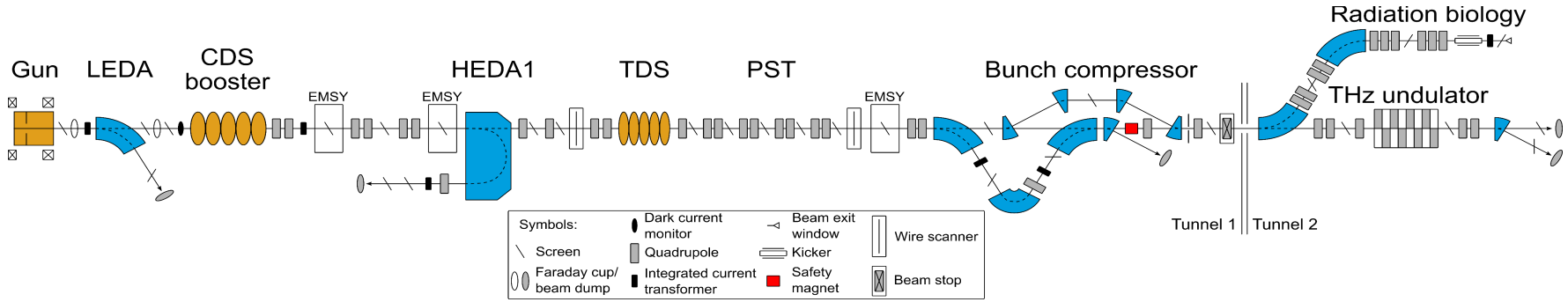
Current Status of the Magnetic Bunch Compressor at PITZ

PITZ Physics Seminar (PPS)



Ekkachai Kongmon

PITZ , 5 January 2023

HELMHOLTZ

Outline of the presentation

Introduction
- Bunch compressor
- PITZ accelerator

PITZ Bunch compressor (BC)
- Designed trajectory
- Rectangular magnetic field

Beam trajectory simulation for BC commissioning
- Set up simulation and methods
- Current of magnetic chicane optimization

