# TRANSFER LINE
# LEIR-PS

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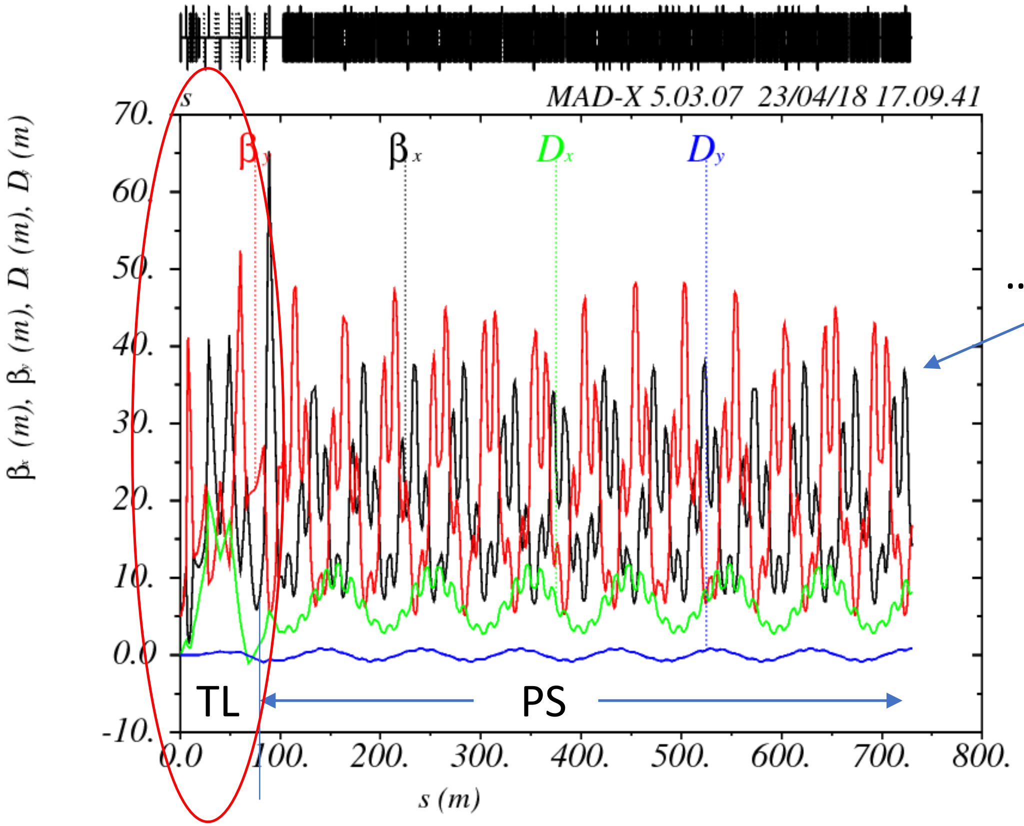
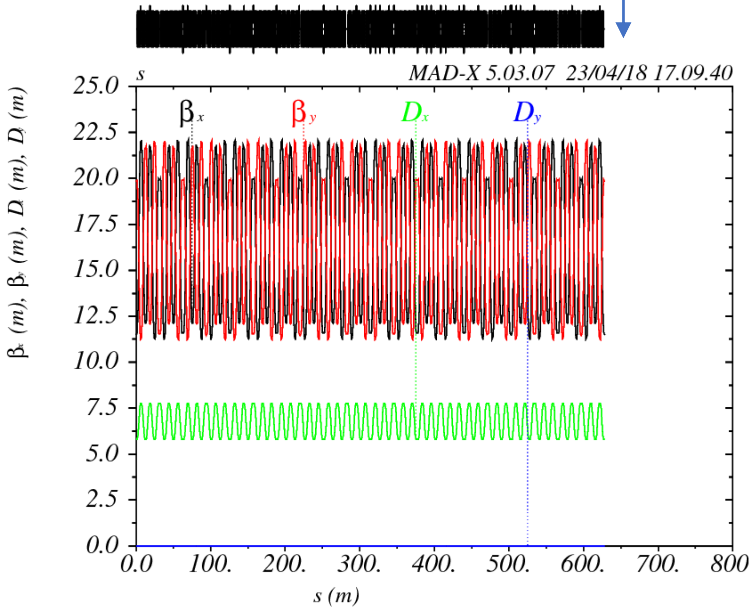
# Introduction

1. In 2015-2016 was noticed that the correction of the transfer line from LEIR to PS was difficult if based on the optics model used by YASP:

