T8 proton beam data & measurements

Update on the analysis of the transfer line measurements

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Acknowledgements:
M. Fraser and N. Charitonidis

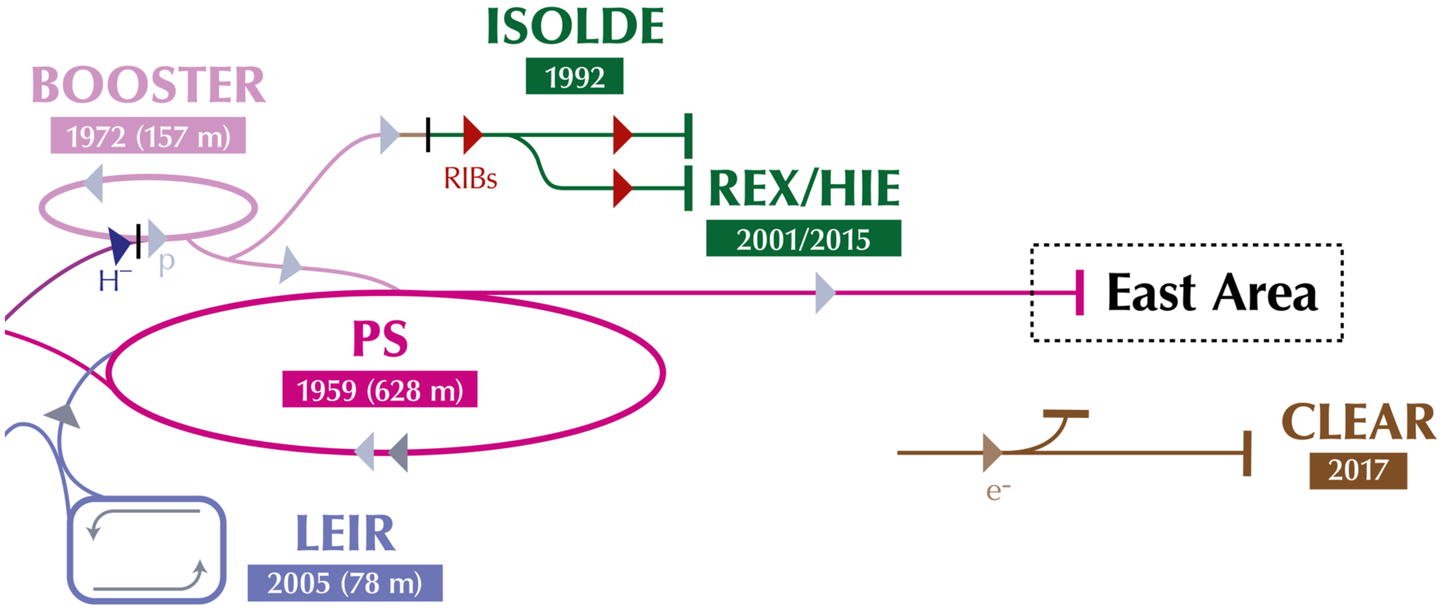
01 Dec 2021

Outline

- Kick response methodology
- Measurements
- Preliminary results

Motivation

- Understanding and comparing with simulations the behaviour of the beam in the T8 line (East Area)



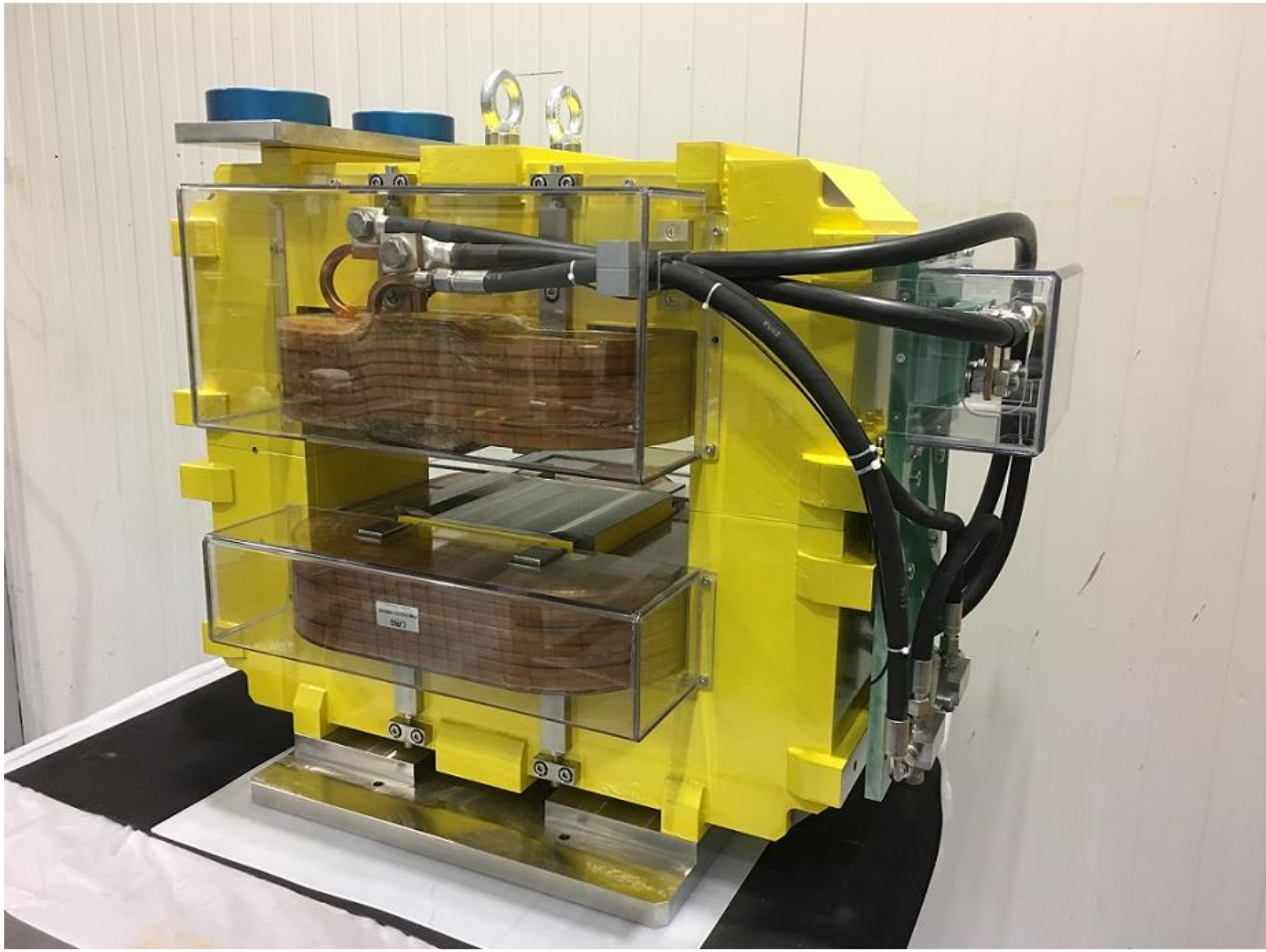
Kick response methodology

We kick the beam using all available correctors magnets in the line:

- **3 Horizontal correctors**
- **3 Vertical correctors**

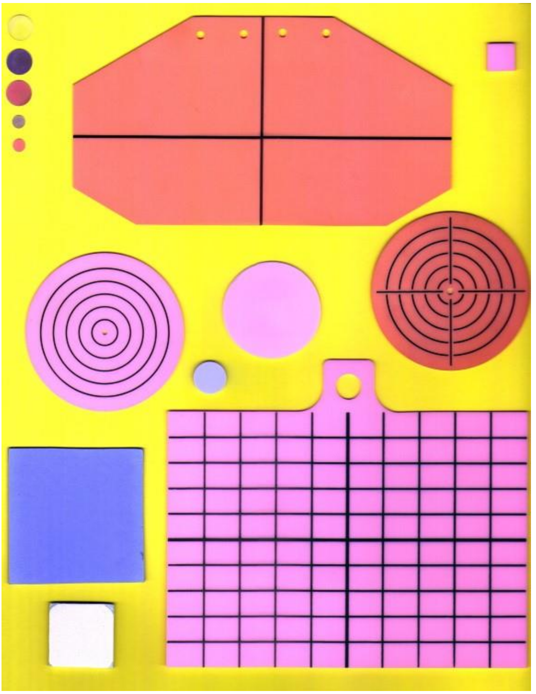
Observe the deflection in position on the 5 BTVs along the line.

