{pmatrix}}_{\substack{[M \times M] \\ U}} \cdot \underbrace{\begin{pmatrix} s_{11} & 0 & \cdots & \cdots & 0 \\ 0 & s_{22} & \ddots & & \vdots \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \vdots & & \ddots & \ddots & 0 \\ \vdots & & & \ddots & s_{N+1\,N+1} \\ 0 & \cdots & \cdots & \cdots & 0 \\ \vdots & & & & \vdots \\ 0 & \cdots & \cdots & \cdots & 0 \end{pmatrix}}_{\substack{[M \times N+1] \\ S}} \cdot \underbrace{\begin{pmatrix} v_{11} & \cdots & v_{1\,N+1} \\ v_{21} & \cdots & v_{2\,N+1} \\ \vdots & & \vdots \\ v_{N+1\,1} & \cdots & v_{N+1\,N+1} \end{pmatrix}}_{\substack{[N+1 \times N+1] \\ V^T}}$$

Charge



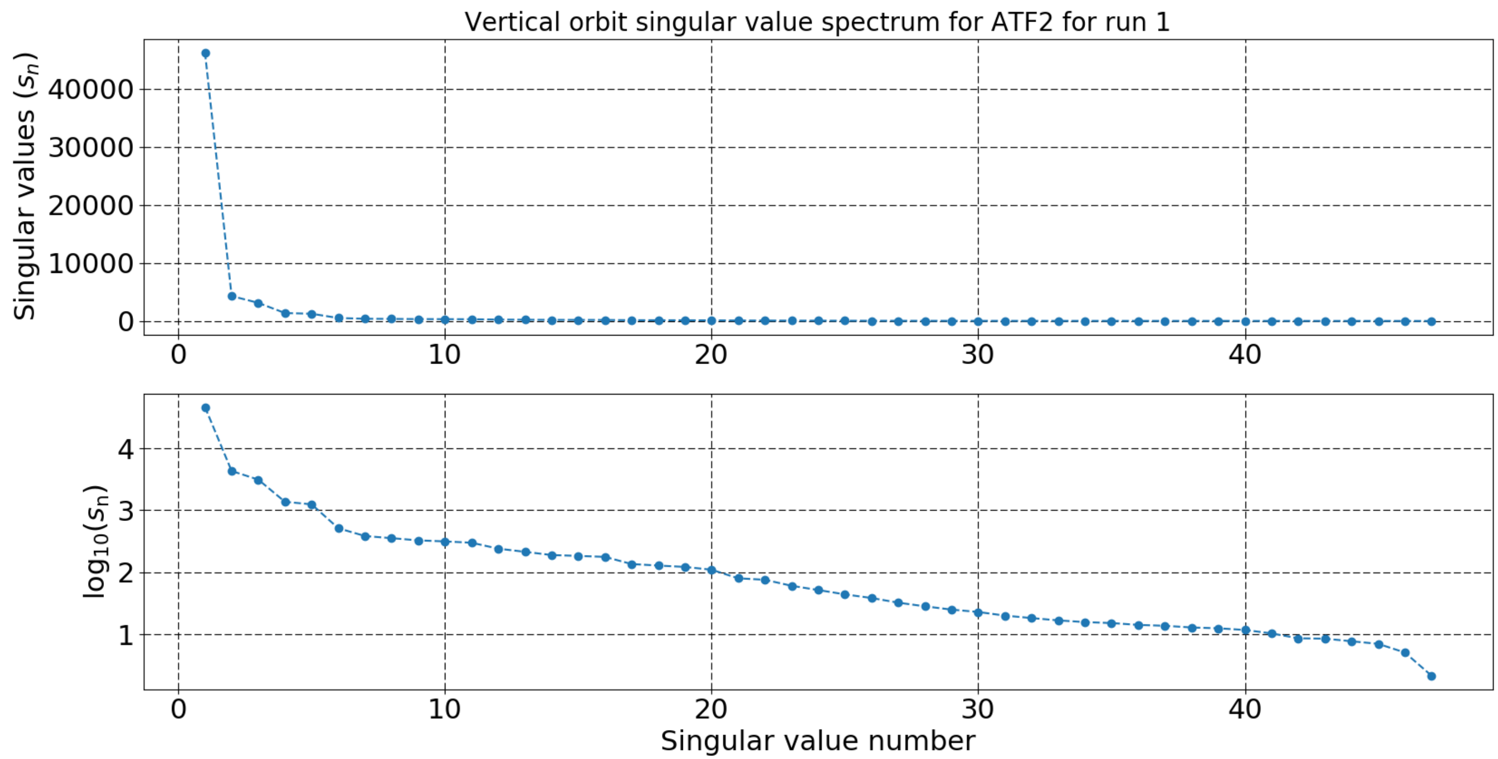
Focus on Run1 for the following SVD studies

SVD – Singular value spectrum

$$S = \begin{pmatrix} s_{11} & 0 & \cdots & \cdots & 0 \\ 0 & s_{22} & \ddots & & \vdots \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \vdots & & \ddots & \ddots & 0 \\ \vdots & & & \ddots & s_{N+1N+1} \\ 0 & \cdots & \cdots & \cdots & 0 \\ \vdots & & & & \vdots \\ 0 & \cdots & \cdots & \cdots & 0 \end{pmatrix}$$

Vertical plane

diag(S) represents how strong the correlations are between parameters.



SVD – Spatial vector

V is called “spatial vector”

$$V = \begin{pmatrix} v_{11} & \cdots & v_{1\,N+1} \\ v_{21} & \cdots & v_{2\,N+1} \\ \vdots & & \vdots \\ v_{N+1\,1} & \cdots & v_{N+1\,N+1} \end{pmatrix}$$