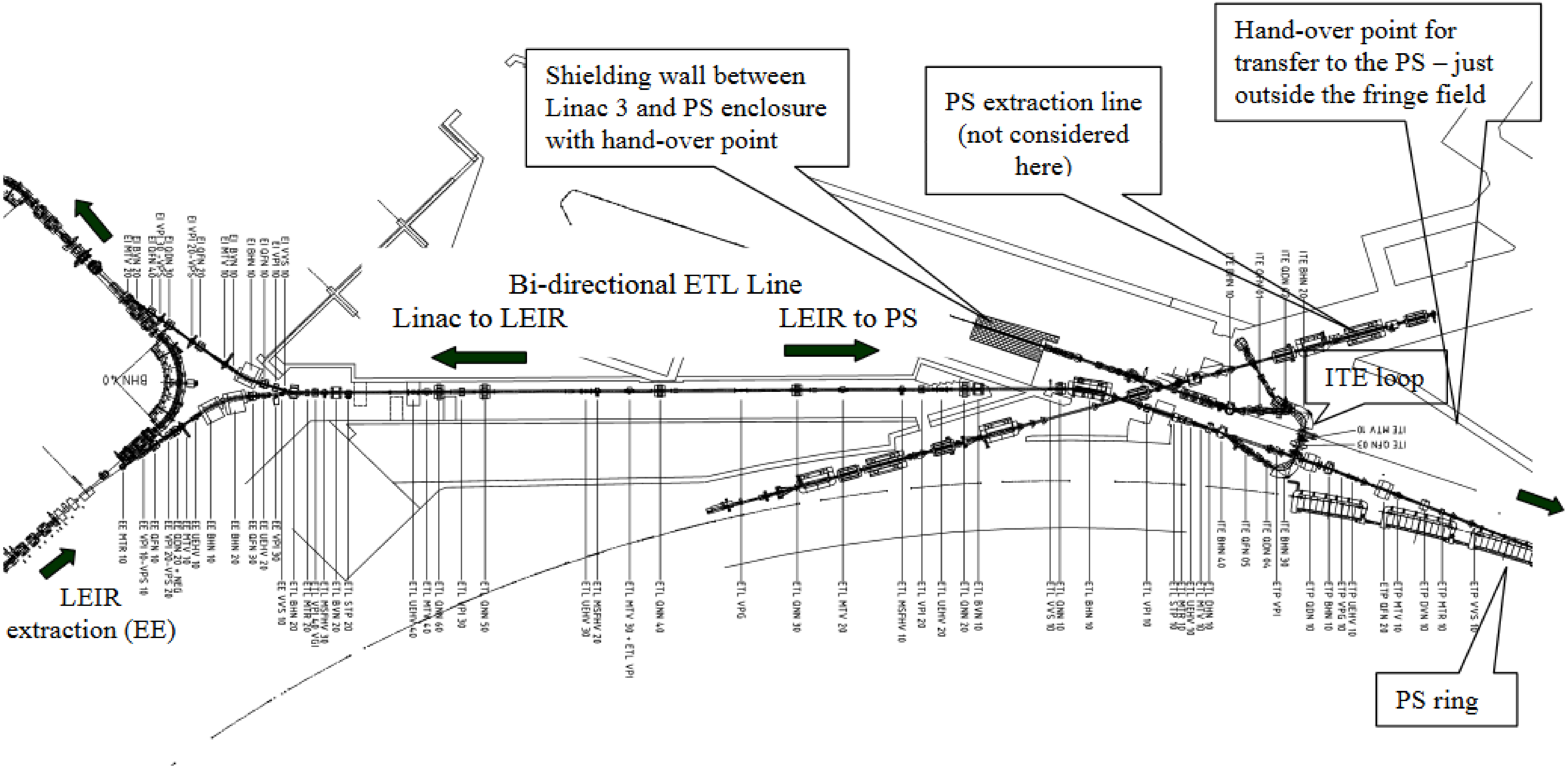



... but not matched to the PS periodic solution




2. Despite of this, with trial an error, a good transmission and injection efficiency has always been possible

# Transfer line



# Fringe field matrix

LEIR-PS matching point (A):

$\beta_x = 20$ m, $\beta_y = 14.8$ m,
$\alpha_x = 1.35$, $\alpha_y = -0.57$,
$D_x = 2.5$ m, $D_y = 0$ m,
$D'_x = -0.12$ , $D'_y = 0$

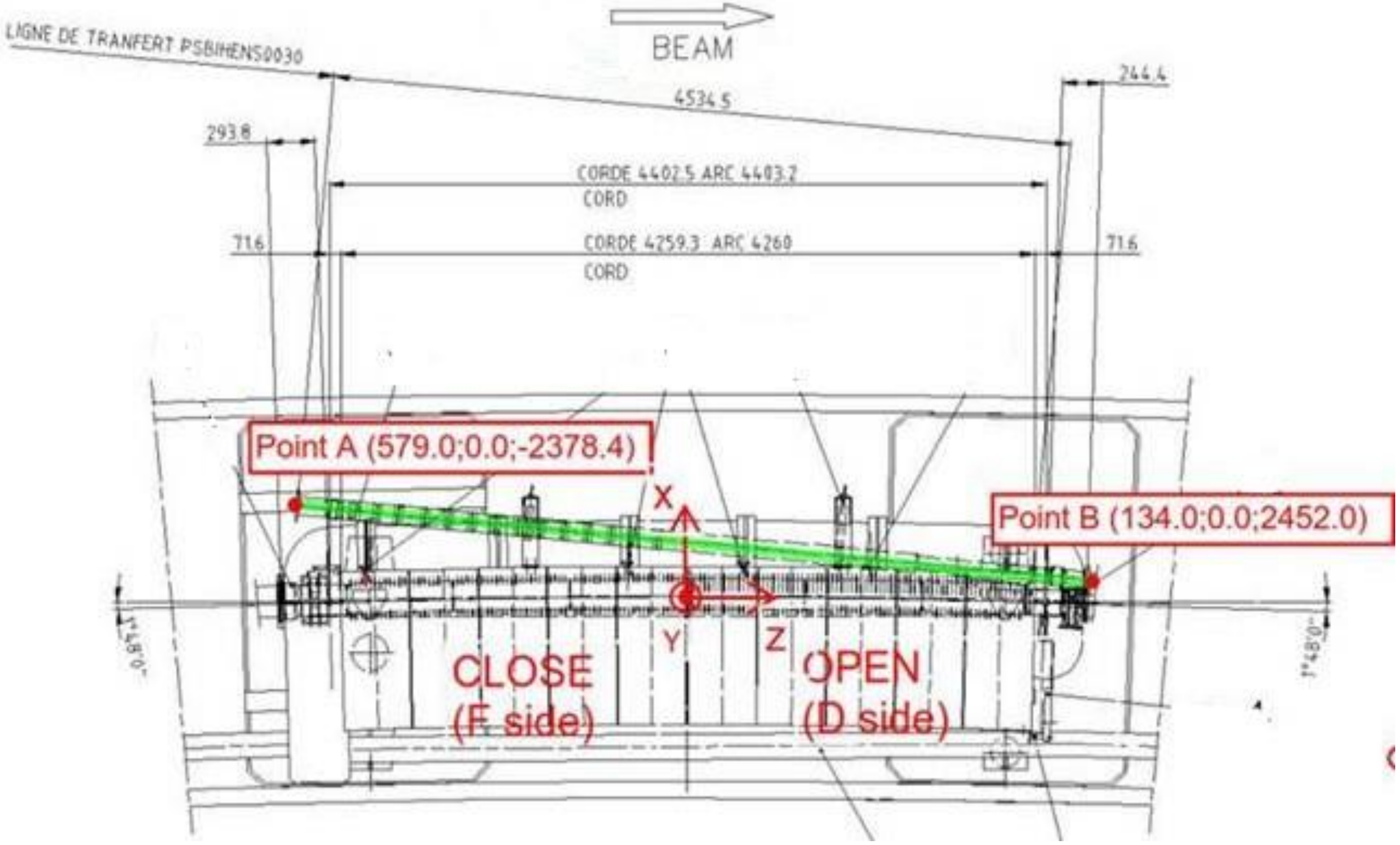
PS septum 26 centre:

$\beta_x = 11.47$ m, $\beta_y = 19.83$ m,
$\alpha_x = 0$, $\alpha_y = 0$,
$D_x = 2.16$m, $D_y = 0$ m,
$D'_x = -0.02$ , $D'_y = 0$

$$M_H = \begin{pmatrix} 1.125 & 6.534 & 0.022 \\ 0.0503 & 1.181 & 0.008 \\ 0 & 0 & 1 \end{pmatrix}$$

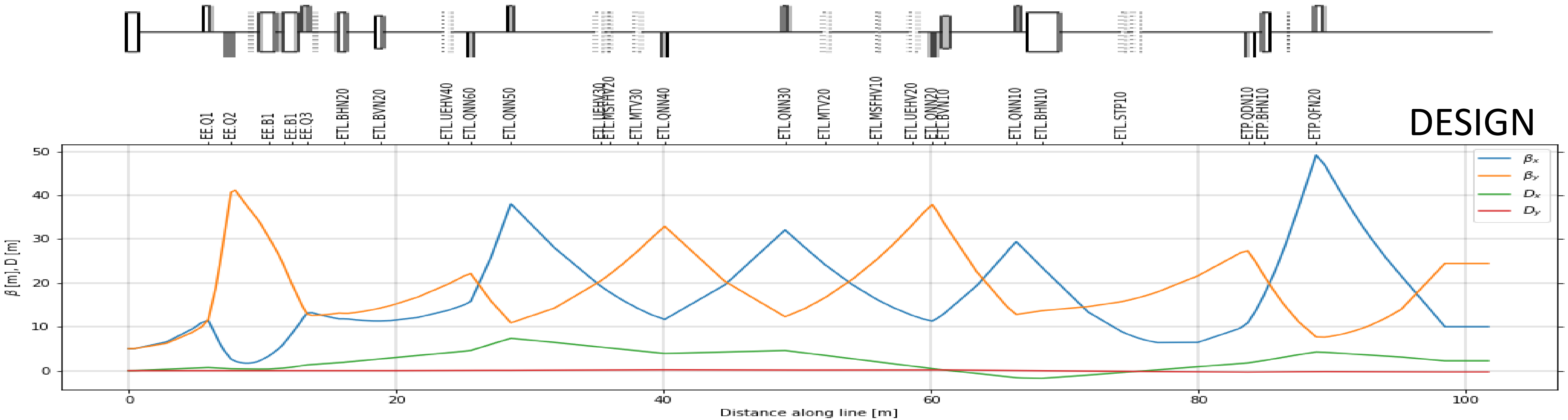
$$M_V = \begin{pmatrix} 0.878 & 5.683 & 0 \\ -0.049 & 0.825 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Reference: M. Martini, 'Injection of the lead ion beam for LHC into the PS'