Beam transportation through BC

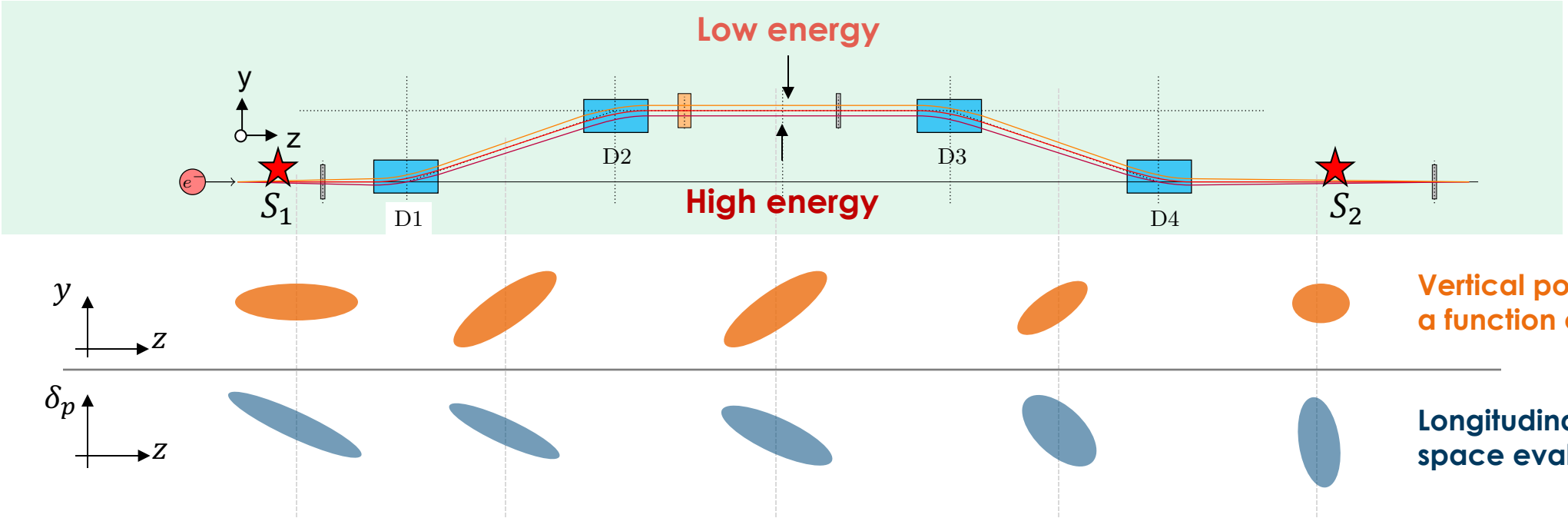
Summary and discussion

Future work

Next BC commissioning

Bunch Compressor

Bunch compression in magnetic chicane



Vertical position as a function of z

Longitudinal phase space evaluation

$$\vec{\chi}(S_2) = R \times \vec{\chi}(S_1)$$

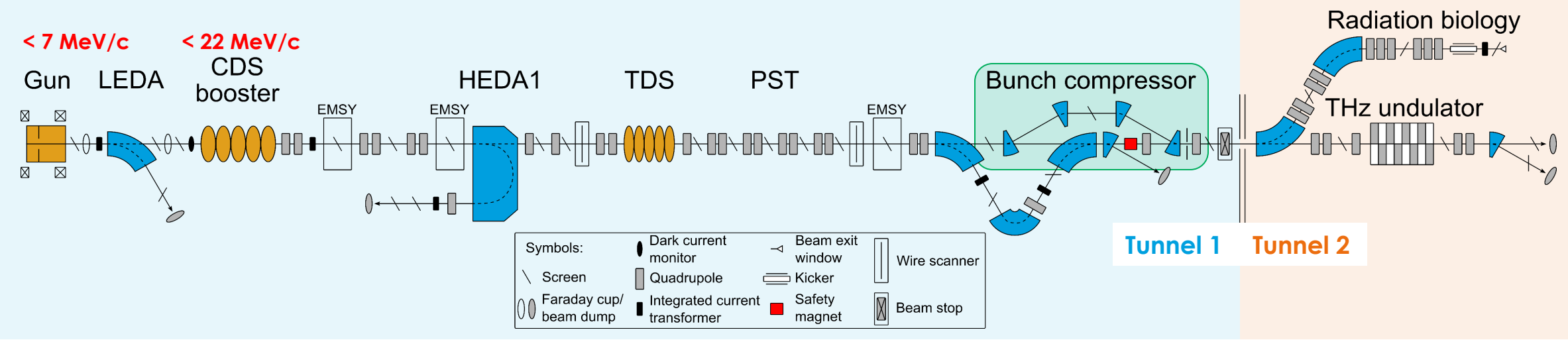
$$\begin{pmatrix} x_f \\ x'_f \\ y_f \\ y'_f \\ z_f \\ \delta_{p,f} \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} & 0 & 0 & 0 & R_{16} \\ R_{21} & R_{22} & 0 & 0 & 0 & R_{26} \\ 0 & 0 & R_{33} & R_{34} & 0 & 0 \\ 0 & 0 & R_{43} & R_{44} & 0 & 0 \\ R_{51} & R_{52} & 0 & 0 & 1 & R_{56} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_i \\ x'_i \\ y_i \\ y'_i \\ z_i \\ \delta_{p,i} \end{pmatrix}$$

$$z_f = \cancel{R_{51} x_i + R_{52} x'_i} + z_i + R_{56} \delta_p$$

$$\boxed{z_f(S_2) = z_i(S_1) + \boldsymbol{R_{56}} \delta_p}$$

PITZ Accelerator

PITZ Bunch compressor



~34 m

Production and optimization of the high brighness THz radiation, called free-electron laser (FEL)