We record current and x, y mean position

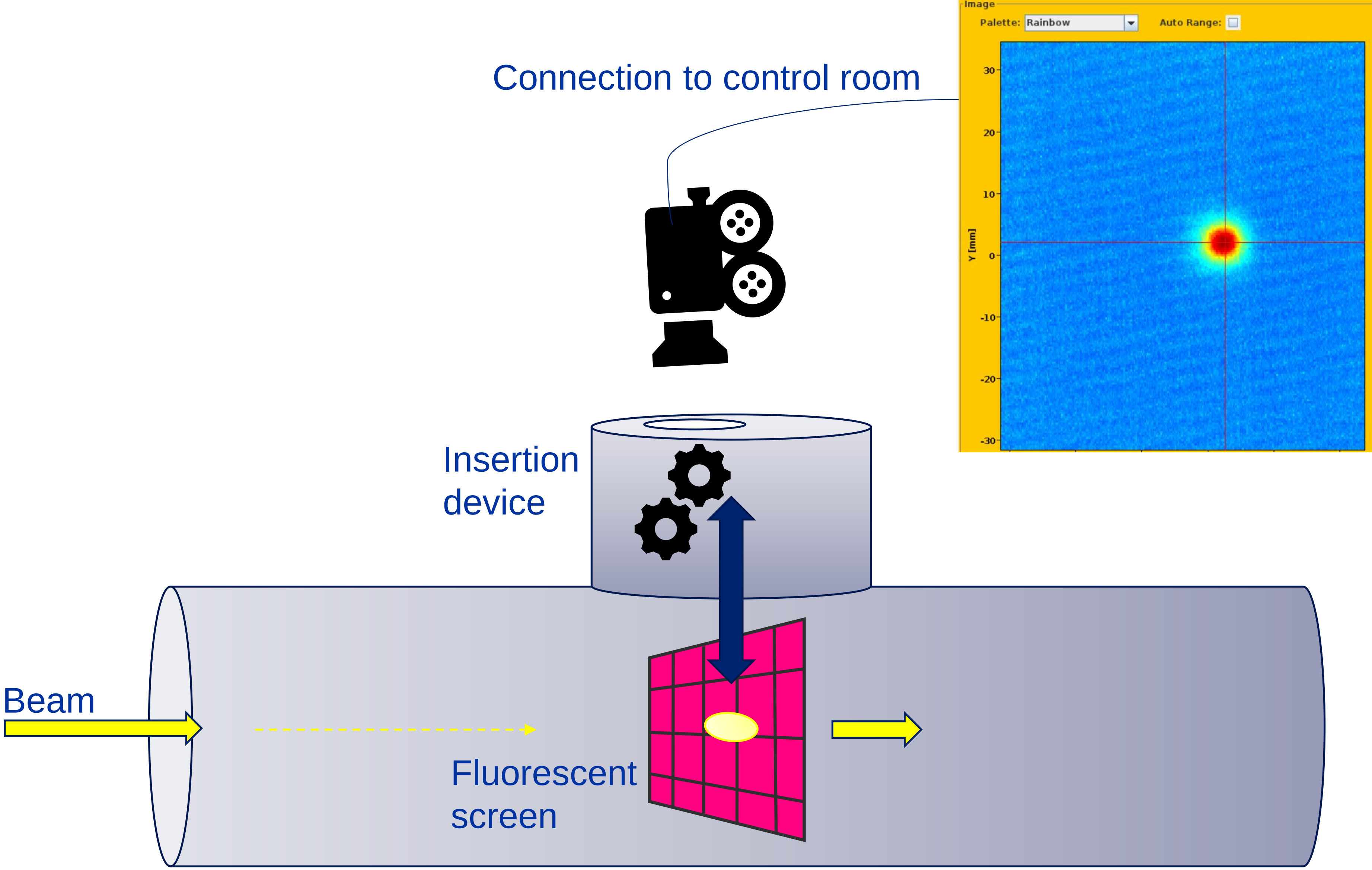


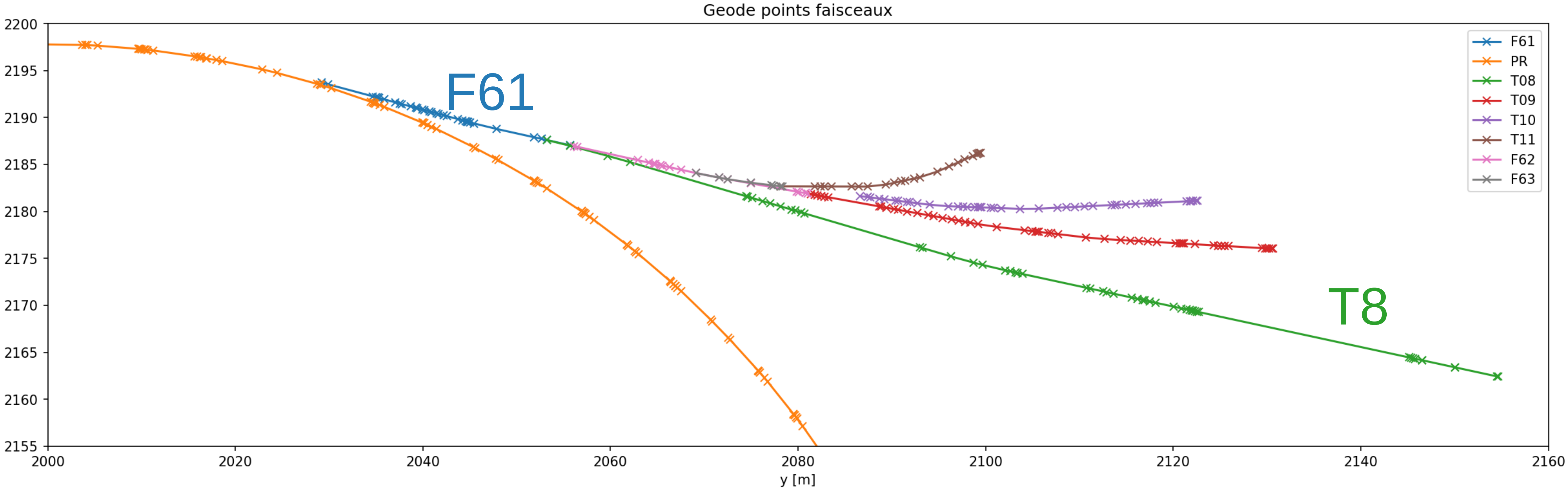
Corrector magnet DHZ01 https://norma-db.web.cern.ch/magnet/idcard/11252/

TV beam observation diagnostics (BTV)

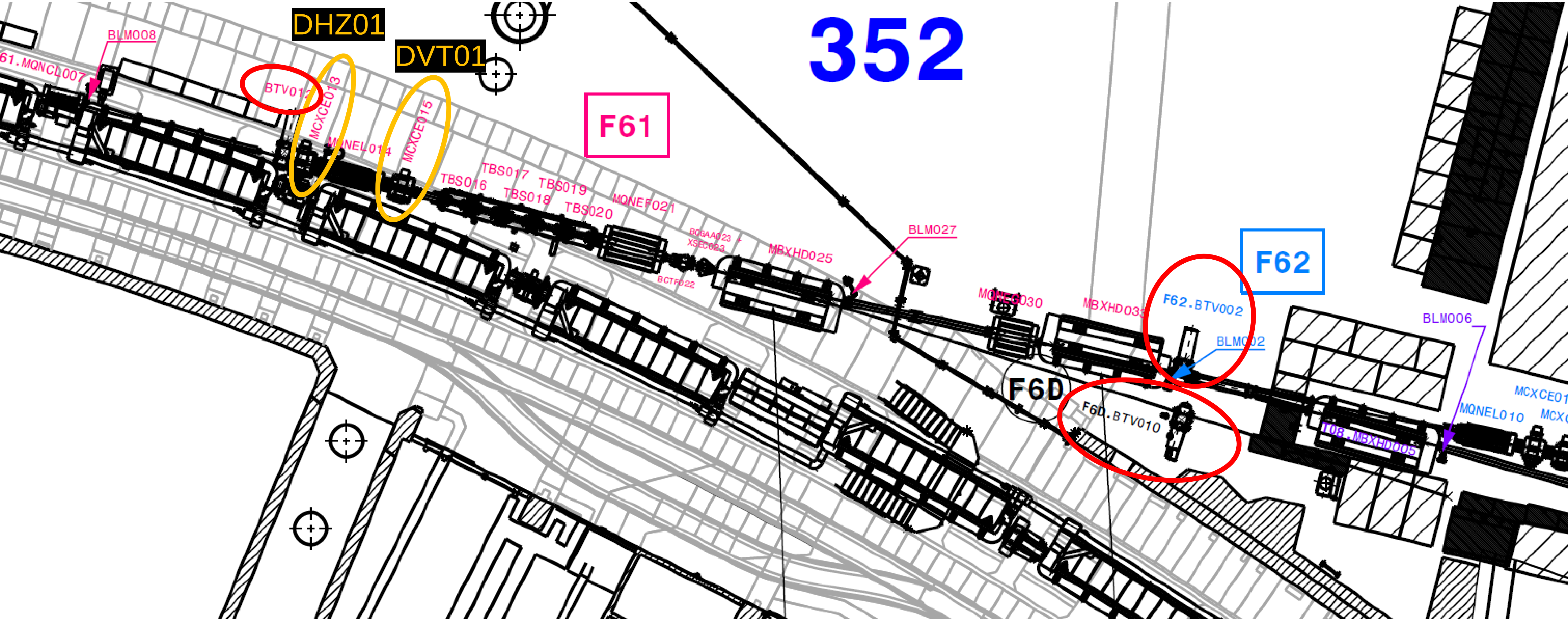


Source: New fluorescent screens, *MPS/CCI Note 74-7 1974*

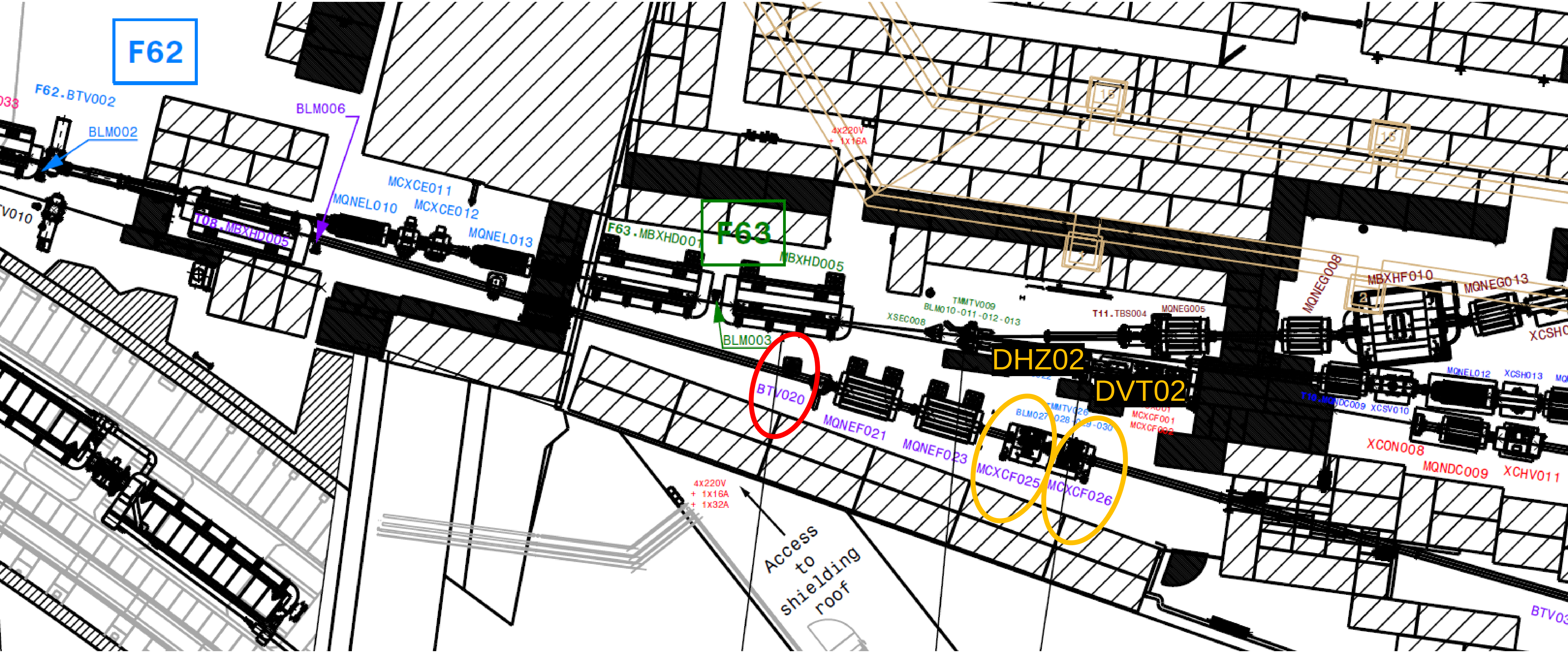



Geode points faisceaux
F61
T8
F61
PR
T08
T09
T10
T11
F62
F63
2200
2195
2190
2185
2180
2175
2170
2165
2160
2155
2000
2020
2040
2060
2080
2100
2120
2140
2160
y [m]