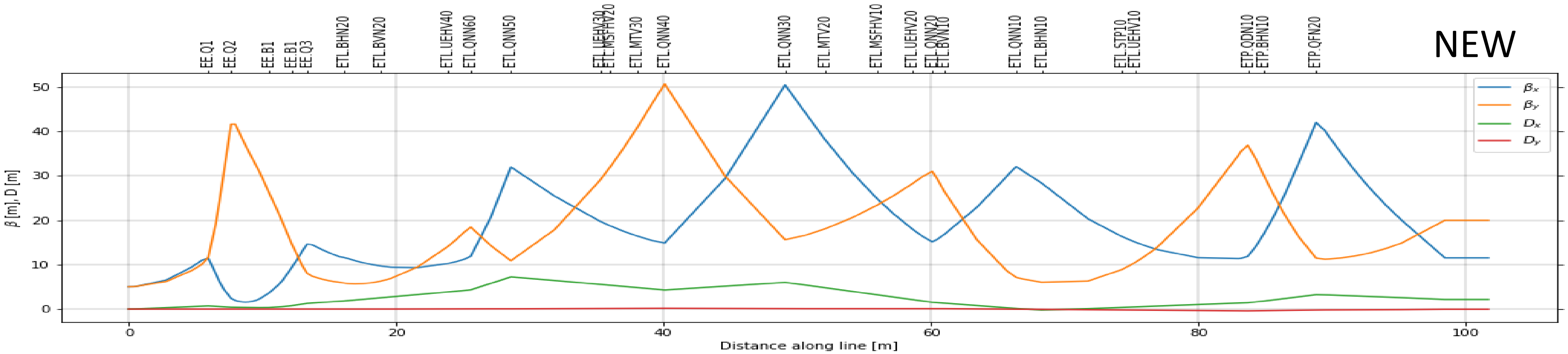



| Optical parameters | $\beta_x$ [m] | $\alpha_x$ | $\beta_y$ [m] | $\alpha_y$ | $D_x$ [m] | $D'_x$ | $D_y$ [m] | $D'_y$ |
|---|---|---|---|---|---|---|---|---|
| PS septum 26 centre | 12.48 | 0 | 19.71 | 0 | 2.21 | -0.02 | 0 | 0 |
| LEIR-PS matching point | 21.50 | 1.62 | 15.21 | -0.71 | 2.78 | -0.17 | 0 | 0 |

# Optics

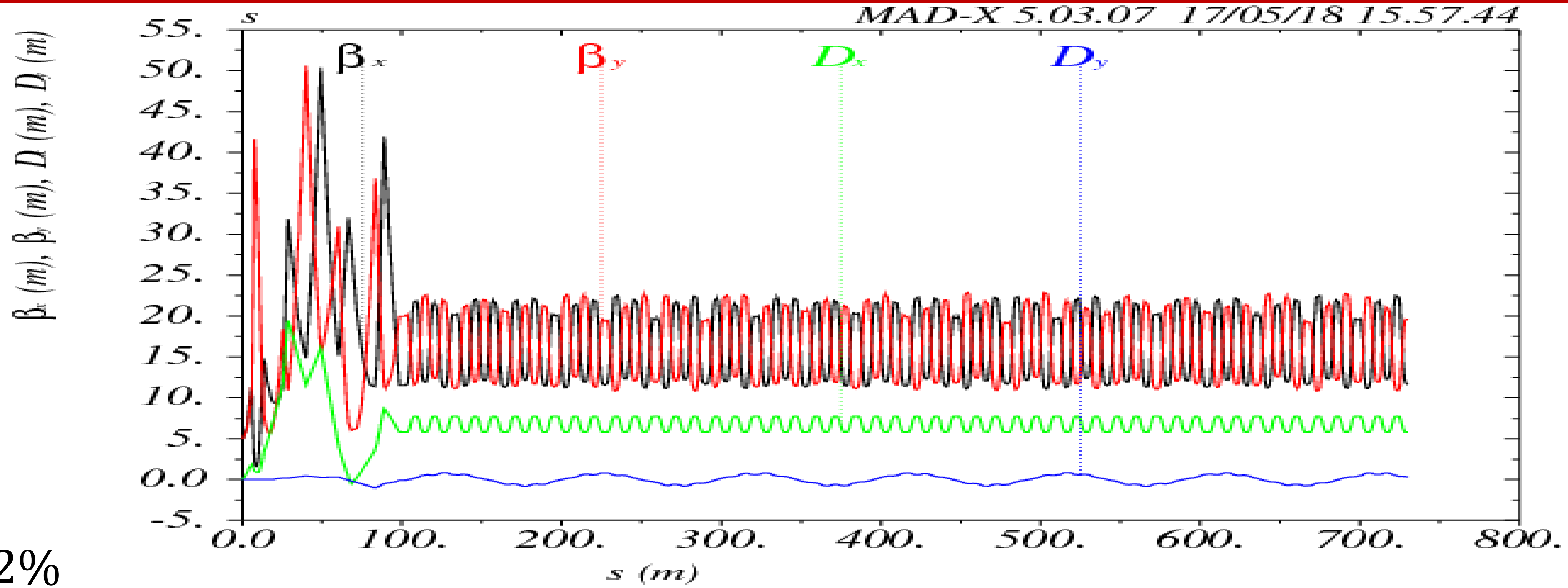


DESIGN
EE.Q1
EE.Q2
EE.B1
EE.B1
EE.Q3
ETL.BHN20
ETL.BVN20
ETL.UEHV40
ETL.QNN60
ETL.QNN50
ETL.MTV30
ETL.QNN40
ETL.QNN30
ETL.MTV20
ETL.MSFHV10
ETL.UEHV20
ETL.QNN10
ETL.BHN10
ETL.STP10
ETP.QDN10
ETP.BHN10
ETP.QFN20
β [m], D [m]
Distance along line [m]
$\beta_x$
$\beta_y$
$D_x$
$D_y$