BPM number

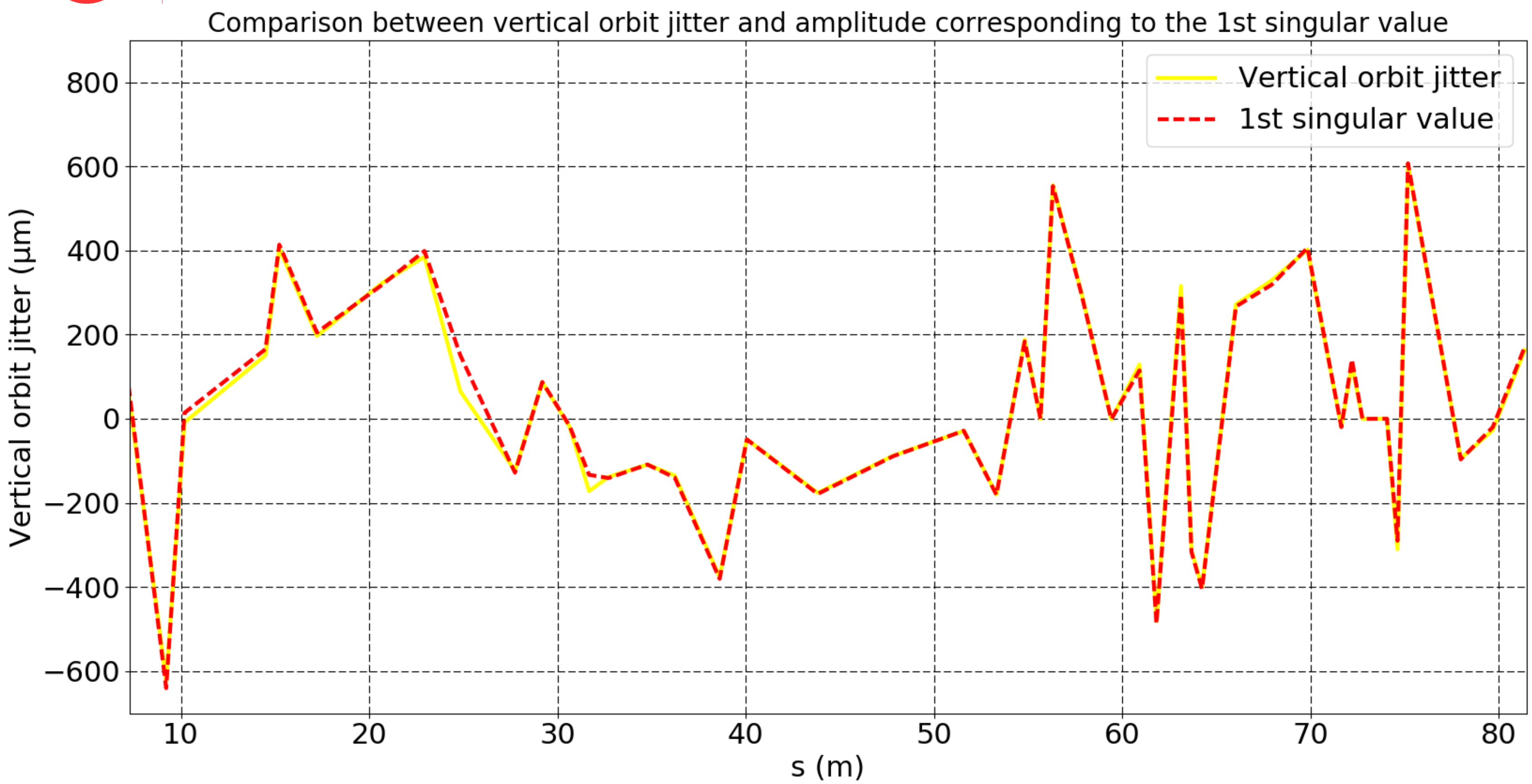
Charge information

Singular value number

SVD – Spatial vector

$$V = \begin{pmatrix} v_{11} & v_{12} & \cdots & \cdots & v_{1N+1} \\ v_{21} & v_{22} & \cdots & \cdots & v_{2N+1} \\ \vdots & \vdots & \vdots & & \vdots \\ v_{N+11} & v_{N+12} & \cdots & \cdots & v_{N+1N+1} \end{pmatrix}$$

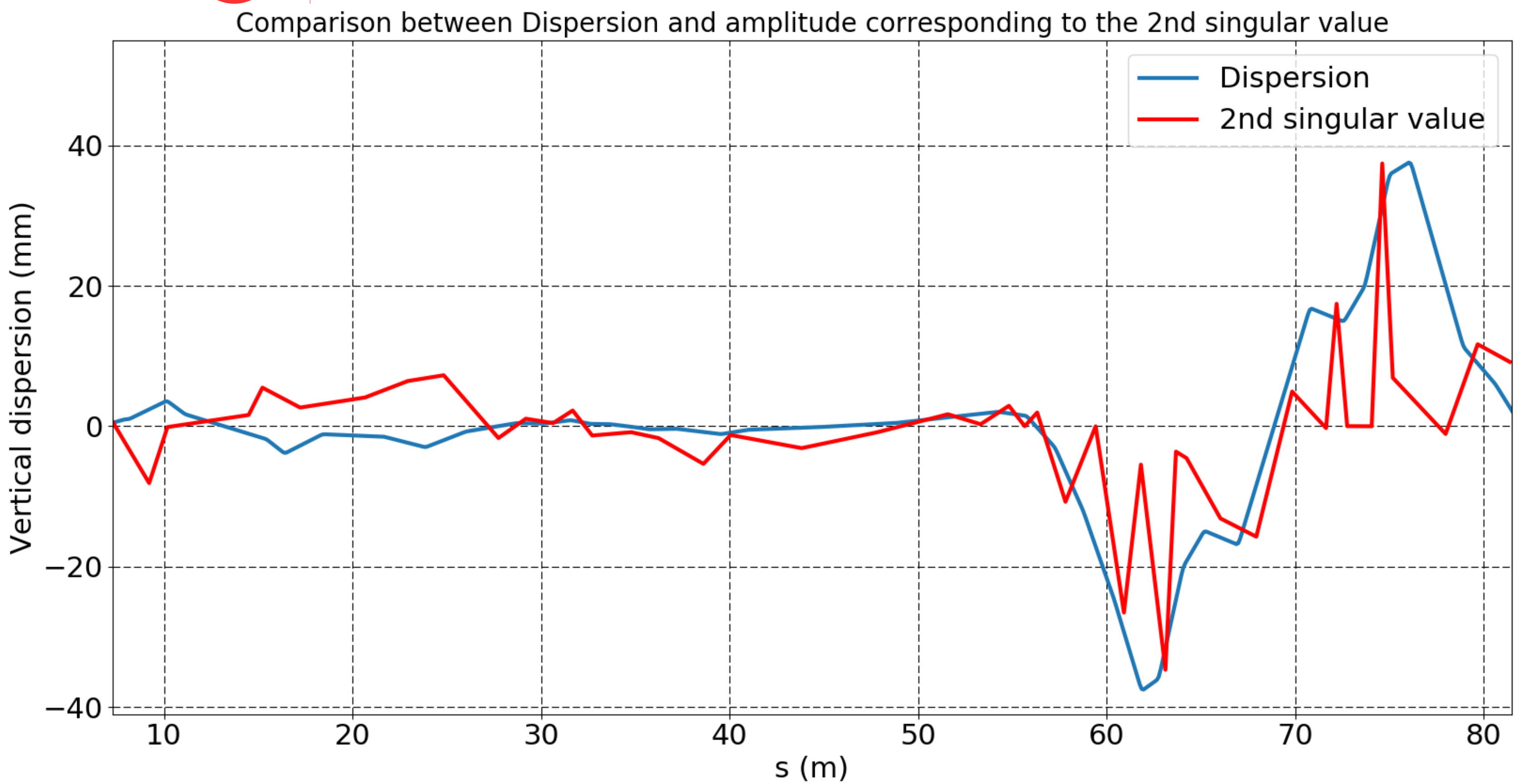
Vertical plane



SVD – Spatial vector

$$V=\begin{pmatrix} v_{11} & v_{12} & \cdots & \cdots & v_{1N+1} \\ v_{21} & v_{22} & \cdots & \cdots & v_{2N+1} \\ \vdots & \vdots & \vdots & & \vdots \\ v_{N+11} & v_{N+12} & \cdots & \cdots & v_{N+1N+1} \end{pmatrix}$$