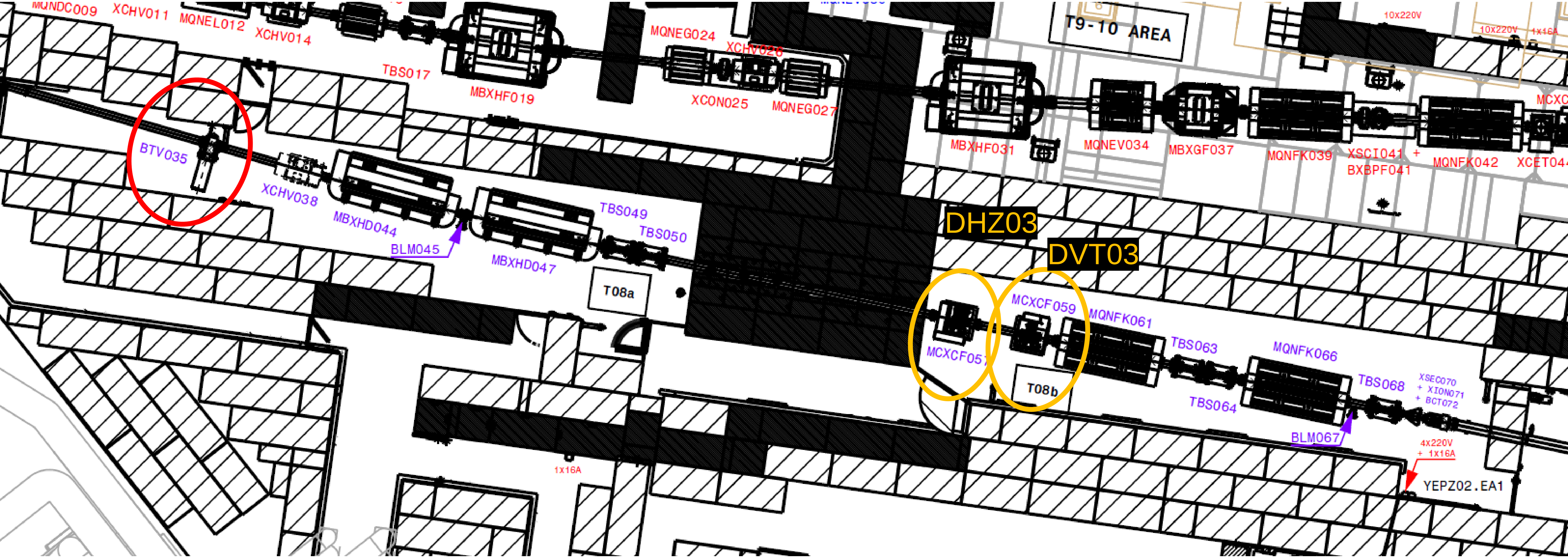
East area – F61 transfer line



East area – T8 transfer line



East area – T8 transfer line



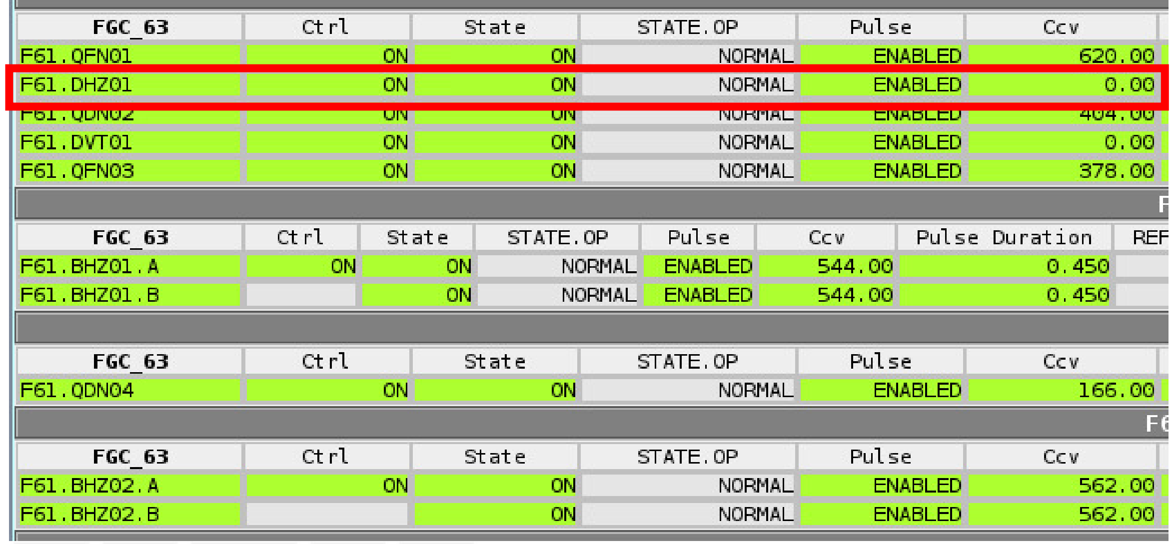
East area – T8 transfer line

Logged data – Dump 03-11 / T8 12-11

Correctors \ BTVs	PR.BTV57	F61.BTV012	F61D.BTV010	F62.BTV002	T08.BTV020	T08.BTV035	T08.BTV096
DHZ01			✓	✓	✓	✓	✓
DVT01			✓	✓	✓	✓	✓
DHZ02						✓	✓
DVT02						✓	✓
DHZ03							✓
DVT03							✓
SMH57		✓	✓	✓	✓	✓	✓
SMH61	✓	✓	✓				
KFA71	✓✓	✓✓	✓	✓	✓	✓	✓
Dispersion	✓✓	✓✓	✓✓	✓	✓	✓	✓

Methodology

- Save the initial settings for all magnets
- Increase/decrease current for a single corrector magnet by hand (no autoscan)
- Measure movement on BTV:
  - Save beam profile in x and y plane
  - Remove the background (remnant fluorescence) using the first acquisition
- Data dumped in JSON and pickles

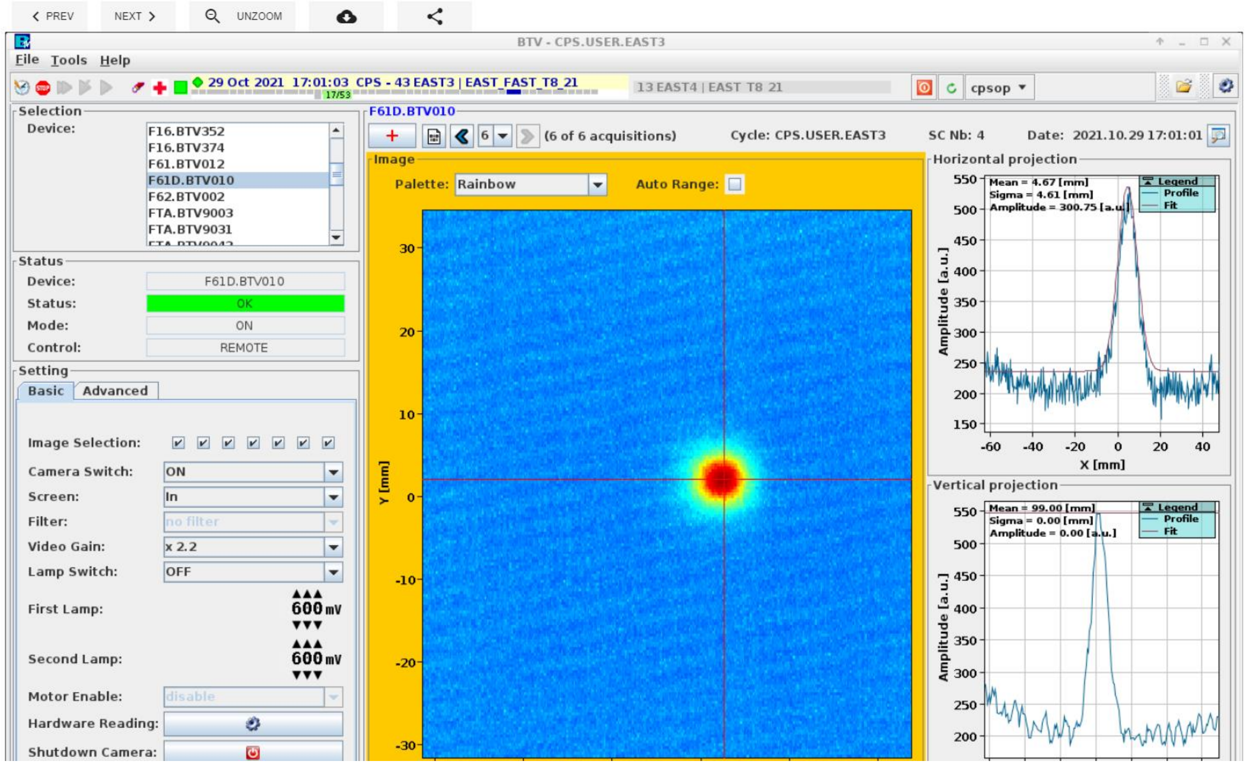


FGC_63	Ctrl	State	STATE.OP	Pulse	Ccv
F61.QFN01	ON	ON	NORMAL	ENABLED	620.00
F61.DHZ01	ON	ON	NORMAL	ENABLED	0.00
F61.QDN02	ON	ON	NORMAL	ENABLED	404.00
F61.DVT01	ON	ON	NORMAL	ENABLED	0.00
F61.QFN03	ON	ON	NORMAL	ENABLED	378.00

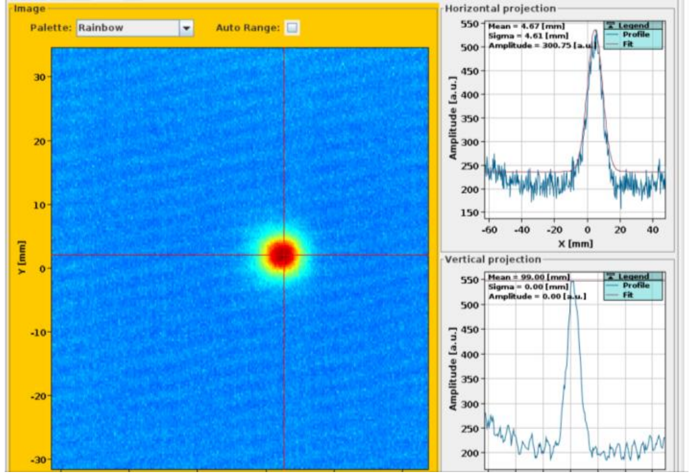
FGC_63	Ctrl	State	STATE.OP	Pulse	Ccv	Pulse Duration	REF
F61.BHZ01.A	ON	ON	NORMAL	ENABLED	544.00	0.450	
F61.BHZ01.B		ON	NORMAL	ENABLED	544.00	0.450	

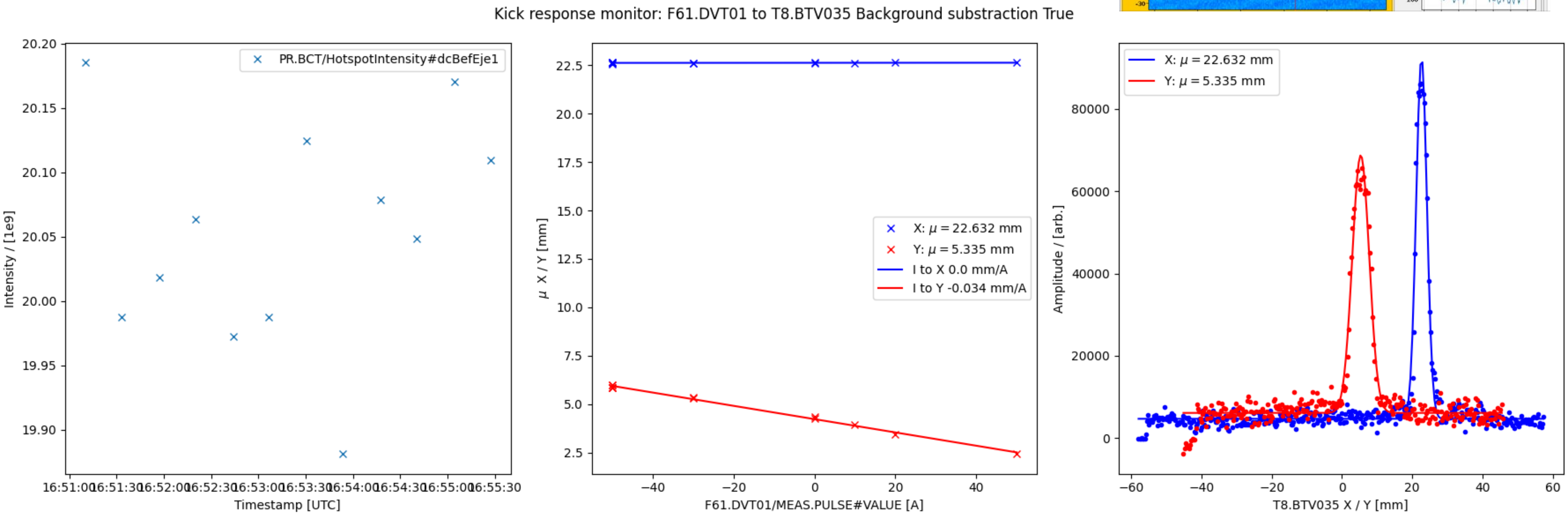
FGC_63	Ctrl	State	STATE.OP	Pulse	Ccv
F61.QDN04	ON	ON	NORMAL	ENABLED	166.00