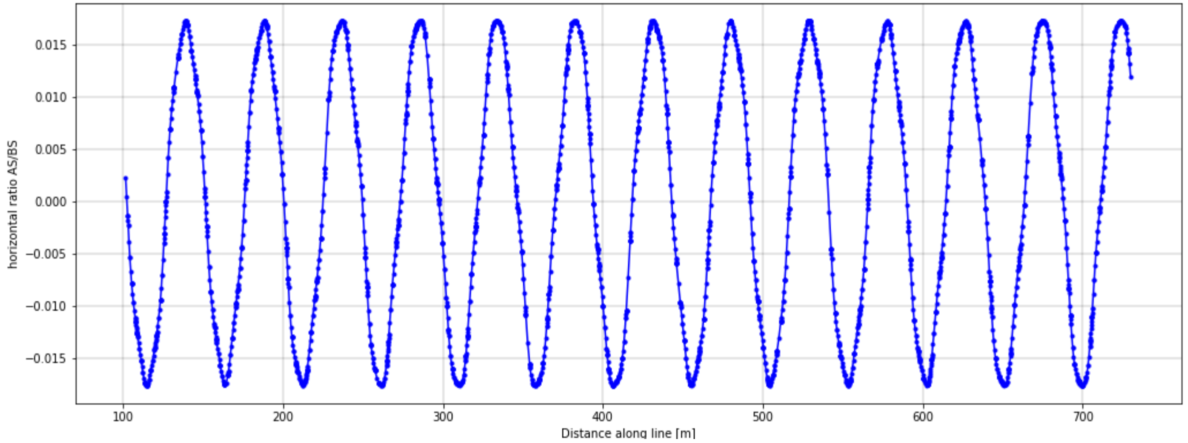



NEW
EE.Q1
EE.Q2
EE.B1
EE.B1
EE.Q3
ETL.BHN20
ETL.BVN20
ETL.UEHV40
ETL.QNN60
ETL.QNN50
ETL.MTV30
ETL.QNN40
ETL.QNN30
ETL.MTV20
ETL.MSFHV10
ETL.UEHV20
ETL.QNN10
ETL.BHN10
ETL.STP10
ETL.UEHV10
ETP.QDN10
ETP.BHN10
ETP.QFN20
β [m], D [m]
Distance along line [m]
$\beta_x$
$\beta_y$
$D_x$
$D_y$