Vertical plane

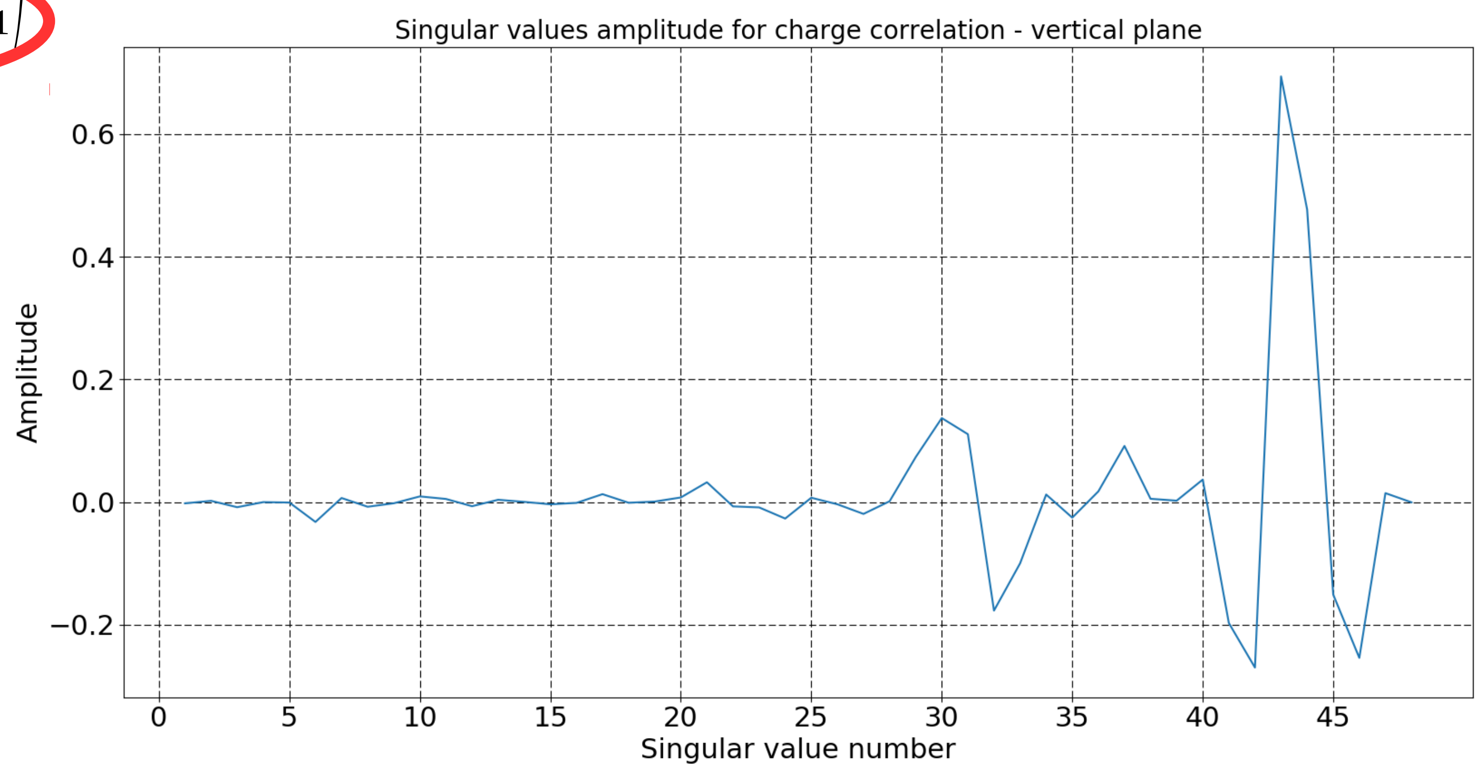


SVD – Spatial vector

$$V = \begin{pmatrix} v_{11} & \cdots & v_{1\,N+1} \\ v_{21} & \cdots & v_{2\,N+1} \\ \vdots & & \vdots \\ v_{N+1\,1} & \cdots & v_{N+1\,N+1} \end{pmatrix}$$

V(end , :) represents the amplitude of the singular values (correlation with the charge).

Vertical plane



SVD – Spatial vector

$$V=\begin{pmatrix} v_{11} & \cdots & v_{1\,N+1} \\ v_{21} & \cdots & v_{2\,N+1} \\ \vdots & & \vdots \\ v_{N+1\,1} & \cdots & v_{N+1\,N+1} \end{pmatrix}$$

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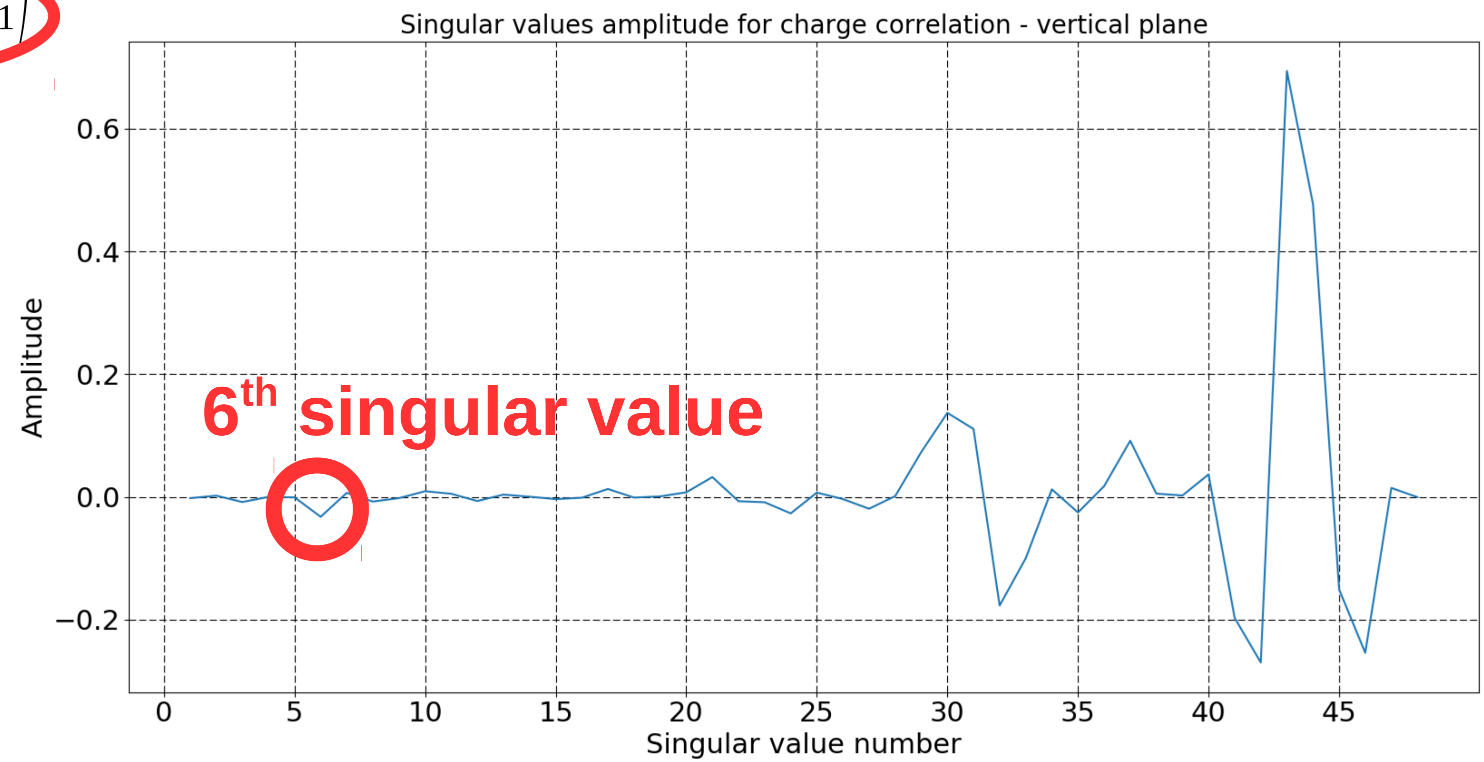
Vertical plane