- SASE
- Seeded
- Super-radiant

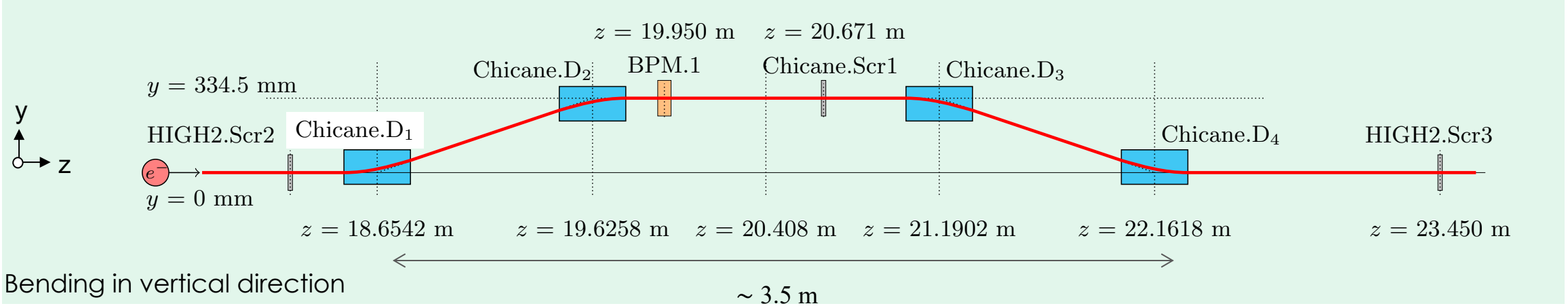
FLASH beamline for biology application

- Irradiation cancer cell

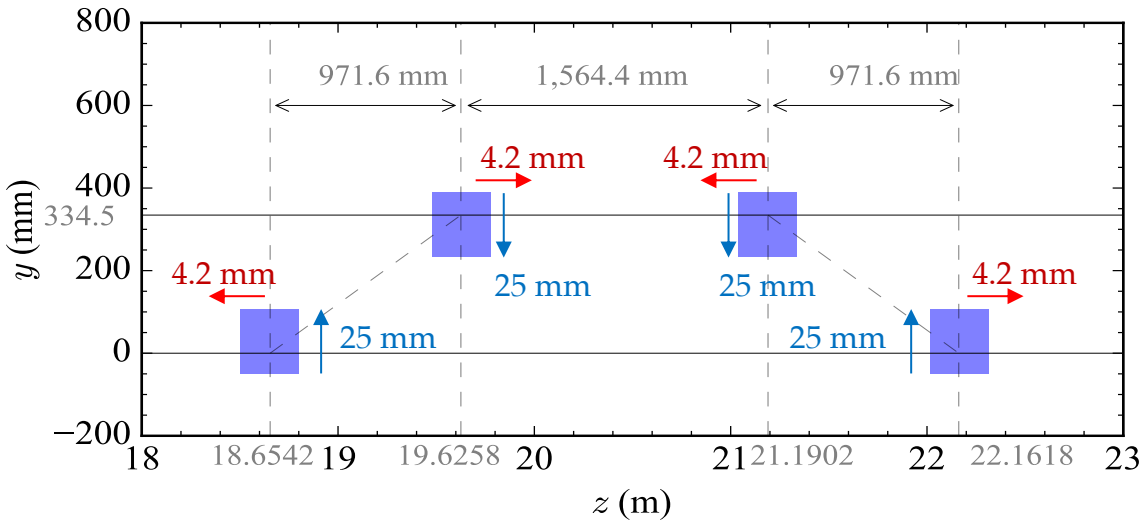
To enhance the performance of FEL, the buch compressor was recenly installed at PITZ accelerator in the vertical direction bending.

PITZ Bunch Compressor

Electron trajectory designed



Bending in vertical direction



Parameters	Value
Beding angle	19 degrees
Bending radius	904.67 mm
Distance D1→ D2 (L_{12})	680 mm
Pole length (L_B)	300 mm

$$R_{56} \approx -2\theta_0^2\{(L_{12} + \frac{2}{3}L_B)\} \quad R_{56} \approx 0.198\,m$$