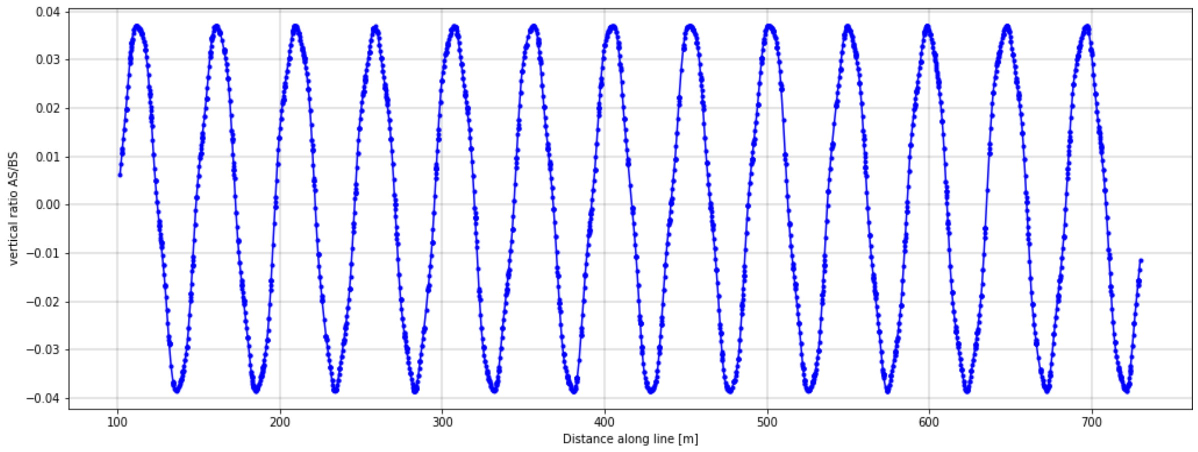
# PS solution



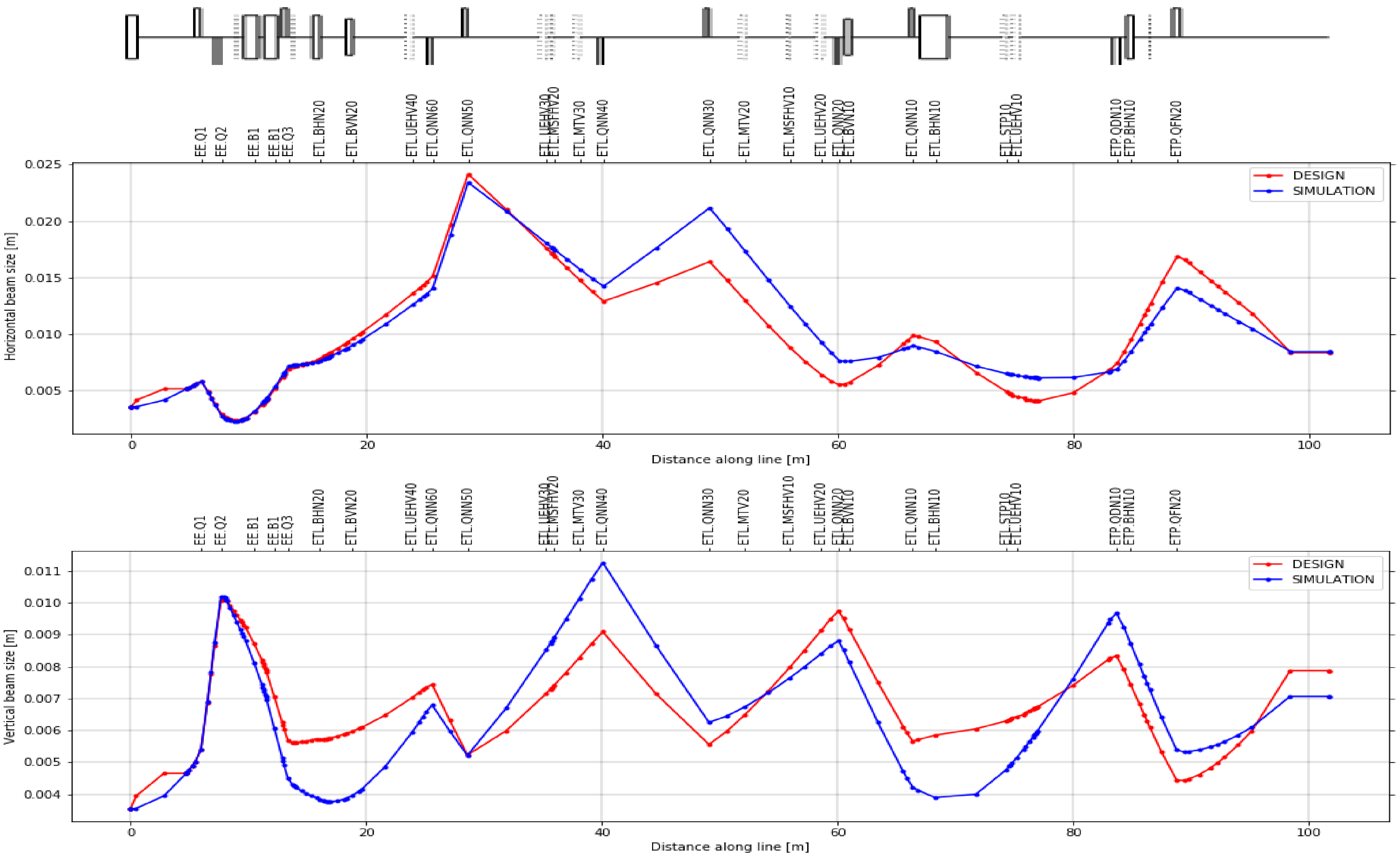

±2%




±4%



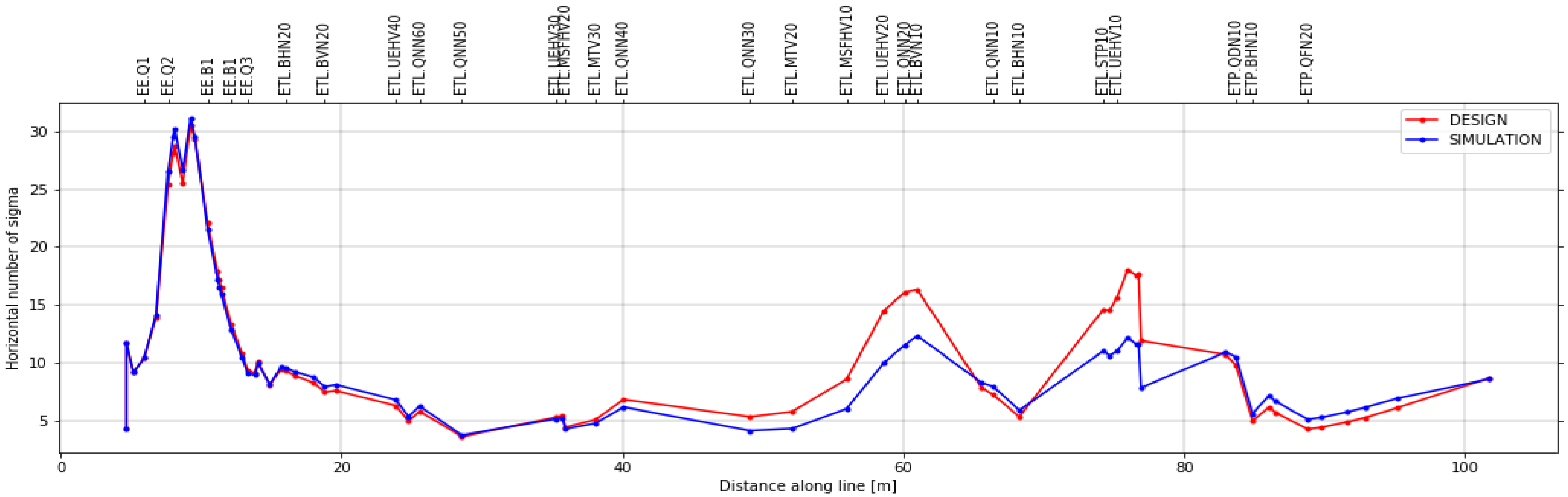
# Beam size

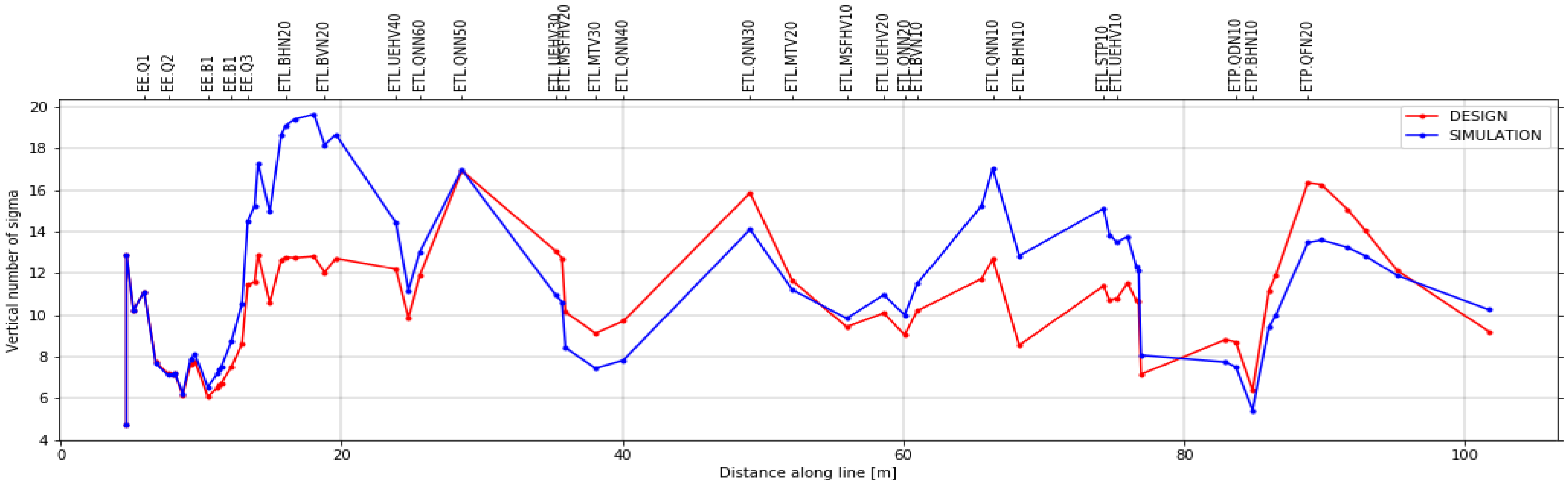



$$\Delta p / p = 0.003$$

$$\varepsilon_n = 1\ \mu m \cdot rad$$

# Aperture




*Number of sigma in the beam pipe*

$$N = \frac{R_{x,y}}{\sigma_{x,y}}$$

$N_x^{MIN} = 3.8$ (ETL.QNN50)

$N_y^{MIN} = 5.4$ (ETP.BHN10)

# Is this optics correct? ➔ORBIT RESPONSE MATRIX

1. Using the existing tools for LHC to measure the optics parameters: **YASP, ALOHA, Accelerator Model, JMAD**, we want to understand which optics better fits the transfer line

2. Since this has not been done before for LEIR, we are now investing sometime in getting the tools ready.

3. For example:
    1. LEIR suffers from stray fields, and this is not taken into account yet in those tools ➔ working on this
    2. LEIR uses BENDS as CORRECTORS, this is not taken into account yet in those tools ➔ working on this

4. While for a closed ring there exist very well established methods to measure the betatron phase and beta functions, the measurement of lattice functions of a transfer line is a non trivial task.

5. The beam only passes the transfer line once and therefore the resolution of the Beam Position Monitors (BPMs) is limited and the trajectory depends strongly on the initial conditions and therefore on the stability of the injector.

# Is this optics correct? ➔ORBIT RESPONSE MATRIX

6. The basic idea is to use model-fits to kick response data, also known as the LOCO principle to determine the lattice parameters.
7. The objective is to develop a model for the transfer lines which includes all the observed effects and can be used to match the optics of the transfer lines correctly to the PS optics and thus ensure the required emittance preservation and transmission efficiency.