FGC_63	Ctrl	State	STATE.OP	Pulse	Ccv
F61.BHZ02.A	ON	ON	NORMAL	ENABLED	562.00
F61.BHZ02.B		ON	NORMAL	ENABLED	562.00



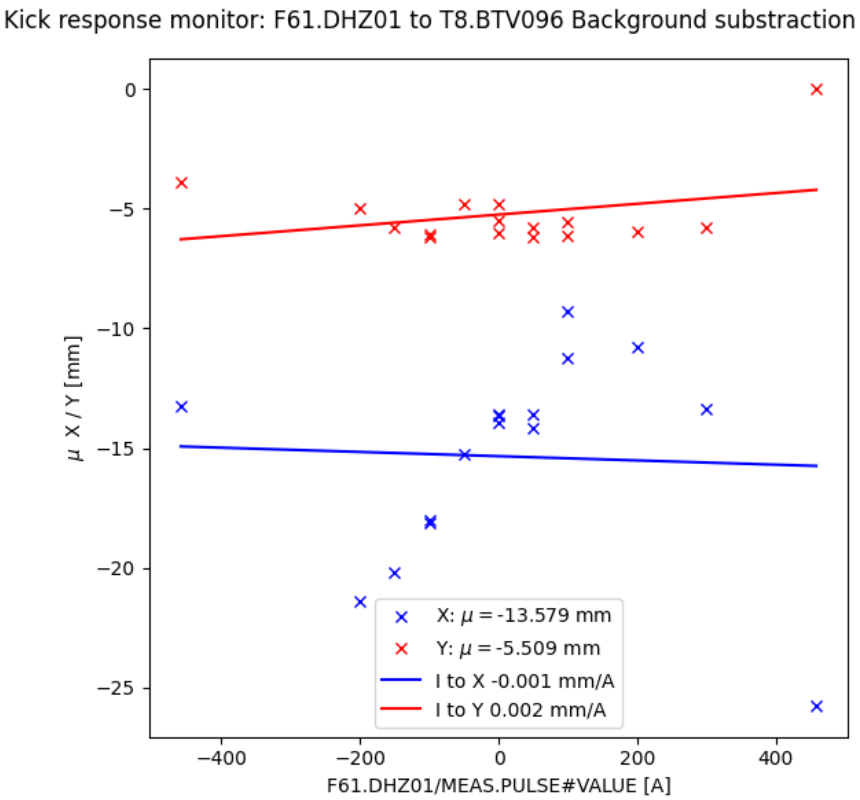
Data logging script

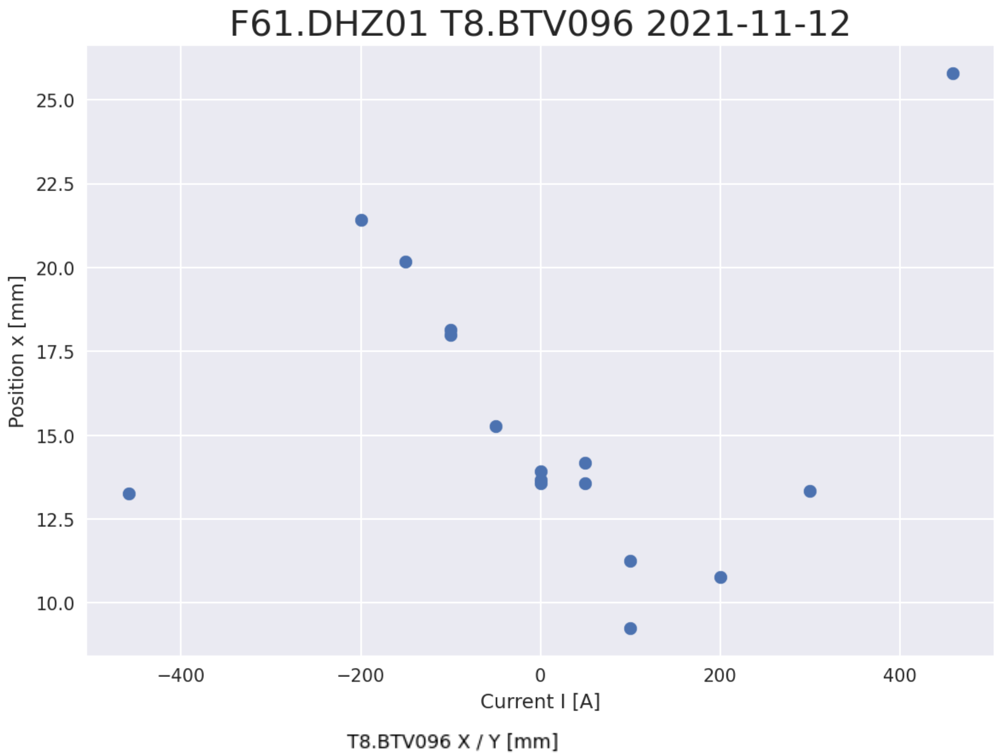




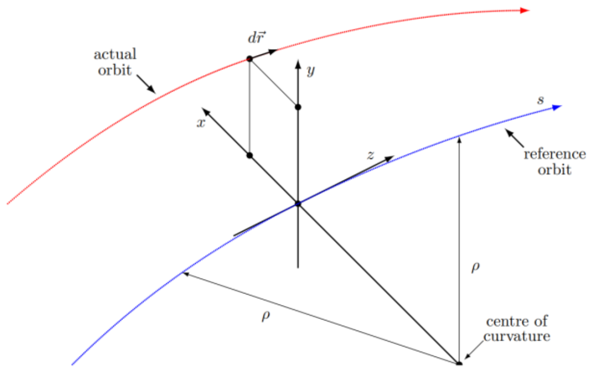
Outliers data points

- Blind choice of current
- Going in extreme currents we loose the beam ➔ bad data point





Need to inverse x position to match MADX convention (x positive left)



Linear fit

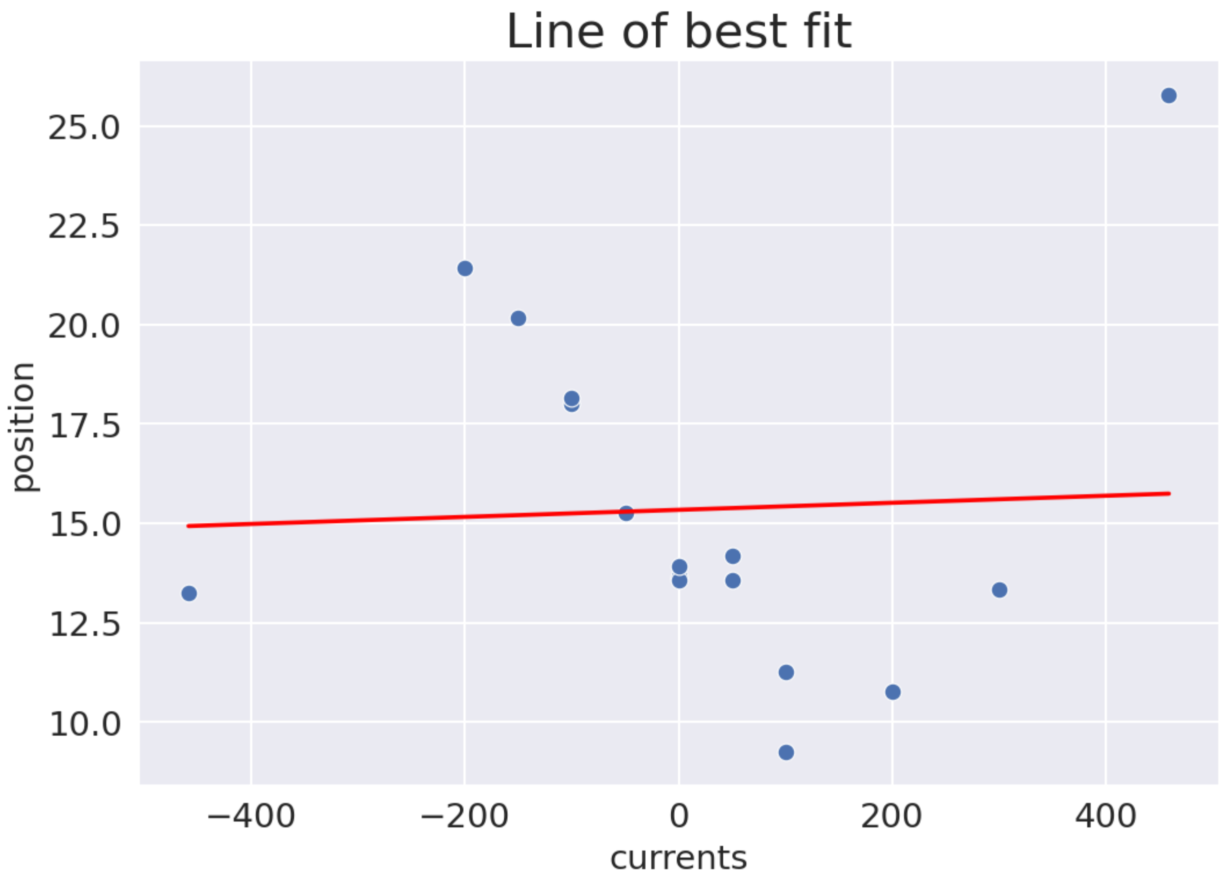
Impossible to make a good fit with these broken points

Need to do some cleaning:

- **Can’t make a single current range cut per corrector because it depends on the BTV distance**

General solution:

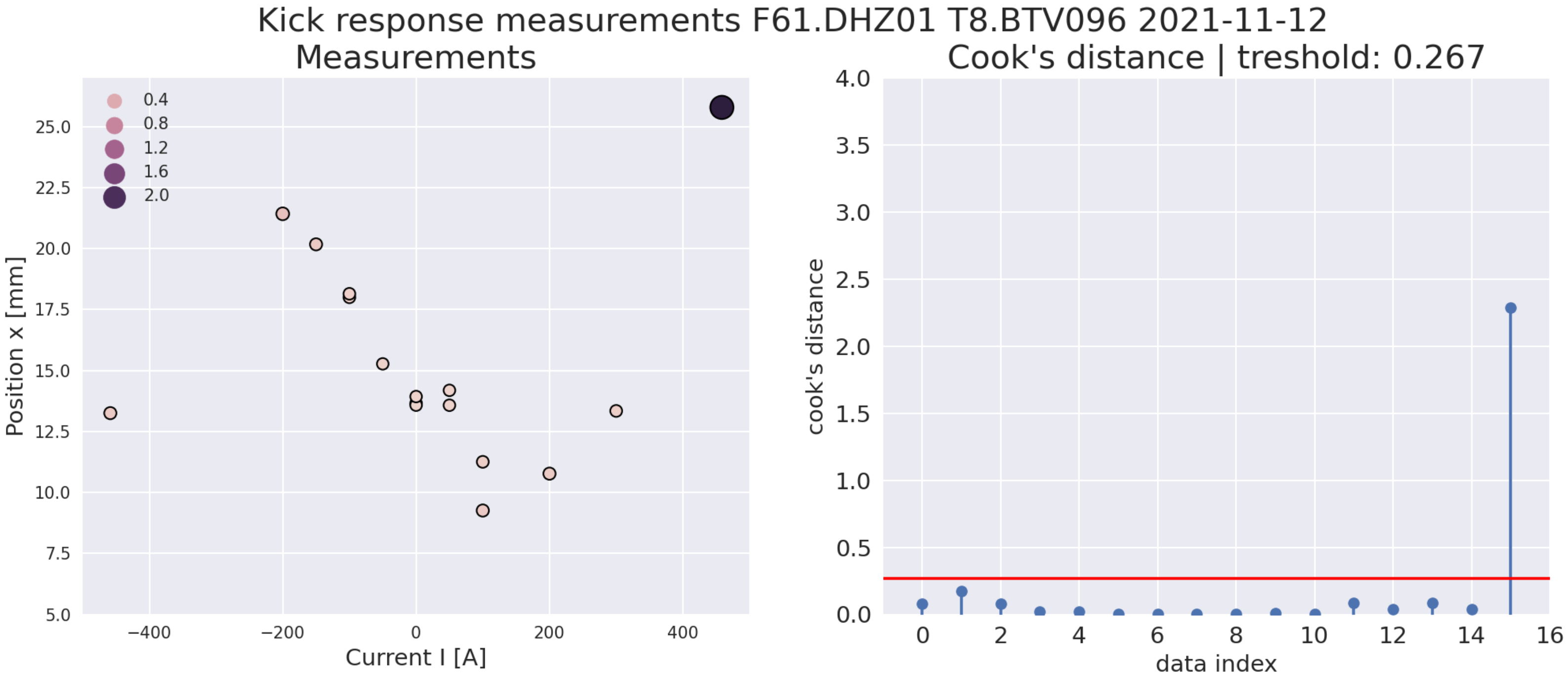
- **Assume the data is linearly correlated.**
- **Cook’s algorithm weighs the data as a functions of how much they impact the fit when performing a least-squares regression analysis**

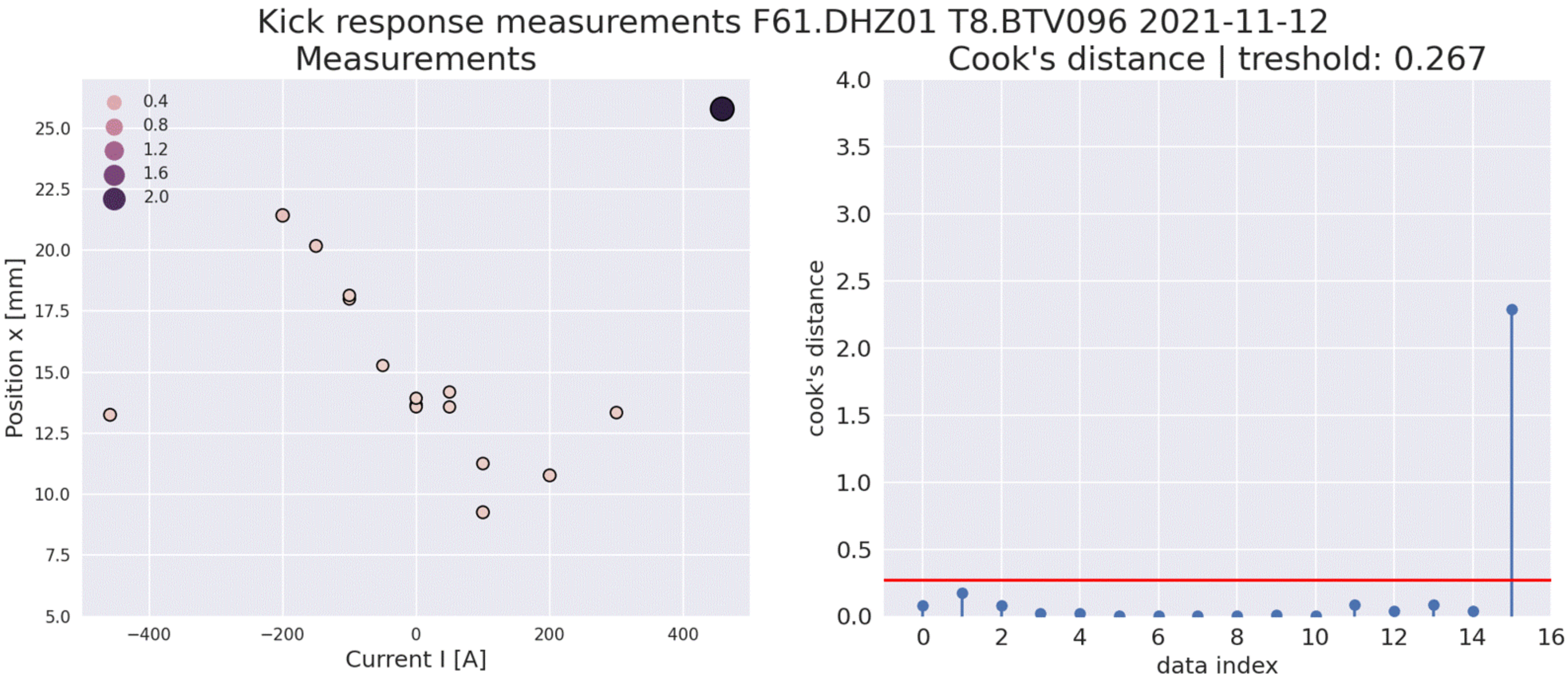


Cook’s algorithm

Remove influential data points (have a large distance):

- **Decide number of iterations**
- **Decide threshold:**
  - Theory suggests 1/N
  - I found 1/(N-1) better suited
- **General solution that can be used for future measurements (next year)**




Kick response measurements F61.DHZ01 T8.BTV096 2021-11-12
Measurements
0.4
0.8
1.2
1.6
2.0
Position x [mm]
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
−400
−200
0
200
400
Current I [A]
Cook's distance | treshold: 0.267
cook's distance
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
14
16
data index