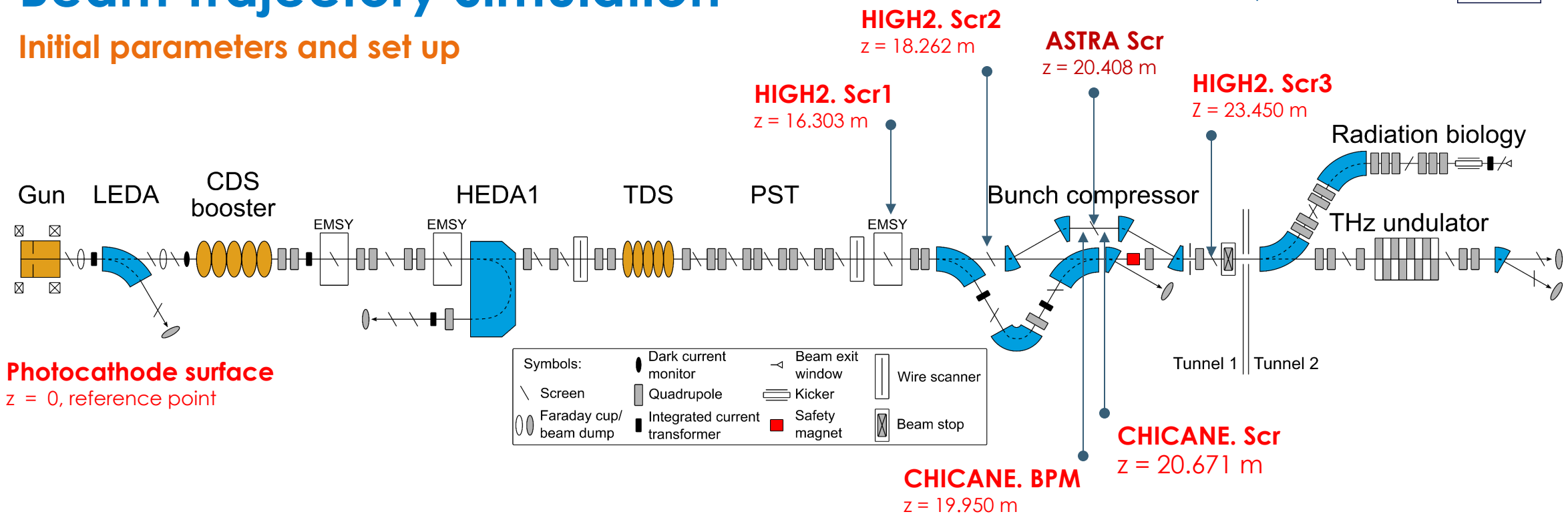
Bunch compressor commissioning

Simulation of Electron Beam Trajectory along the Bunch Compressor (Chicane)

To find the optimum currents of magnetic chicane for electron beam transportation in experiment.

Beam Trajectory Simulation

Initial parameters and set up



Beam momentum	16, **17**, 18 MeV/c
Dipole field	3D field from CST
Dipole current	Positive for D1 and D4 Negative for D2 and D3

Start position	HIGH2. Scr1
End position	HIGH2. Scr3
Space charge	No
CSR	No

Goal parameters

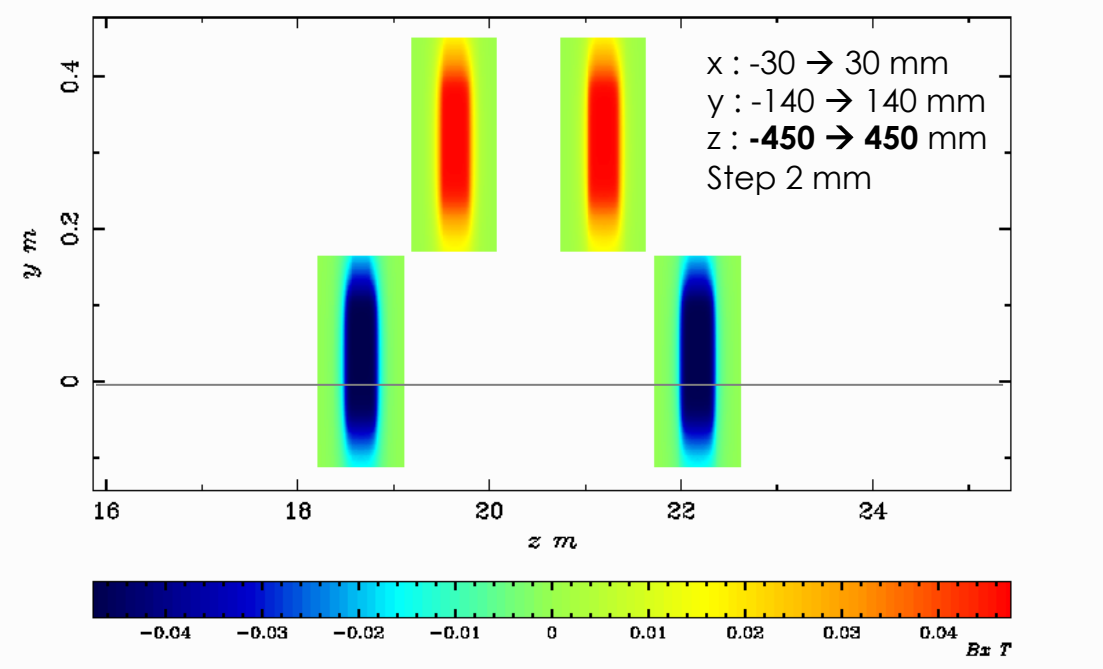
"Optimization of dipole currents for electron trajectory:"

On-axis $(\Delta y = 0)$	**ASTRA Scr,**
Zero vertical angle $(y' = 0)$	**HIGH2.Scr3**