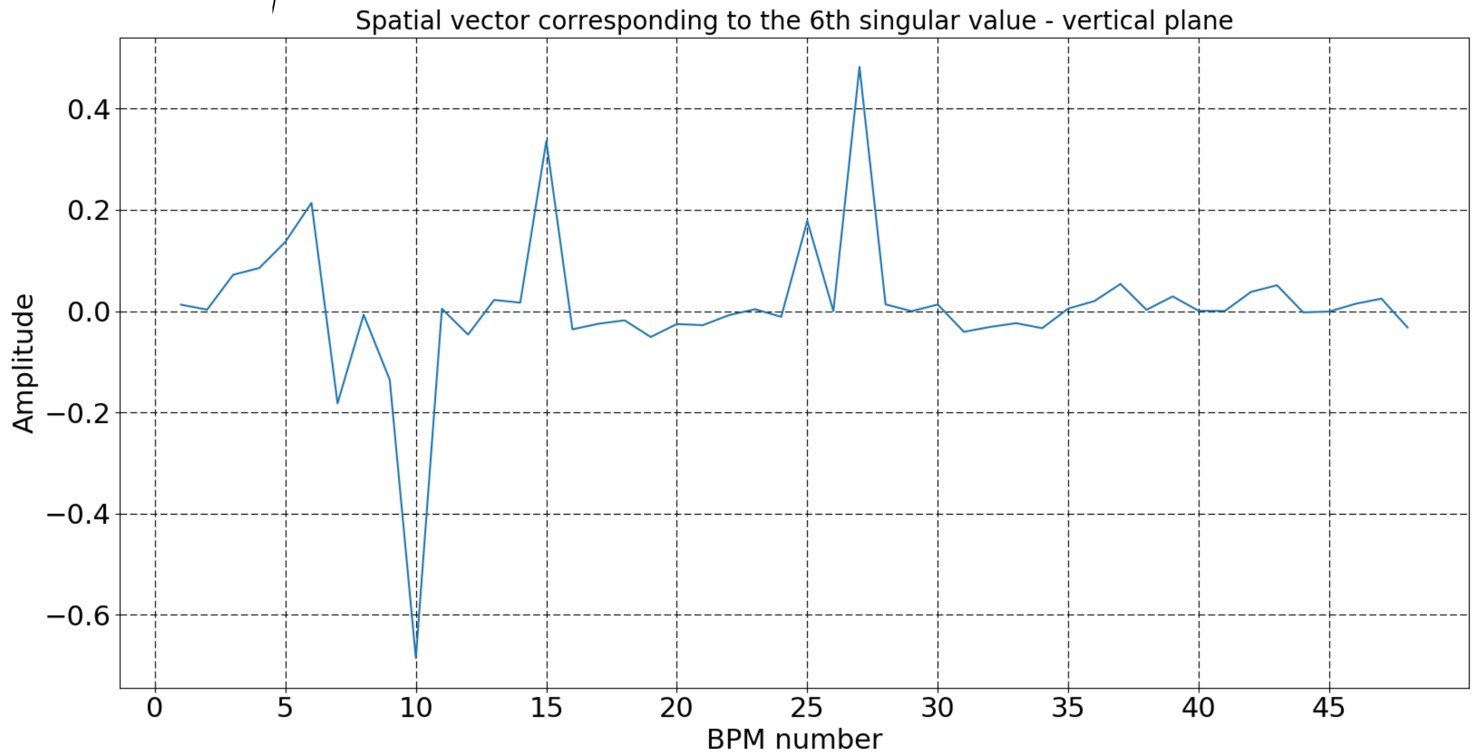


SVD – Spatial vector

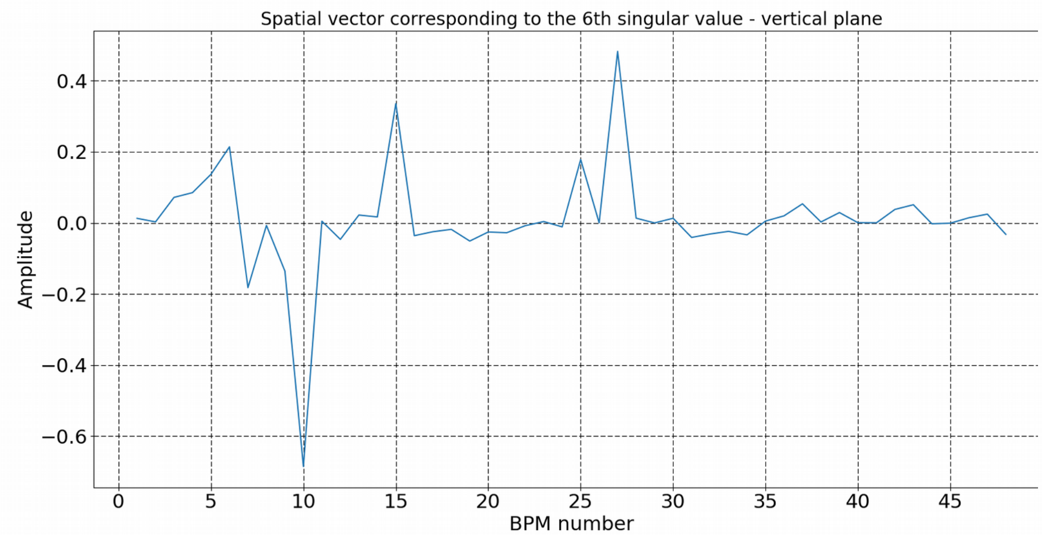
$$V=\begin{pmatrix} v_{11} & \cdots & v_{16} & \cdots & v_{1\,N+1} \\ v_{21} & \cdots & v_{26} & \cdots & v_{2\,N+1} \\ \vdots & \cdots & \vdots & & \vdots \\ v_{N+1\,1} & \cdots & v_{N+1\,6} & \cdots & v_{N+1\,N+1} \end{pmatrix}$$

V(: , 6) represents the amplitude of the charge correlation along the beam line.