F61 | T8 | IRRAD | CHARM

Corrector

DHZ01

DVT01

DHZ02

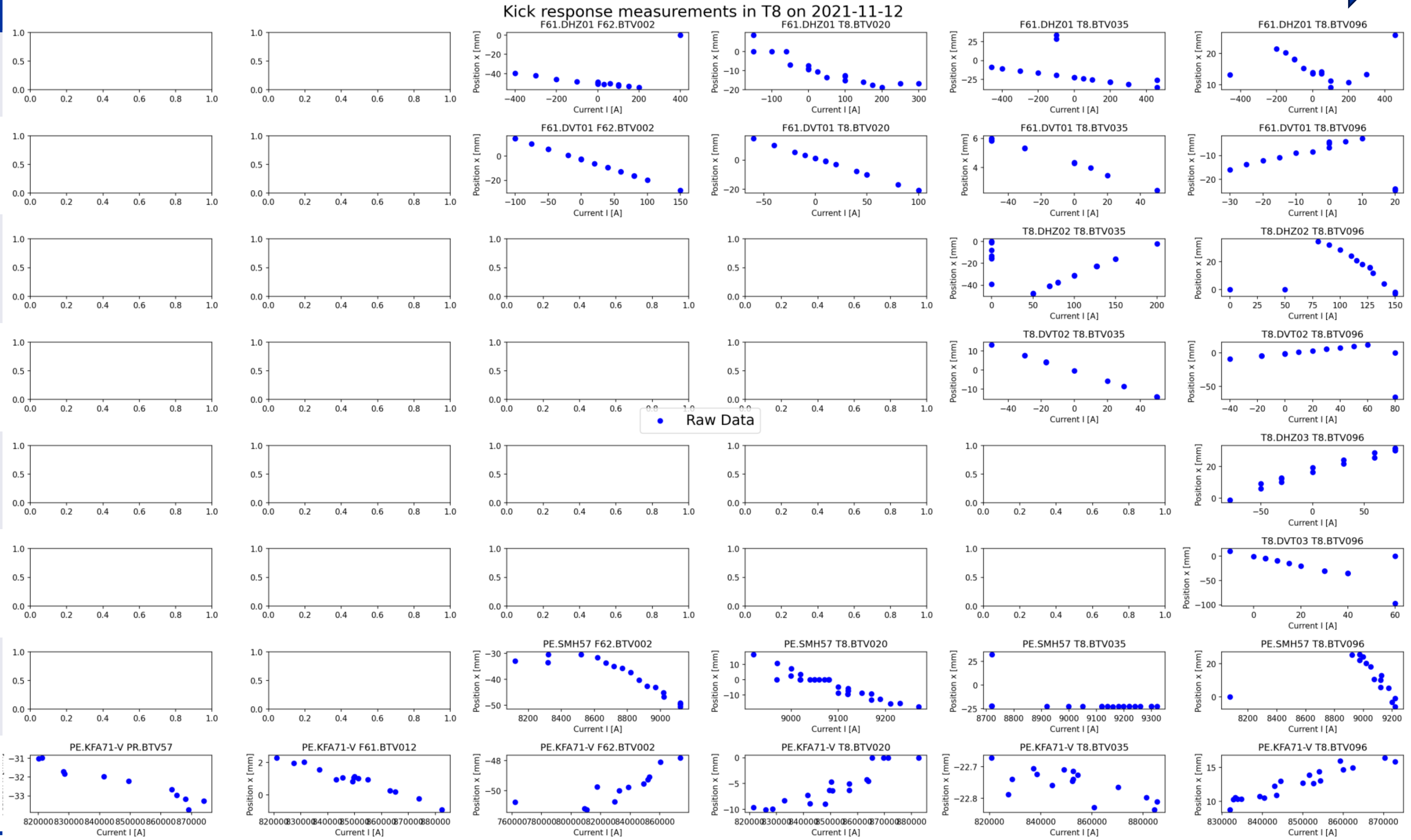
DVT02

DHZ03

DVT03

SMH57

KFA71



F61 | T8 | IRRAD | CHARM

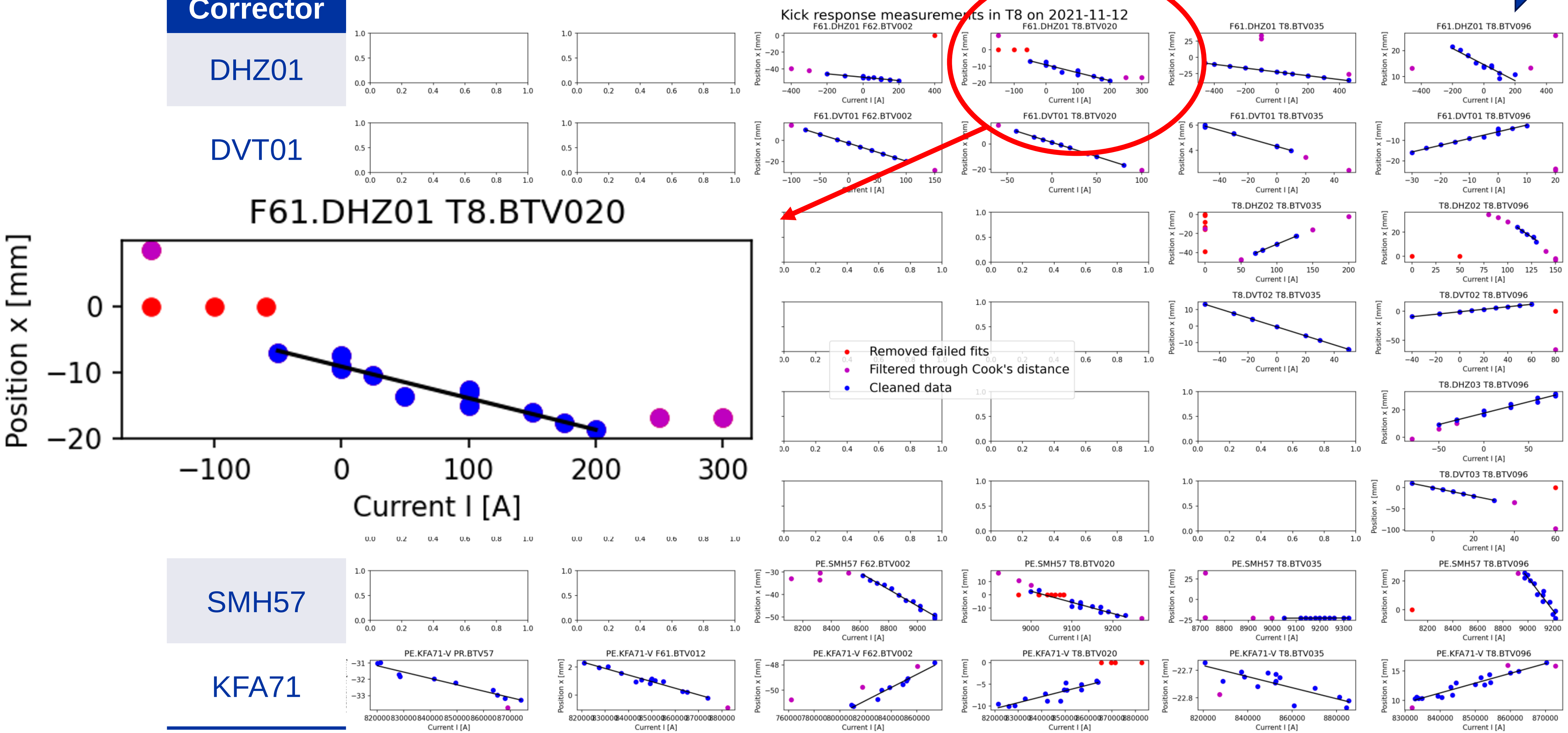
Corrector

DHZ01

DVT01

SMH57

KFA71



MAD-X simulation

- **Compare measurements with MAD-X simulation.** Used to design, simulate and optimise particle accelerators

- **Change the Hkicker and Vkicker KICK**

```
/******************************* Quadrupoles **
kQFN1 = 0.5227822960499999;
kQDN2 = -0.1898669999999998;
kQFN3 = 0.1936693364999998;
kQDN4 = -0.08743875;
kQFN5 = 0.1971543952499998;
kQDN6 = -0.1971543952499998;
kQDN7 = -0.0932526774;
kQFN8 = 0.101960327775;
/******************************* Sextupoles ***
/******************************* Kickers ******
/******************************* HKickers *****
kDHZ1 = 0;
kDHZ2 = 0;
kDHZ3 = 0;
/******************************* VKickers *****
kDVT1 = 0;
kDVT2 = 0;
kDVT3 = 0;
```

```
//---------------------------- Beamline Sequence -----------

f61t8_op: SEQUENCE, refer = exit, l = 144.53536726075137;
F61.START : F61.START, AT=0;
Q74 : Q74, AT=0.87287-0.74;
F61.MQNCL007 : QFN1, AT=0.87287;
ARBMATRIX : ARBMATRIX, AT=5.79992;
F61.BTV012 : F61.BTV012, AT=6.10592;
F61.MCXCE013 : DHZ1, AT=6.505920000000001;
F61.MQNEL014 : QDN2, AT=8.240920000000001;
F61.MCXCE015 : DVT1, AT=8.97592;
F61.TBS016 : F61.TBS016, AT=10.50822;
F61.TBS017 : F61.TBS017, AT=11.275319999999999;
F61.TBS018 : F61.TBS018, AT=12.042419999999998;
F61.TBS019 : F61.TBS019, AT=12.809519999999997;
F61.TBS020 : F61.TBS020, AT=13.576619999999997;
F61.MQNEF021 : QFN3, AT=15.189919999999995;
F61.BCTF022 : F61.BCTF022, AT=15.992919999999994;
F61.BCGAA023 : F61.BCGAA023, AT=16.264919999999993;
F61.XSEC023 : F61.XSEC023, AT=16.544919999999999;
F61.MBXHD025 : BHZ1, AT=19.46512266938191;
F61.MQNEG030 : QDN4, AT=24.35481266938191;
F61.MBXHD033 : BHZ2, AT=27.45503661148076;
T08.MBXHD005 : BHZ3, AT=34.106089811731664;
T08.BTV020 : T08.BTV020, AT=47.19608981173166;
```

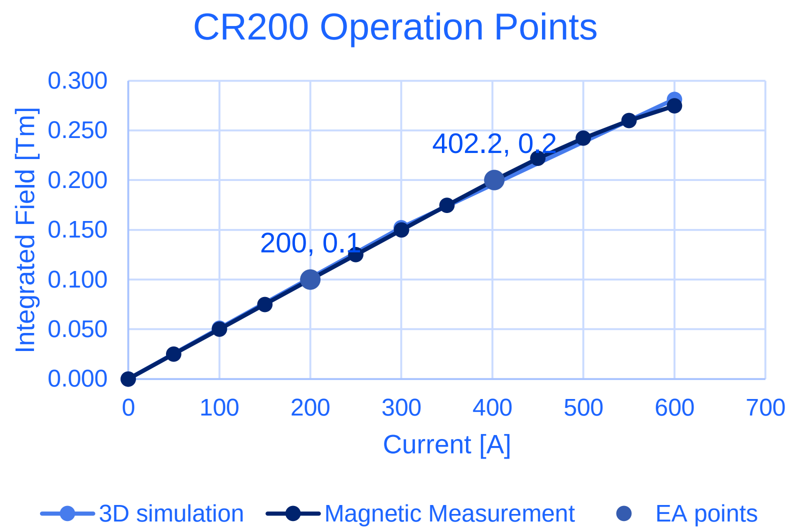
Source: *N. Charitonidis and J. Bernhard*

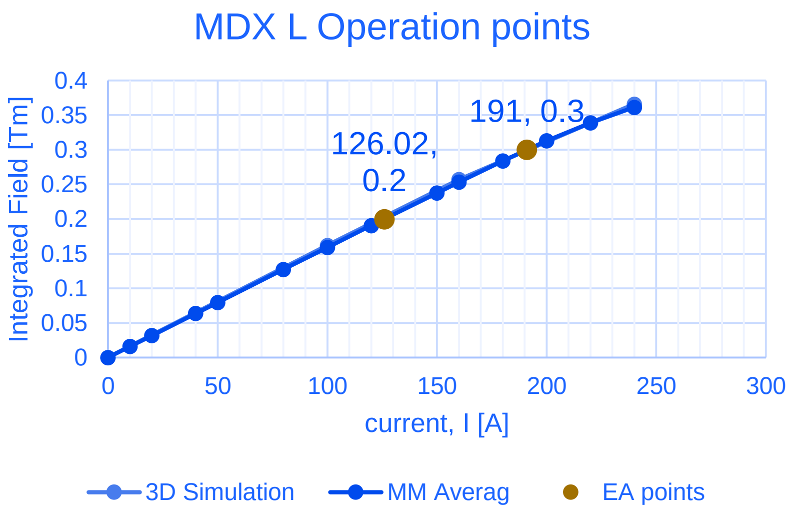
MAD-X simulation

Convert the currents used in the CCC with a transfer function for each type of corrector

$$KICK = \frac{I_{corrector} \cdot TF}{B \cdot \rho}$$

Corrector	Transfer function (TF) Tm/A	Type
F61.DHZ01	0.1/200	CR200
F61.DVT01	0.1/200	CR200
T8.DHZ02	0.2/126.02	MDXL
T8.DVT02	0.2/126.02	MDXL
T8.DHZ03	0.2/126.02	MDXL
T8.DVT03	0.2/126.02	MDXL



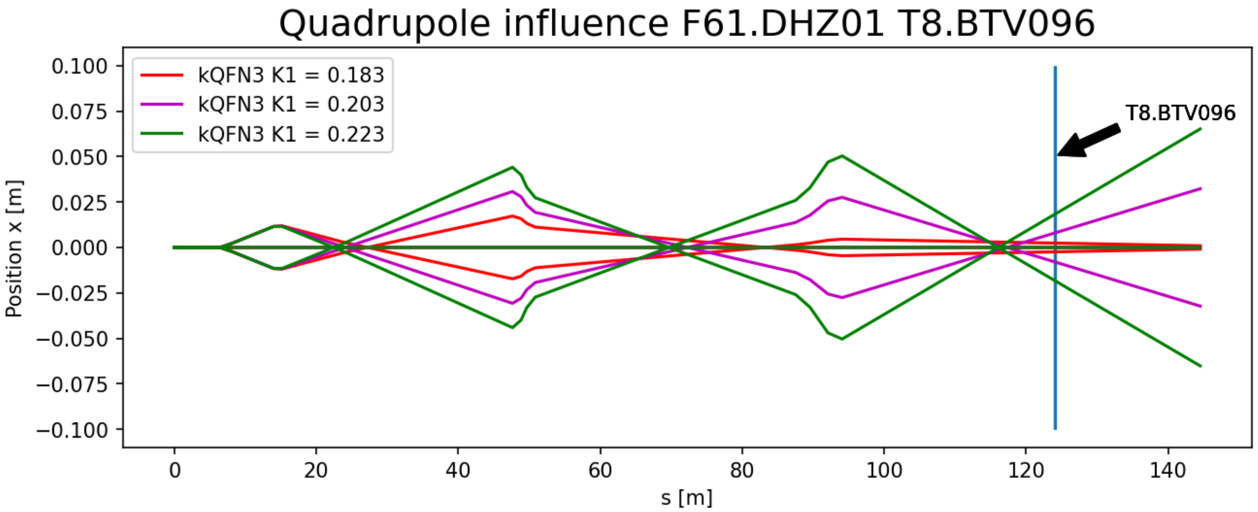


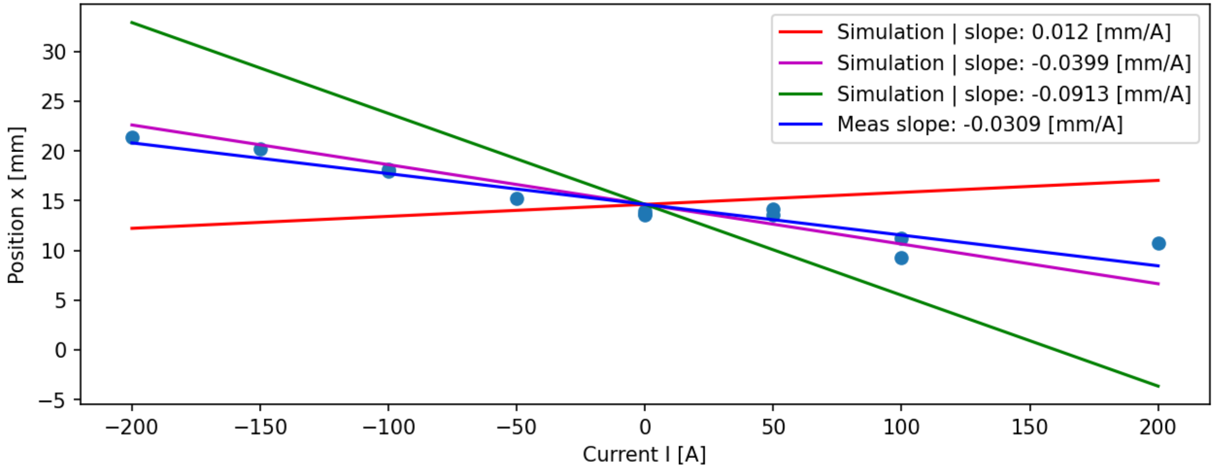
MAD-X simulation

Convert the currents used in the CCC with a transfer function for each type of quadrupole

$$K1 = \frac{I_{quad} \cdot TF}{L_{quad} \cdot B \cdot \rho}$$

Quadrupole	Current A CCC	Transfer function (TF) T/A	Length m	Type
QFN01	620	9.4/200	0.74	Q74 L
QDN02	404	8.26/200	1.2	Q120 C
QFN03	378	12.875/250	1.2	QFL
QDN04	166	6.875/197.23	0.8	QFS
QFN05	370	12.875/250	1.2	QFL
QDN06	370	12.875/250	1.2	QFL
QDN07	310	7.39/200	2	Q200L
QFN08	240	7.39/200	2	Q200L