8. The key quantity is the **ORBIT RESPONSE MATRIX, R** ➔ describes the effect of a set of **Nc** corrector kicks on the position readings of each of the **Nm** BPMs

$$\vec{u} = R\vec{\delta}.$$

$$\vec{u} = \begin{pmatrix} u_1 \\ u_2 \\ \dots \\ u_{N_M} \end{pmatrix}, \quad \vec{\delta} = \begin{pmatrix} \delta_1 \\ \delta_2 \\ \dots \\ \delta_{N_C} \end{pmatrix},$$

9. Nc = 3 in H and 2 in V
10. Nm = 7 in H and 7 in V

11. The easiest way to **measure Rij** is to acquire two trajectories one with positive kick and the other with negative and calculate the difference of the two at each monitor:

$$R_{ij}^{\text{meas}} = \frac{\Delta u_i}{\Delta \delta_j},$$

# Is this optics correct? ➔ORBIT RESPONSE MATRIX

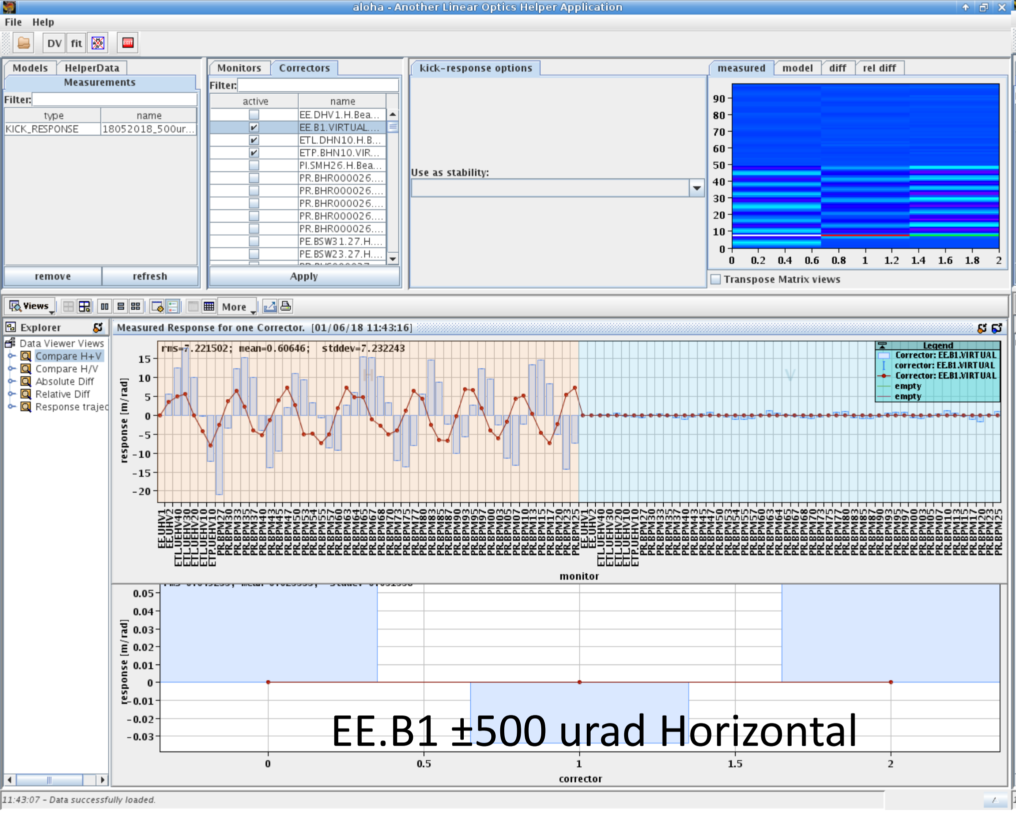
12. The response matrix has to be calculated for the model as well.
13. In this case:

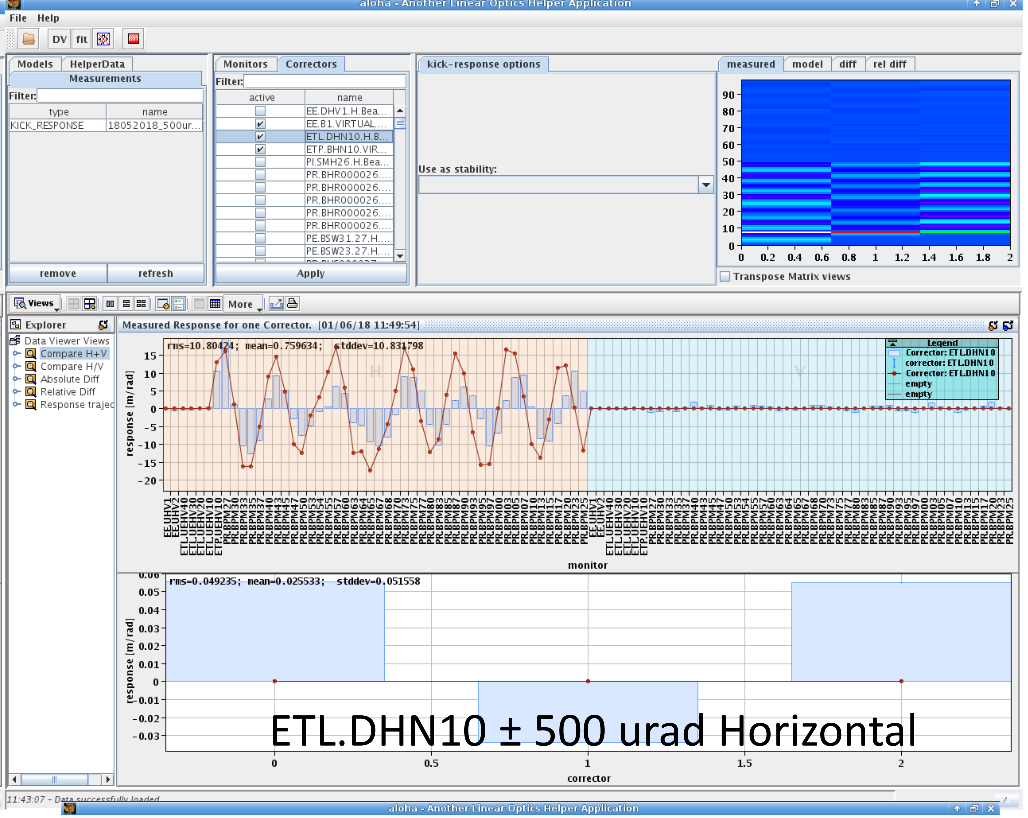
$$R_{ij}^{\text{model}} = \begin{cases} \sqrt{\beta_i \beta_j} \sin(\mu_i - \mu_j) & \text{for } \mu_i > \mu_j, \\ 0 & \text{otherwise.} \end{cases}$$