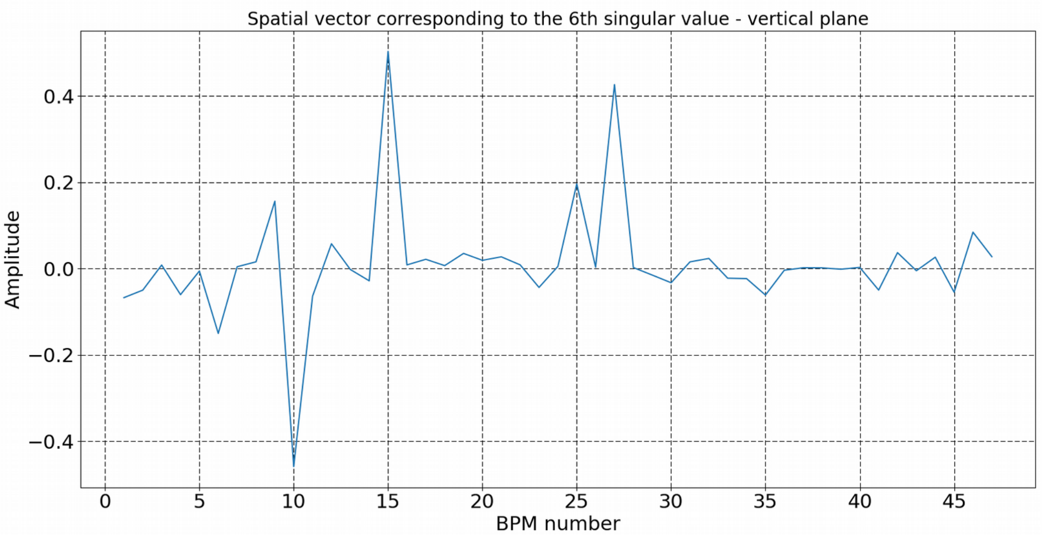
Vertical plane



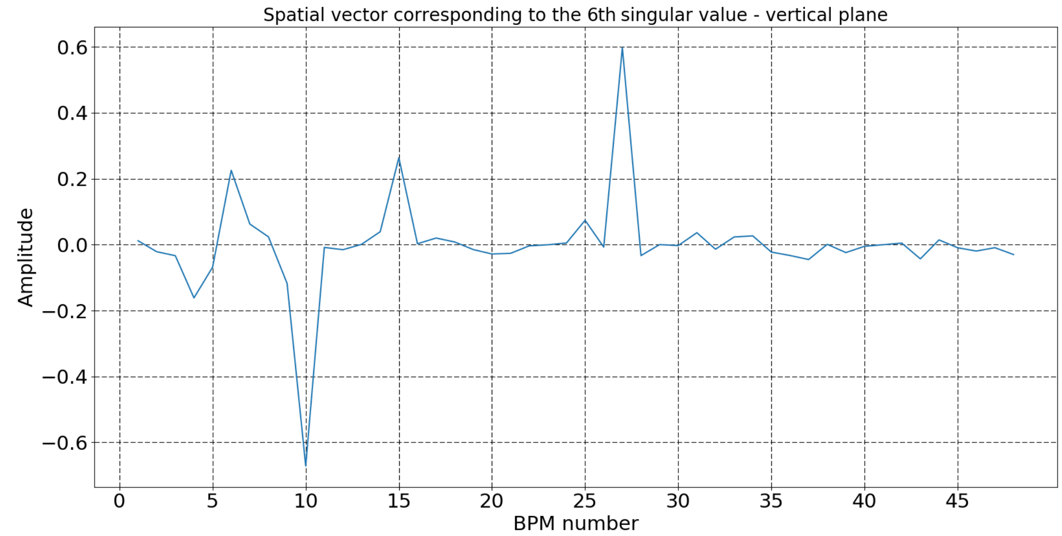
SVD – Spatial vectors



Run1

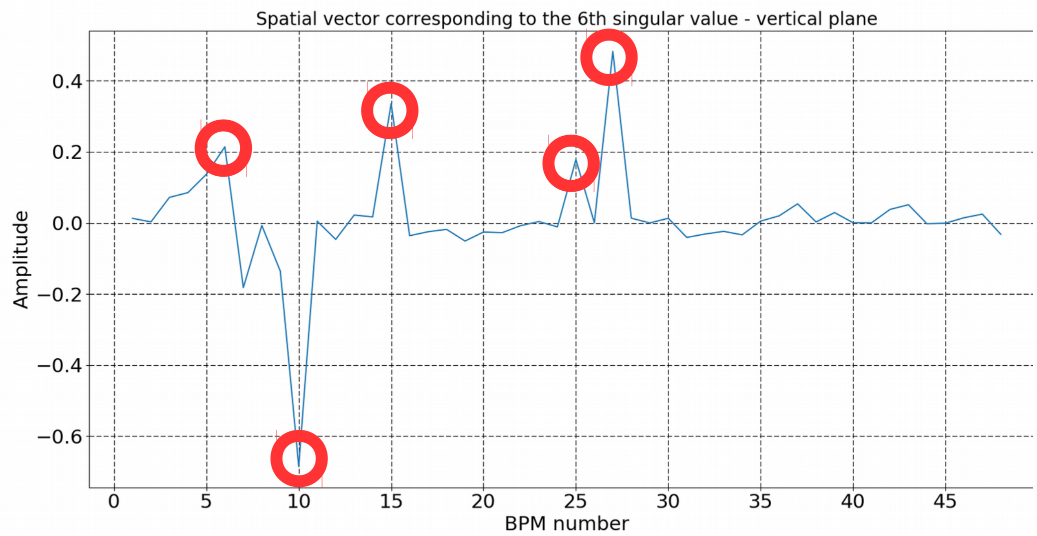


Run2

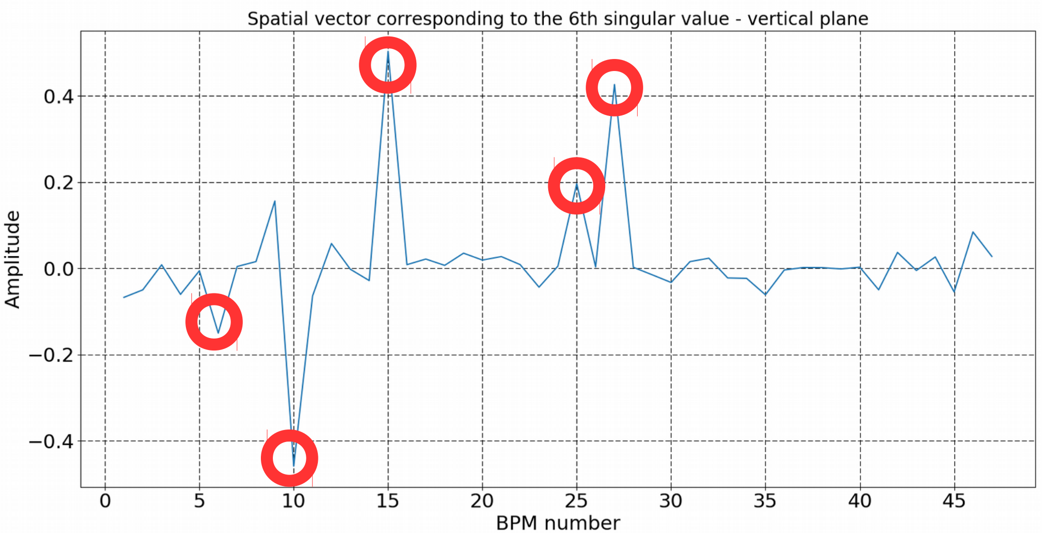


Run3

SVD – Spatial vectors

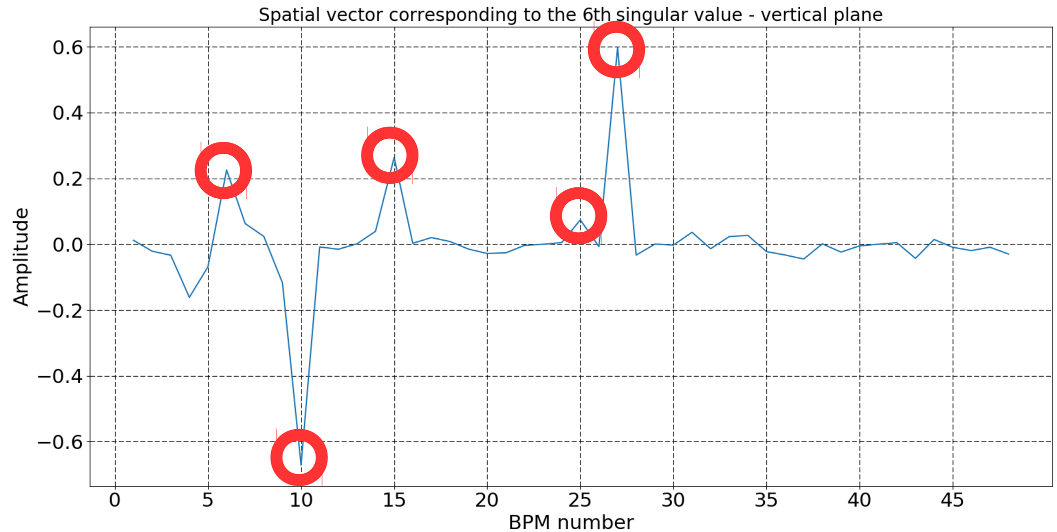


Run1



Run2

PEAKS



Run3

BPM number	BPM name	s(m)	Type
6	MQF4X	14.490	Stripline
10	MQD8X	22.935	Stripline
15	MQD13X	31.680	Stripline
25	MQM14FF	54.816	CBPM
27	MQM13FF	56.316	CBPM

Reconstructed matrix

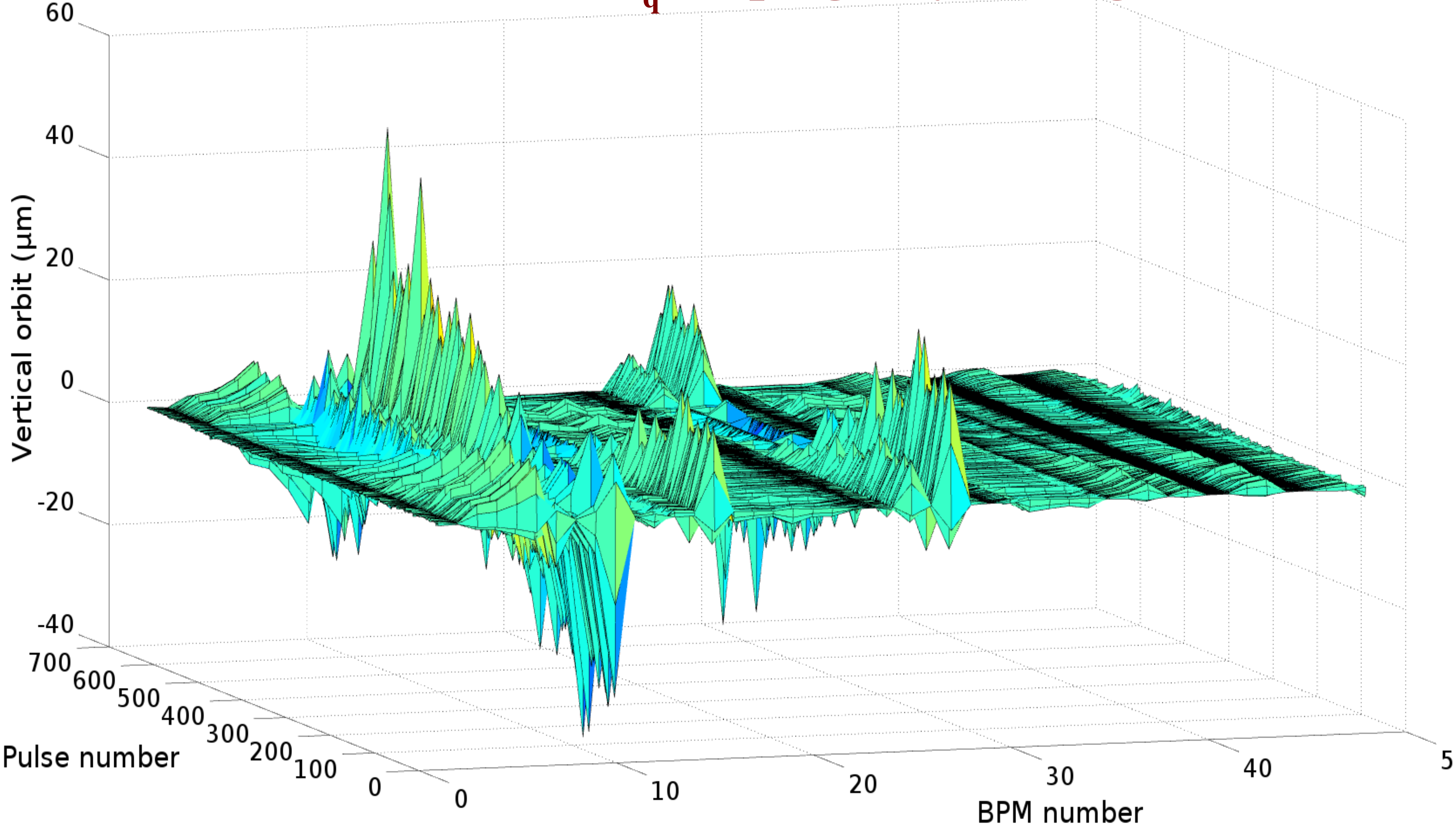
Reconstructed matrix D_q keeping only 6th singular value