Results Dump

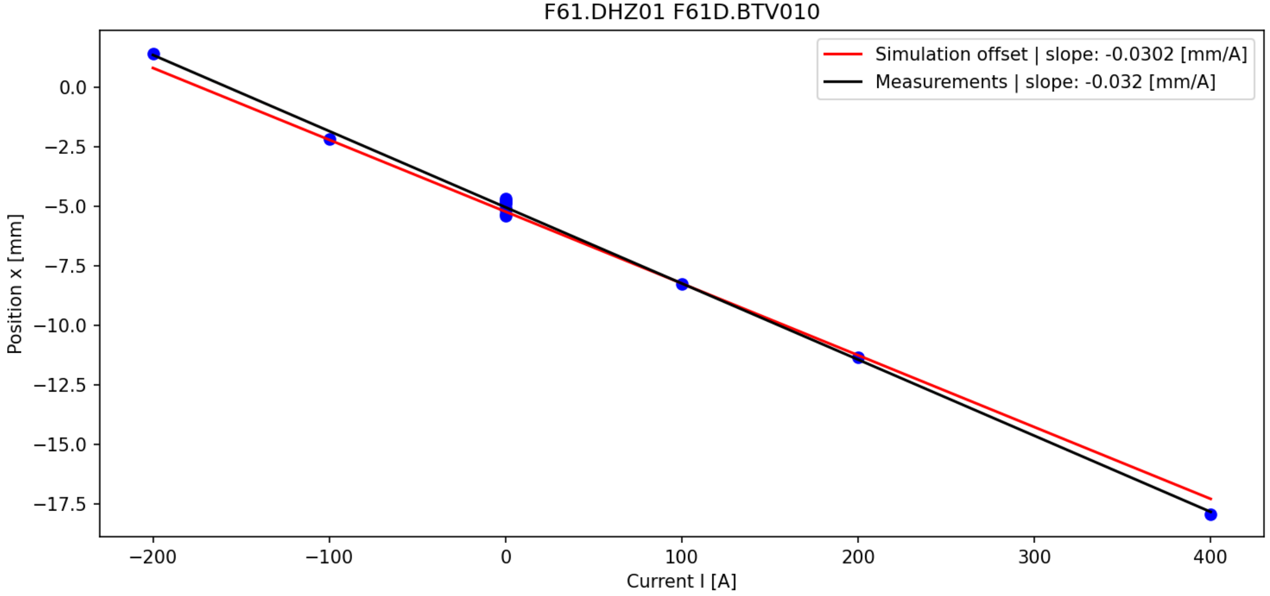
Relative difference between simulation and measurements:

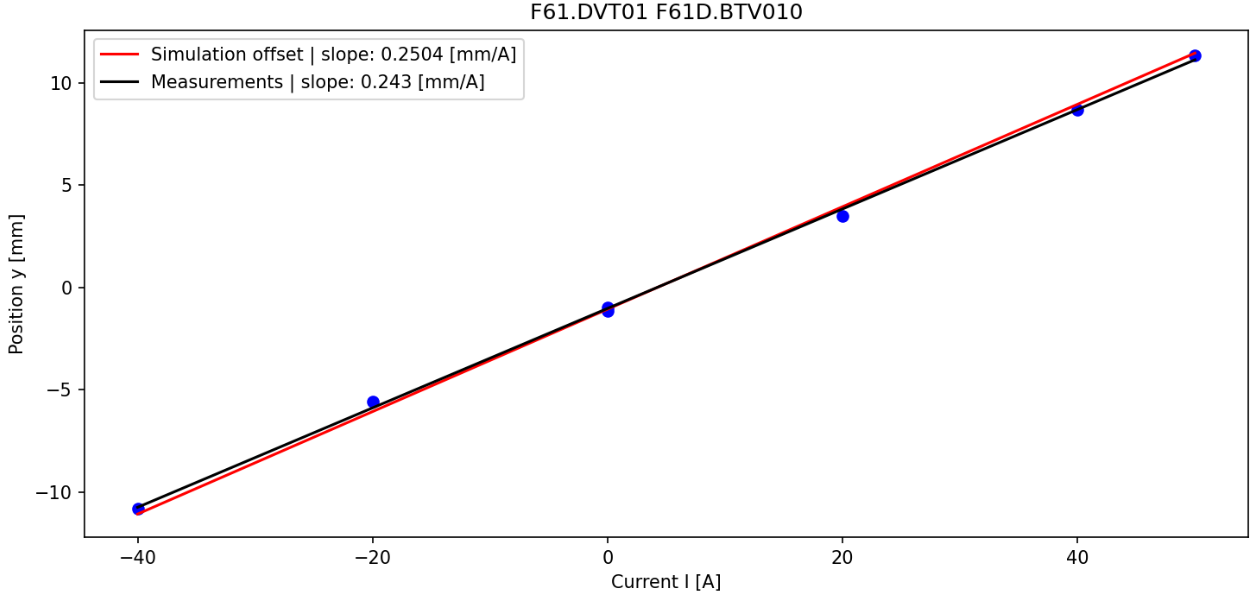
- DHZ01 F61D.BTV010: 5.63 %
- DVT01 F61D.BTV010: 3.05 %

- ➔ **Good agreement with simulation**

BTVs / Correctors	PR.BTV57	F61.BTV012	F61D.BTV010	F62.BTV002	T08.BTV020	T08.BTV035	T08.BTV096
DHZ01			✓	✓	✓	✓	✓
DVT01			✓	✓	✓	✓	✓
DHZ02						✓	✓
DVT02						✓	✓
DHZ03							✓
DVT03							✓
SMH57		✓	✓	✓	✓	✓	✓
SMH61	✓	✓	✓				
KFA71	✓✓	✓✓	✓	✓	✓	✓	✓
Dispersion	✓✓	✓✓	✓✓	✓	✓	✓	✓

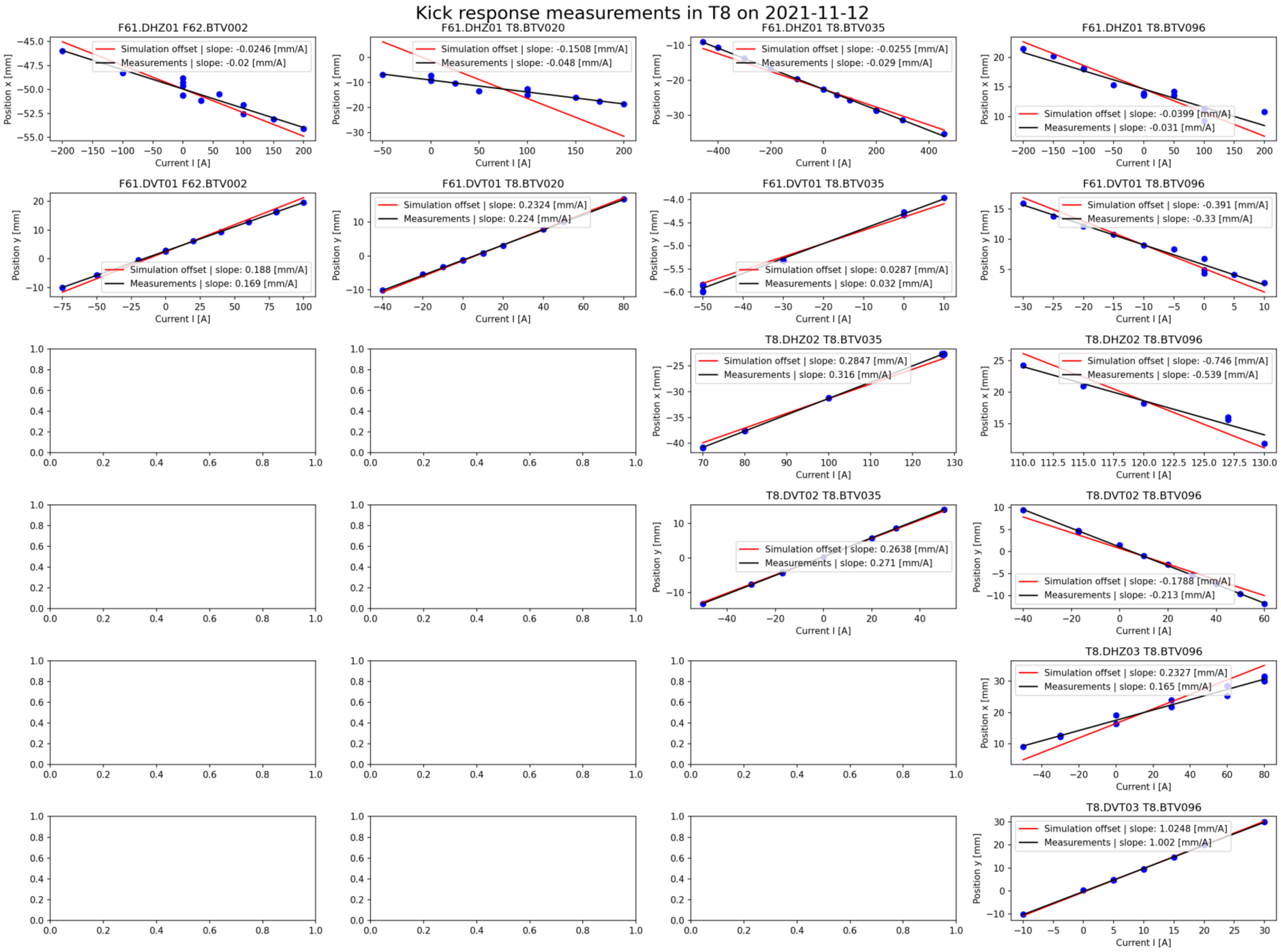
Kick response measurements in Dump on 2021-11-03