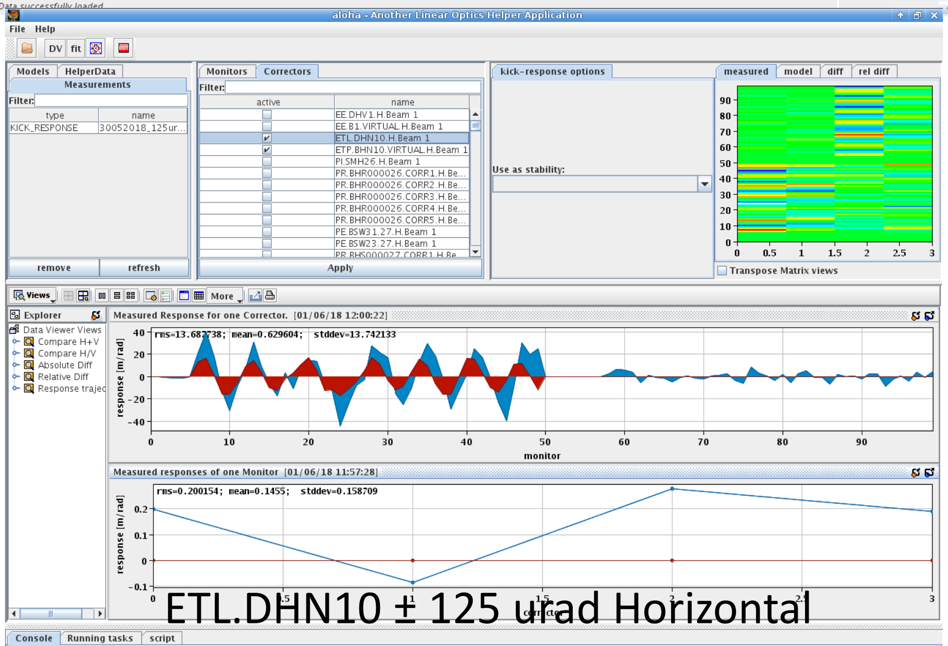
βi : beta function at the monitor
βj : beta function at the corrector
μi - μj = phase difference

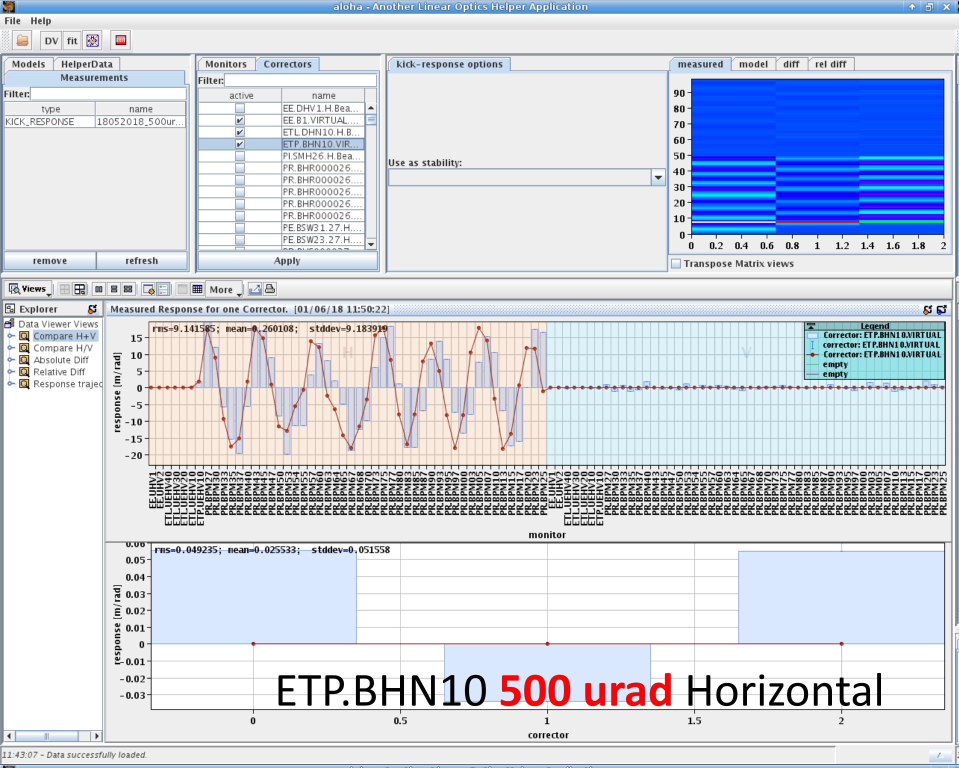
14. This is valid for a linear machine, if coupling or non-linear effects have to be included, then numerical calculations are needed.

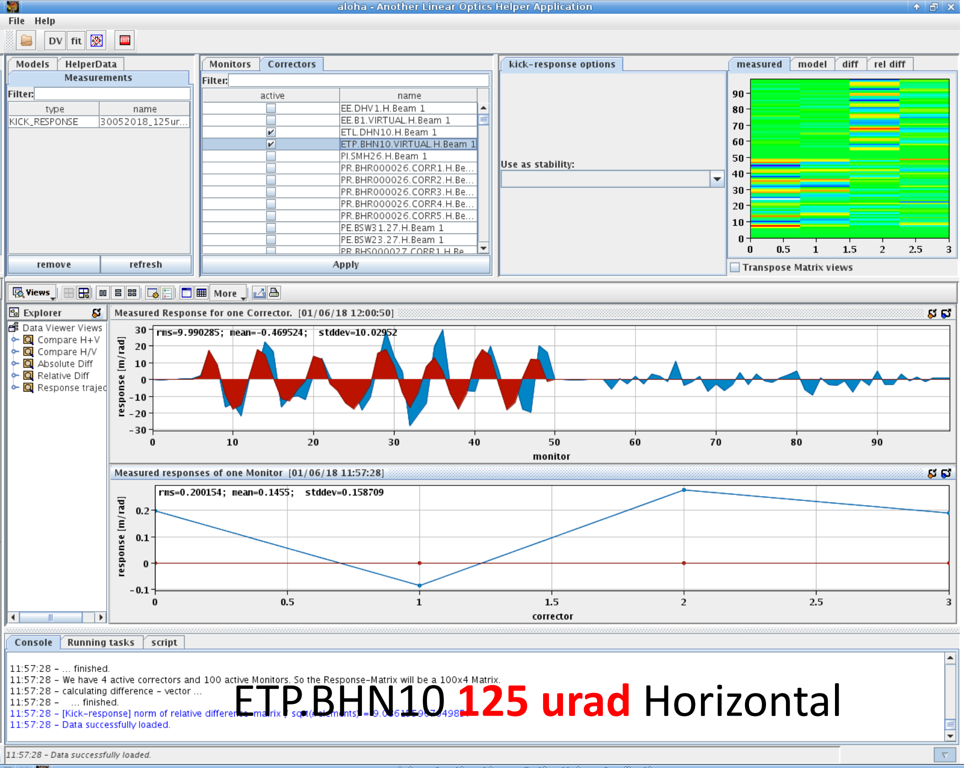
15. Status of the analysis: we have taken data, we are in the process of analysing.