$$S=\begin{pmatrix} s_{11} & 0 & \cdots & \cdots & 0 \\ 0 & s_{22} & \ddots & & \vdots \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \vdots & & \ddots & \ddots & 0 \\ \vdots & & & \ddots & s_{N+1N+1} \\ 0 & \cdots & \cdots & \cdots & 0 \\ \vdots & & & & \vdots \\ 0 & \cdots & \cdots & \cdots & 0 \end{pmatrix} \Rightarrow S_q=\begin{pmatrix} 0 & \cdots & \cdots & \cdots & \cdots & 0 \\ \vdots & \ddots & \ddots & & & \vdots \\ \vdots & \ddots & s_{66} & \ddots & & \vdots \\ \vdots & & \ddots & 0 & \ddots & 0 \\ \vdots & & & \ddots & \ddots & 0 \\ 0 & \cdots & \cdots & \cdots & \cdots & 0 \\ \vdots & & & & & \vdots \\ 0 & \cdots & \cdots & \cdots & \cdots & 0 \end{pmatrix}$$

$$D_q=US_qV^T$$

Surface plot Run1

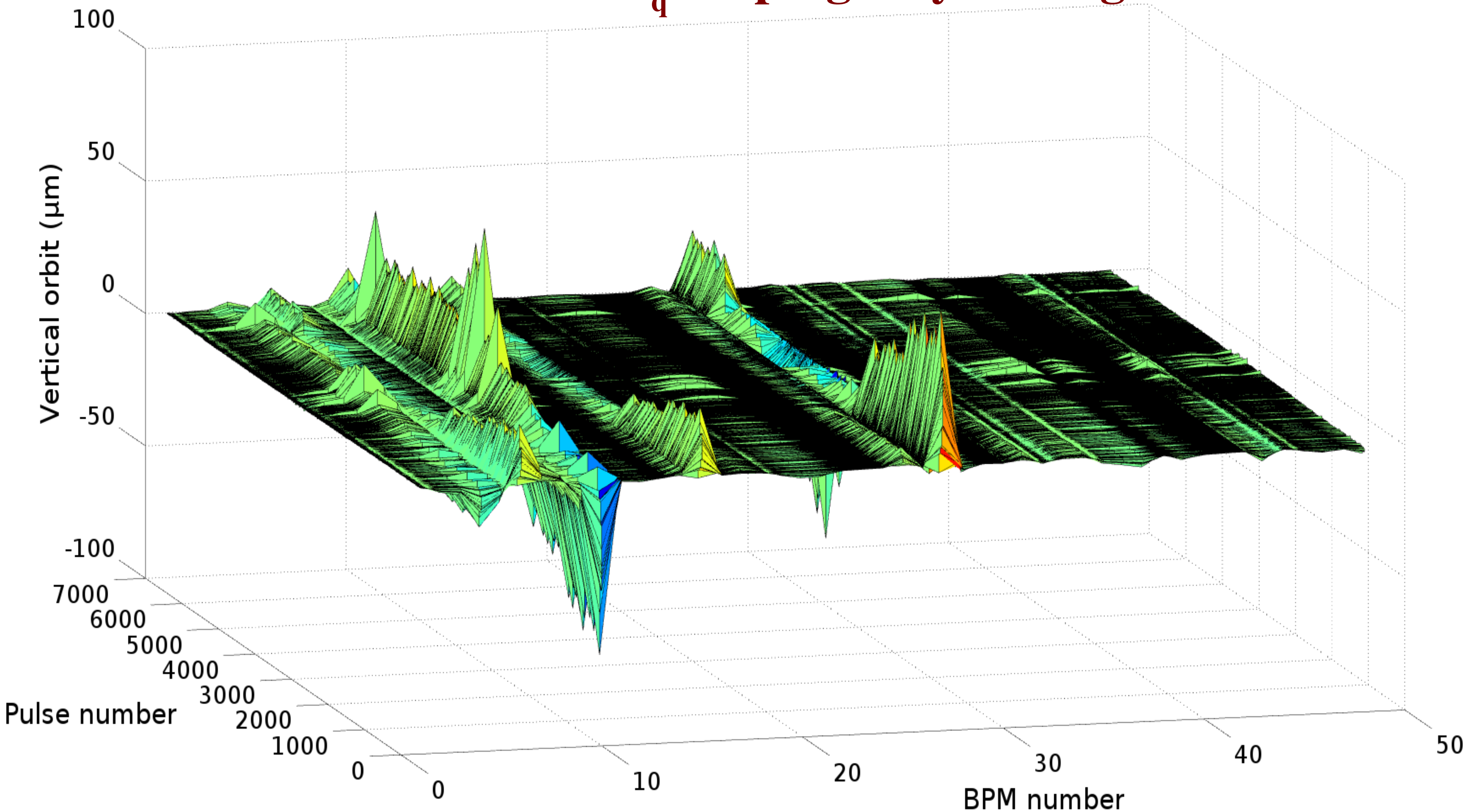
Reconstructed matrix D_q keeping only 6^{th} singular value



Run1

Surface plot Run3

Reconstructed matrix D_q keeping only 6th singular value

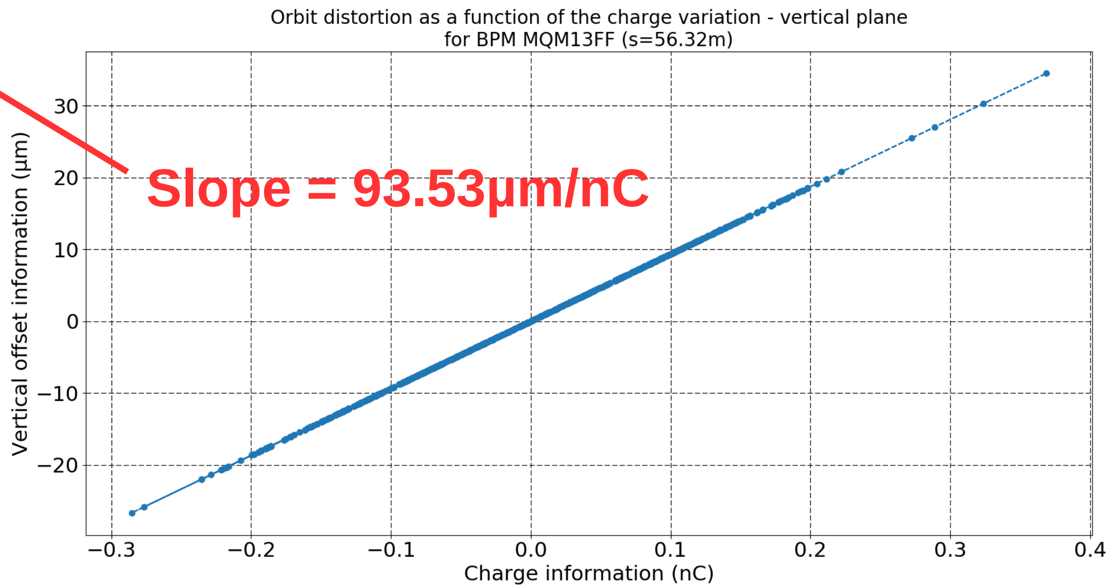


Run3

Vertical orbit distortion

BPM name	s(m)	d_q (µm/nC) run3	d_q (µm/nC) run1
MQF4X	14.490	**46.86**	**41.48**
MQD8X	22.935	**-139.50**	**-132.84**
MQD13X	31.680	**54.80**	**65.06**
MQF19X	40.058	-5.90	-4.96
MQD20X	43.824	-5.48	-5.36
MQF21X	47.816	-0.78	-1.53
MQM16FF	51.582	0.08	0.73
MQM15FF	53.316	1.02	-2.17
MQM14FF	54.816	**34.55**	**15.35**
MFB2FF	55.654	1.56	0.03
MQM13FF	56.316	**124.24**	**93.53**
MQM12FF	57.816	6.59	6.91
MQM11FF	59.416	0.02	0.02
MQD10BFF	60.916	2.53	2.59
MQD10AFF	61.816	-7.93	-7.52
MQF9BFF	63.116	-6.06	-5.90
MSF6FF	63.676	-4.61	-4.81
MQF9AFF	64.236	-6.53	-5.53
MQD8FF	66.036	4.99	4.70
MQF7FF	67.936	6.84	6.85
MQD6FF	69.836	10.41	9.39
MQF5BFF	71.636	0.51	0.19
MSF5FF	72.196	5.63	5.02
MQF5AFF	72.756	0.11	1.06
MQD4BFF	74.056	0.05	0.05
...	...	...	...