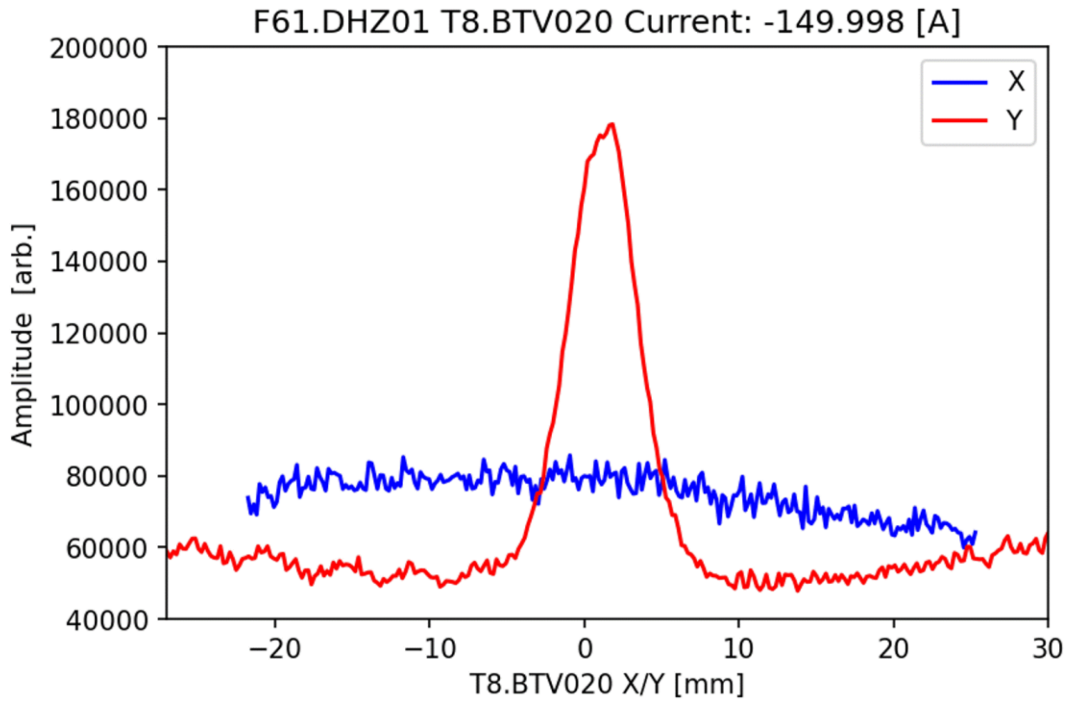


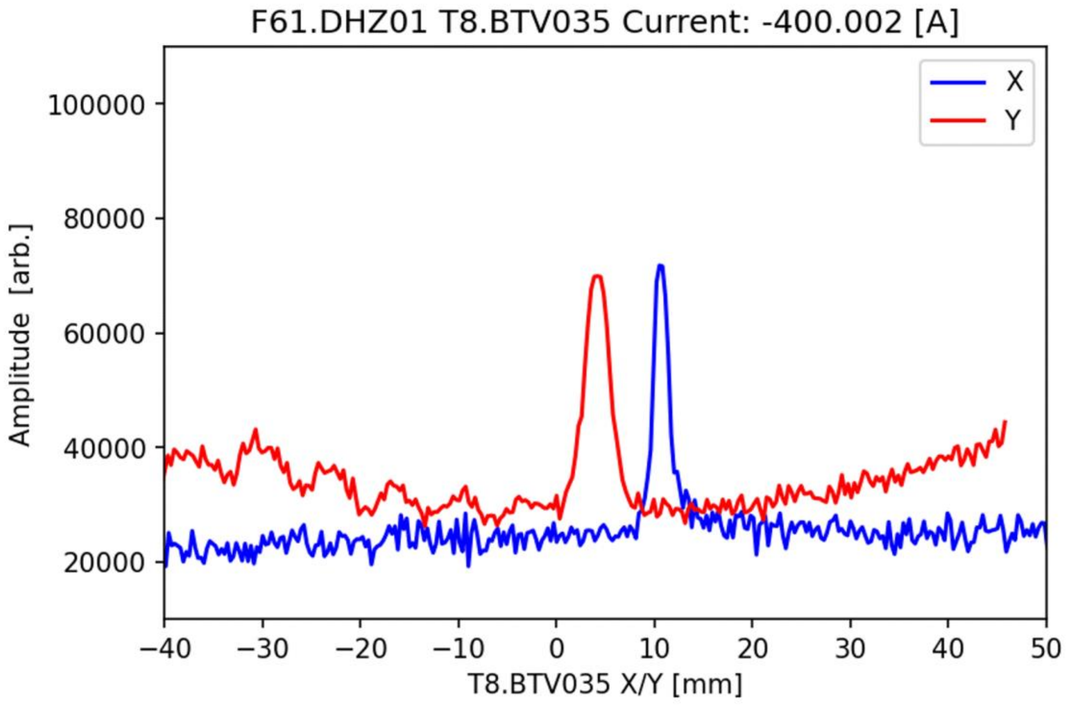
Results T8

- **Possible to predict beam deflection with a certain current**
- **Except one with DHZ01**
- **Note: positions are not absolute**



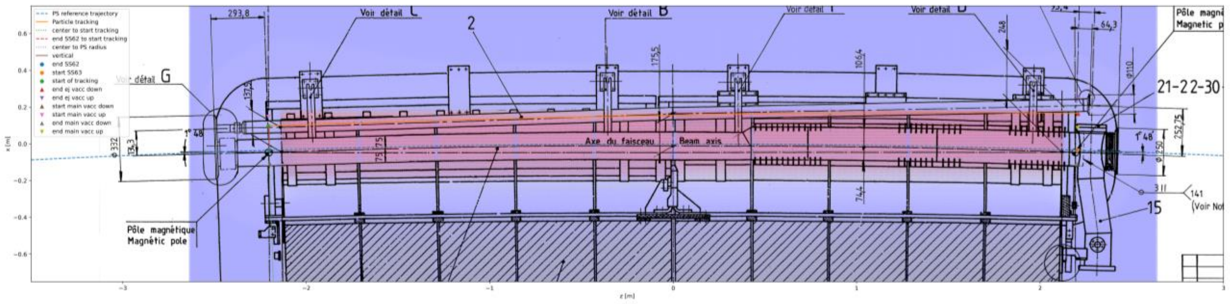
Diagnostics





Looking forward

- **Use MAD-X model to fit the data better**
  - Change parameters in the line with an optimiser
- **Stitched line from PS ring to T8**
  - Compare with KFA71, SMH57 and SMH61
- **Investigating options with OP to include IRRAD BPM and East Area BTV's in YASP via UCAP devices**
- **Use the septum measurements to help build the stray field model through MU62**



Questions ?

Reference:

- **Measurements:** **https://gitlab.cern.ch/mfraser/f6x-t8-optics/-/tree/clean_data**
- **Analysis:** **https://gitlab.cern.ch/eljohnso/acc-models-tls-eliott-fork/-/blob/EliottBranch/ps_extraction/east-fast-extraction/kick_response_t8_analysis.ipynb**
- **PS Logbook entries**
  - Initial test: https://be-op-logbook.web.cern.ch/elogbook-server/GET/showEventInLogbook/3398951
  - Dump: https://logbook.cern.ch/elogbook-server/GET/showEventInLogbook/3414119
  - T8: https://logbook.cern.ch/elogbook-server/GET/showEventInLogbook/3417681

JSON format – Current Data

- **Save currents with a timestamp for every magnet (not only the one we are changing)**


```
{
  "__type__":"datetime",
  "data":"2021-11-12T21:15:46.300000+00:00"
},
{
  "__type__":"datetime",
  "data":"2021-11-12T21:16:00.700000+00:00"
},
{
  "__type__":"datetime",
  "data":"2021-11-12T21:16:15.100000+00:00"
},
{
  "__type__":"datetime",
  "data":"2021-11-12T21:16:29.500000+00:00"
},
{
  "__type__":"datetime",
  "data":"2021-11-12T21:16:43.900000+00:00"
```

```
[
  {
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      549.9929809570312,
      549.9912109375,
      549.9859008789062,
      549.9864501953125,
      549.9898681640625,
      549.989013671875,
      549.9918823242188,
      549.98583984375,
      549.99072265625,
      549.984130859375,
      549.9842529296875,
      549.9876098632812,
      549.986083984375,
      549.993896484375,
      549.99365234375
    ],
    "F61.DHZ01/MEAS.PULSE#VALUE":[15],
    "F61.QDN02/MEAS.PULSE#VALUE":[15],
    "F61.DVT01/MEAS.PULSE#VALUE":[15],
    "F61.QFN03/MEAS.PULSE#VALUE":[15],
    "F61.BHZ01.A/MEAS.PULSE#VALUE":[15],
    "F61.BHZ01.B/MEAS.PULSE#VALUE":[15],
    "T8.DHZ02/MEAS.PULSE#VALUE":[15],
    "T8.DVT02/MEAS.PULSE#VALUE":[15],
    "T8.DHZ03/MEAS.PULSE#VALUE":[15],
    "T8.DVT03/MEAS.PULSE#VALUE":[15],
    "F61.QDN04/MEAS.PULSE#VALUE":[15],
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    "T8.QDN06/MEAS.PULSE#VALUE":[15],
    "T8.QDN07/MEAS.PULSE#VALUE":[15],
    "T8.QFN08/MEAS.PULSE#VALUE":[15],
    "PE.SMH57/MEAS.PULSE#VALUE":[15],
    "PE.SMH61/MEAS.PULSE#VALUE":[15],
    "PE.KFA71-V/Acquisition#kickStrengthAqn":[15]
```
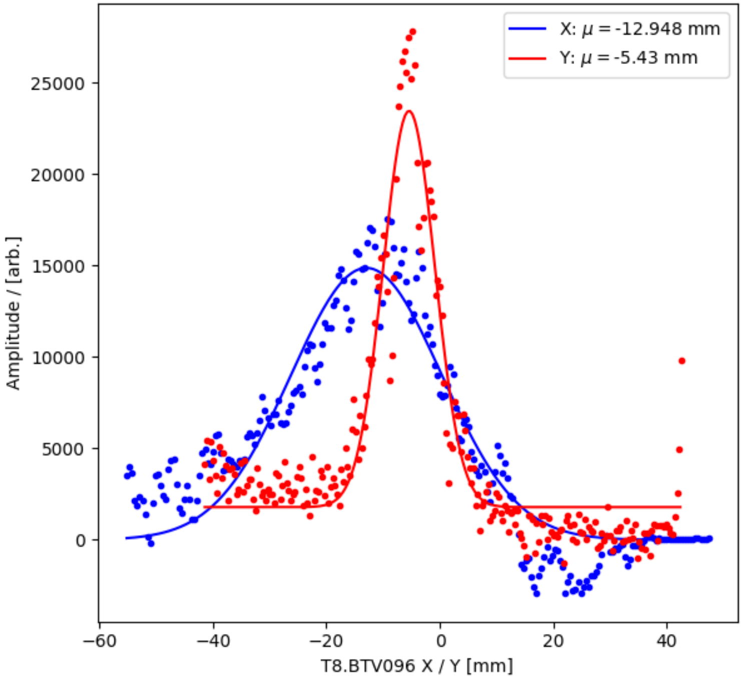

JSON format - BTV data



PositionSet1 = Xx
PositionSet2 = Yx
projDataSet1 = Xy
projDataSet2 = Yy

{
  "T8.BTV096": [
    {
      "/Acquisition#projPositionSet1":
        "__type__":"np.ndarray",
        "data": [
          [
            -55.2,
            -54.74,
            -54.28,
            -53.82,
            -53.36,
            -52.900000000000006,
            -52.440000000000005,
            -51.980000000000004,
            -51.52,
            -51.06,
            -50.6,
            -50.14,
            -49.68,
            -49.22,
            -48.760000000000005,
            -48.300000000000004,

7 acquisitions

{
  "T8.BTV096": [
    {
      "/Acquisition#projPosit
        "__type__":"np.ndarr
        "data": [
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          [224],
          [224],
          [224],
          [224],
          [224],
          [224]
        ]
      },
      "/Acquisition#projPosit
        "__type__":"np.ndarr
        "data": [
          [228],
          [228],
          [228],
          [228],
          [228],
          [228],
          [228]

Live gaussian fit

"/Acquisition#projPositionSet1": {
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  "data": [7]
},
"/Acquisition#projPositionSet2": {
  "__type__":"np.ndarray",
  "data": [7]
},
"/Acquisition#projDataSet1": {
  "__type__":"np.ndarray",
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