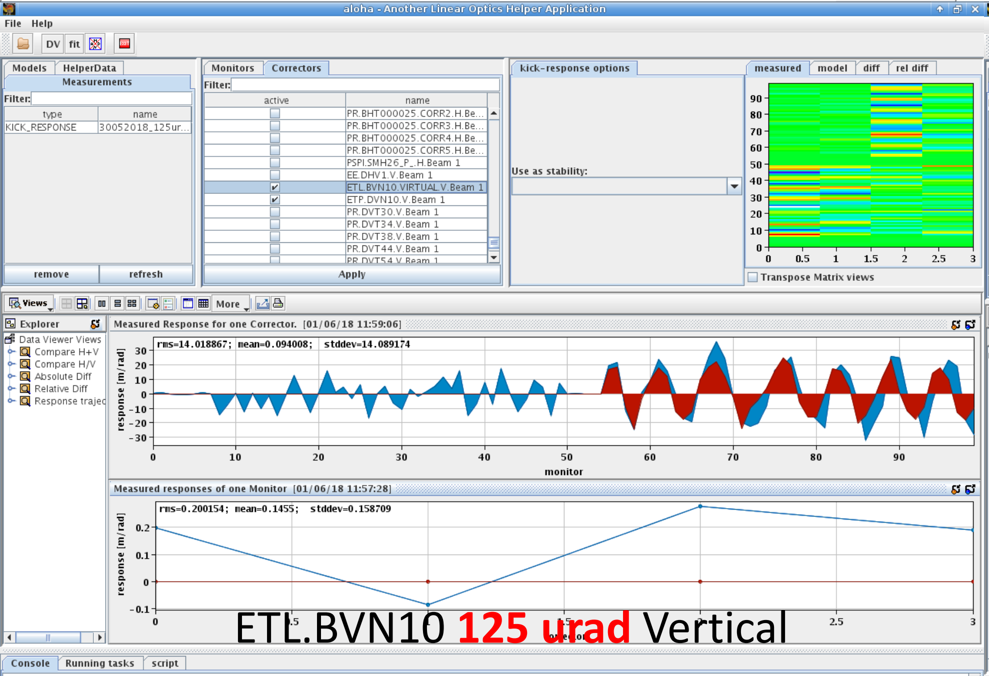

aloha - Another Linear Optics Helper Application
Measured Response for one Corrector. [01/06/18 11:43:16]
EE.B1 ±500 urad Horizontal

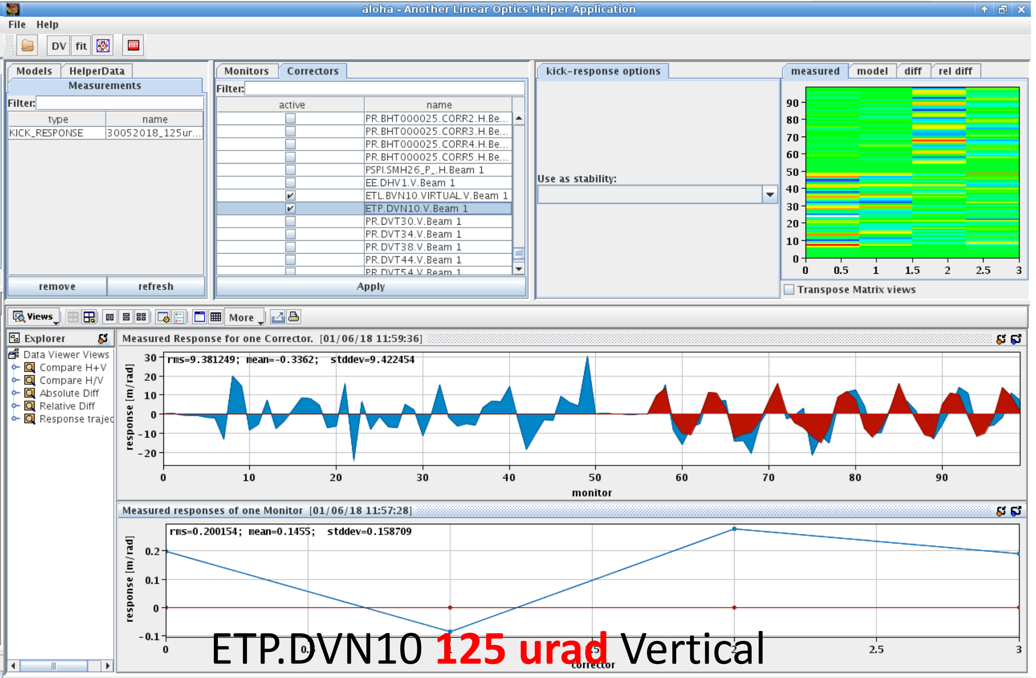

aloha - Another Linear Optics Helper Application
Measured Response for one Corrector. [01/06/18 11:49:54]
ETL.DHN10 ± 500 urad Horizontal


aloha - Another Linear Optics Helper Application
Measured Response for one Corrector. [01/06/18 12:00:22]
Measured responses of one Monitor [01/06/18 11:57:28]
ETL.DHN10 ± 125 urad Horizontal


aloha - Another Linear Optics Helper Application
Measured Response for one Corrector. [01/06/18 11:50:22]
ETP.BHN10 500 urad Horizontal


aloha - Another Linear Optics Helper Application
Measured Response for one Corrector. [01/06/18 12:00:50]
Measured responses of one Monitor [01/06/18 11:57:28]
ETP.BHN10 125 urad Horizontal


aloha - Another Linear Optics Helper Application
Measured Response for one Corrector. [01/06/18 11:59:06]
Measured responses of one Monitor [01/06/18 11:57:28]
ETL.BVN10 125 urad Vertical


aloha - Another Linear Optics Helper Application
Measured Response for one Corrector. [01/06/18 11:59:36]
Measured responses of one Monitor [01/06/18 11:57:28]
ETP.DVN10 125 urad Vertical

# Conclusions

1. Work in progress
2. Using LHC tools and adapting them to LEIR case
3. The stray field descriptiion is from many years ago, we have contacted the MAGNET team to have more recent values
4. With the new optics the transmission efficiency is 98%

# SPEAR SLIDES

# Beam parameters

Ions of $Pb^{54+}$ with A = 208 and m = 195.32 GeV/c$^2$

Total kinetic energy in extraction $E_{k,ext}$ = 15.02 GeV

Total energy in extraction $E_{ext}$ = 210.34 GeV

Total momentum in extraction $P_{ext}$ = 78.06 GeV/c

Relativistic parameters $\beta_{rel} = \frac{pc}{E} = 0.371$ $\gamma_{rel} = \frac{1}{\sqrt{1-\beta^2}} = 1.077$

# Beam size

$$Geometric\ emittance \quad \varepsilon = \varepsilon_n/(\beta_{rel} \cdot \gamma_{rel}) = 2.5\ \mu m$$

$$\varepsilon_x^n = \varepsilon_y^n \qquad \varepsilon_x = \varepsilon_y$$

$$where \quad \varepsilon_n = 1\ \mu m \cdot rad \quad is\ the\ normalized\ emittance$$

$$\sigma_{D_x,D_y} = \frac{\Delta p}{p} \cdot D_{x,y} \qquad with \quad \frac{\Delta p}{p} = 0.003\ (worst\ case)$$

$$\sigma_{\beta_x,\beta_y} = \sqrt{\beta_{x,y} \cdot \varepsilon_{x,y}}$$

$$Total\ beam\ size: \qquad \sigma_{x,y} = \sqrt{\sigma_{\beta_x,\beta_y}^2 + \sigma_{D_x,D_y}^2}$$

# kL values

| QUADRUPOLES | k L ($m^{-1}$) |
|---|---|
| EE.QFN10 | 0.463518 |
| EE.QDN20 | -0.380824 |
| EE.QFN30 | 0.255181 |
| ETL.QNN10 | 0.098527 |
| ETL.QNN20 | -0.127474 |
| ETL.QNN30 | 0.101173 |
| ETL.QNN40 | -0.10641 |
| ETL.QNN50 | 0.175188 |
| ETL.QNN60 | -0.170497 |
| ETP.QDN10 | -0.155017 |
| ETP.QFN20 | 0.15187 |

Initial conditions at

LEIR extraction septum

(ER.SMH40)

$$\beta_x = \beta_y = 5 \text{ m}$$

$$D_x = D_y = 0 \text{ m}$$