Let's introduce: **d_q** the orbit distortion due to the charge in **µm/nC**.



Vertical orbit distortion

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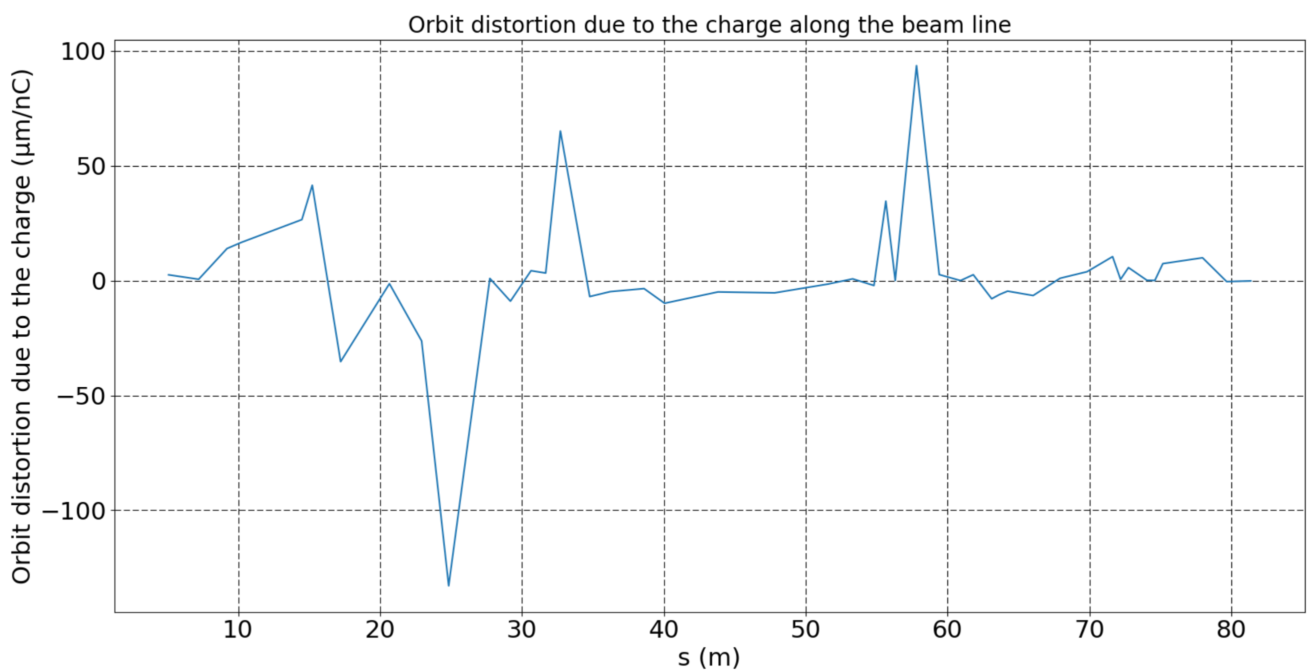
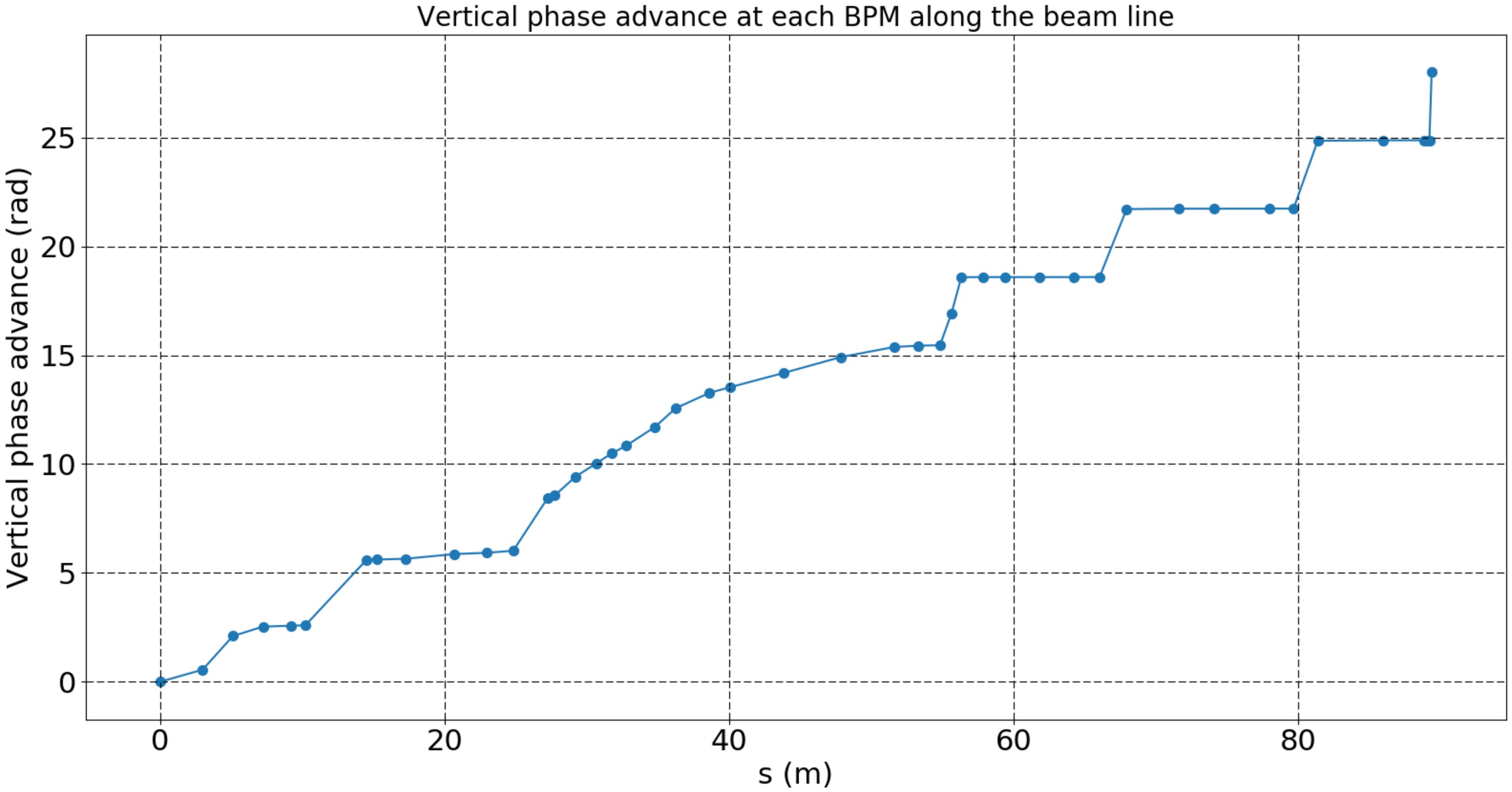
MSF6FF	63.676	-4.61	
MQF9AFF	64.236	-6.53	
MQD8FF	66.036	4.99	
MQF7FF	67.936	6.84	
MQD6FF	69.836	10.41	
MQF5BFF	71.636	0.51	
MSF5FF	72.196	5.63	
MQF5AFF	72.756	0.11	
MQD4BFF	74.056	0.05	
...	...	...	

Let's introduce: $\mathbf{d_q}$ the orbit distortion due to the charge in **µm/nC**.

Run1



Vertical phase advance



Outlook

● Knowing the charge-linked physical effects, assess incoming beam jitter from experimental data.

● Implement a Dispersion Free Steering (and Wakefield Free Steering) correction in ATF2.

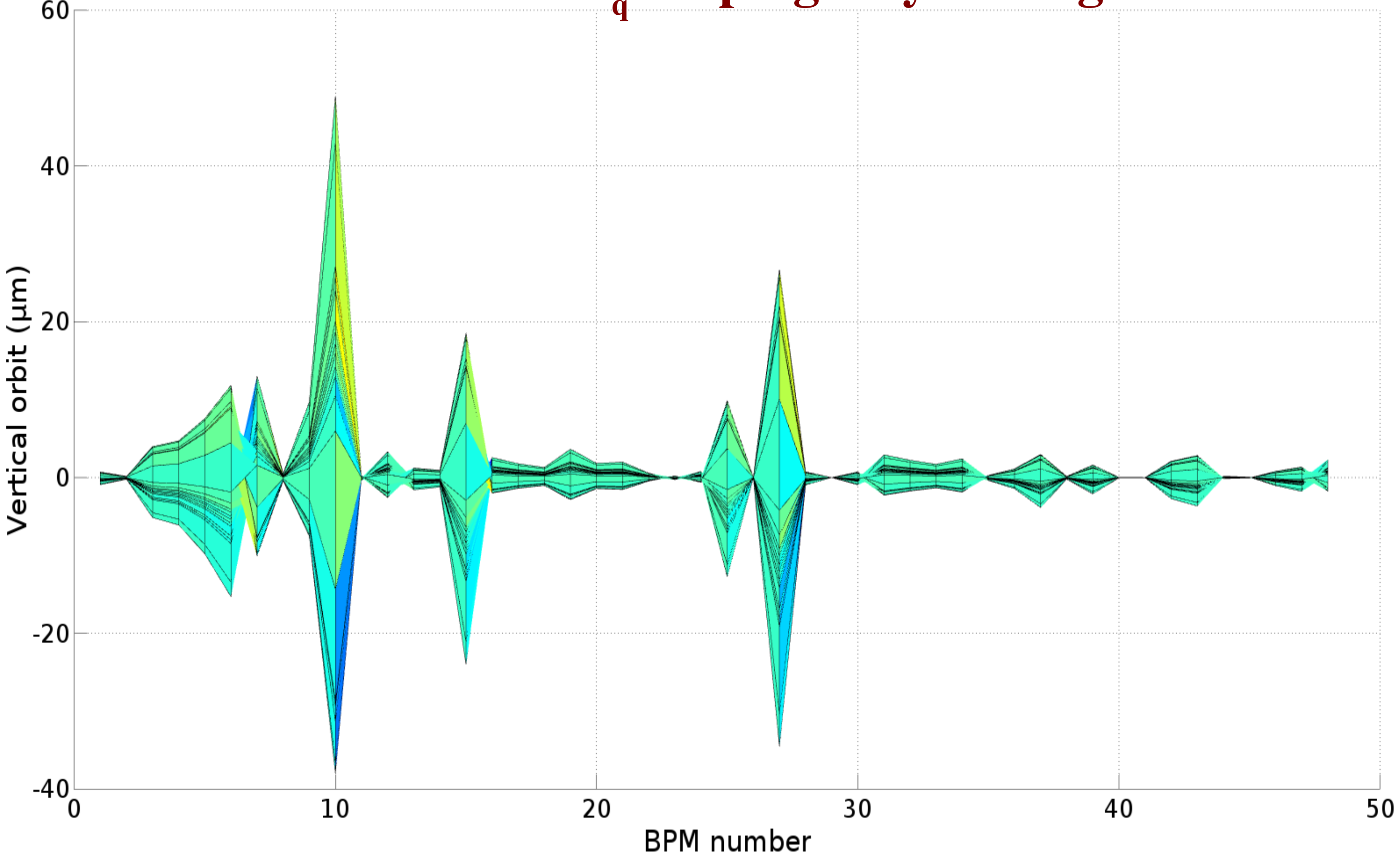
● Pursue the studies using the SVD calculation technics using these correction schemes.

● Reproduce in simulation the observed phenomena.

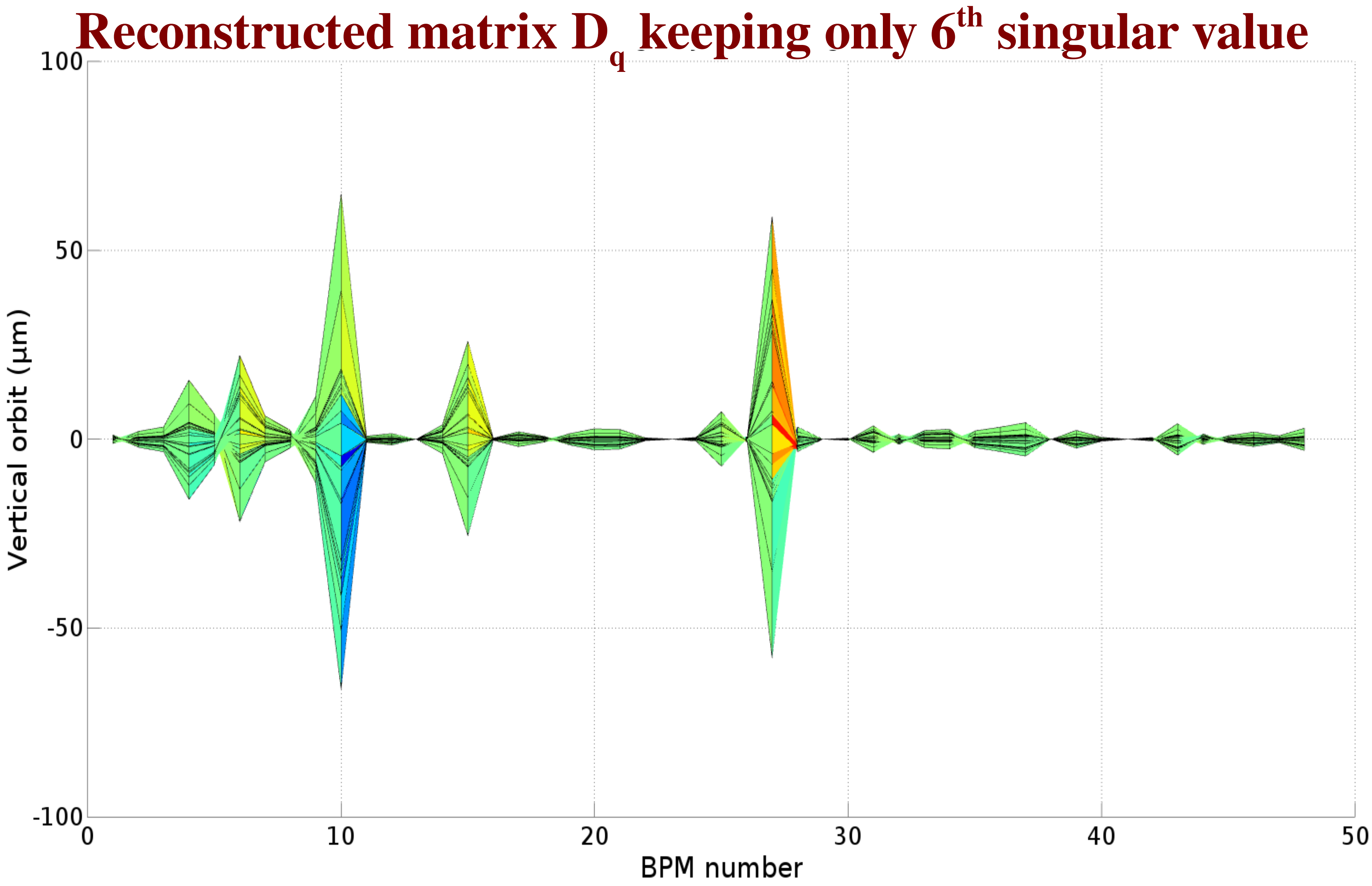
Thank you

Backup slides – Surface plot Run1

Reconstructed matrix D_q keeping only 6^{th} singular value



Backup slides – Surface plot Run3



Backup slides