Beam Trajectory Simulation

Field map from ASTRA and optimization methods

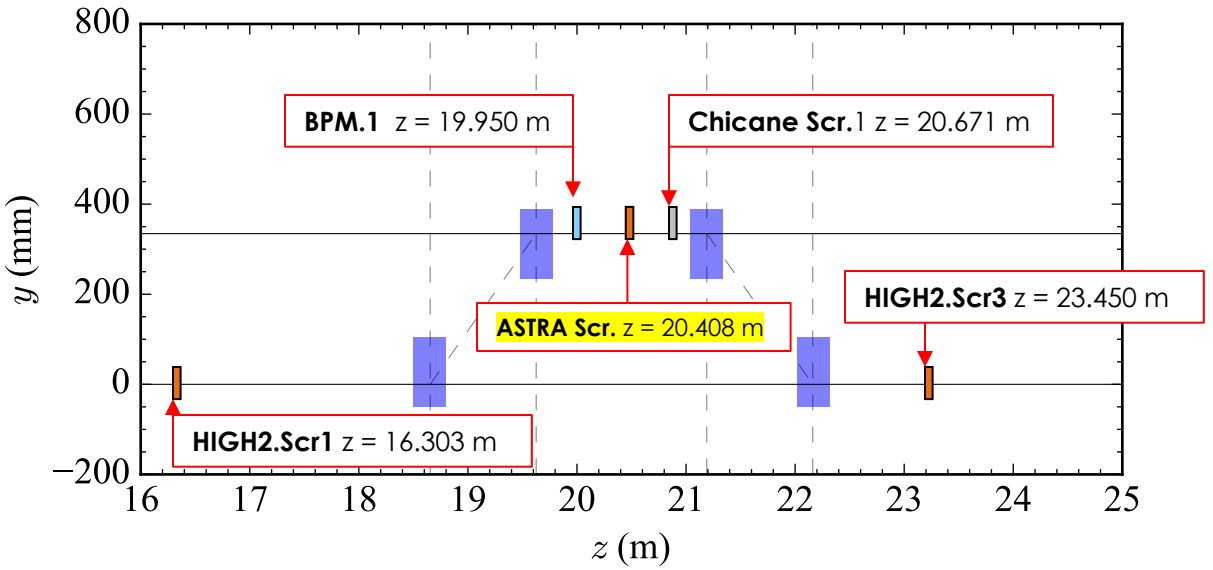
Dipole Magnetic field map from ASTRA



Positive currents for D1 and D4

Negative currents for D2 and D3

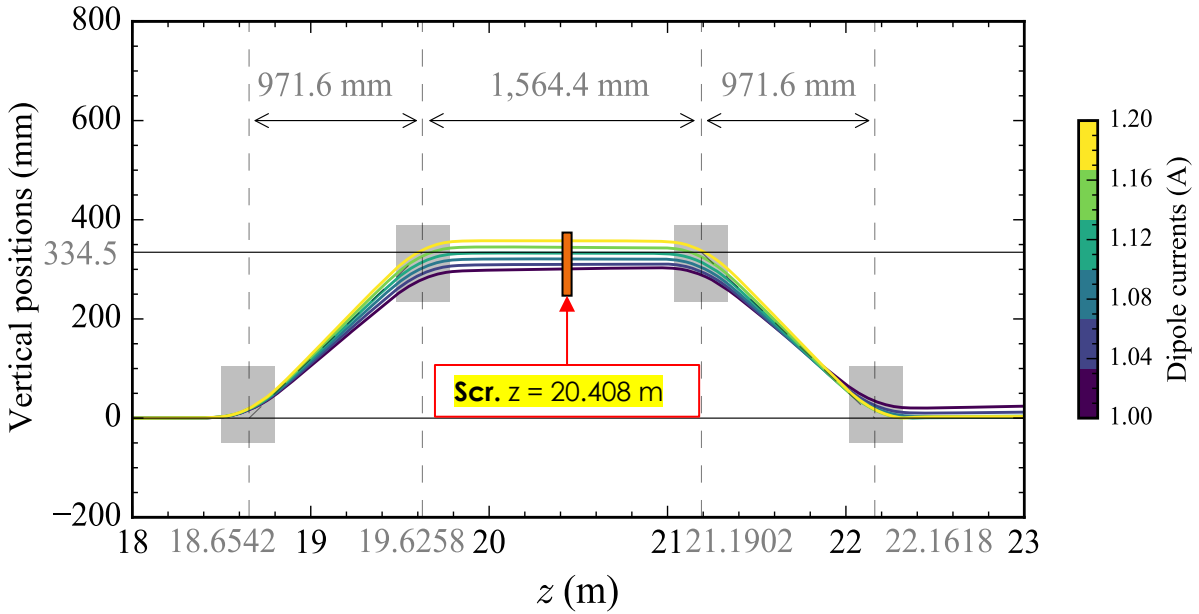
Optimization methods



1. D1 = -D2 = -D3 = D4
2. **D1 = -D3 and -D2 = D4** → ***Previous set up**
3. D1 = D4 and -D2 = -D3

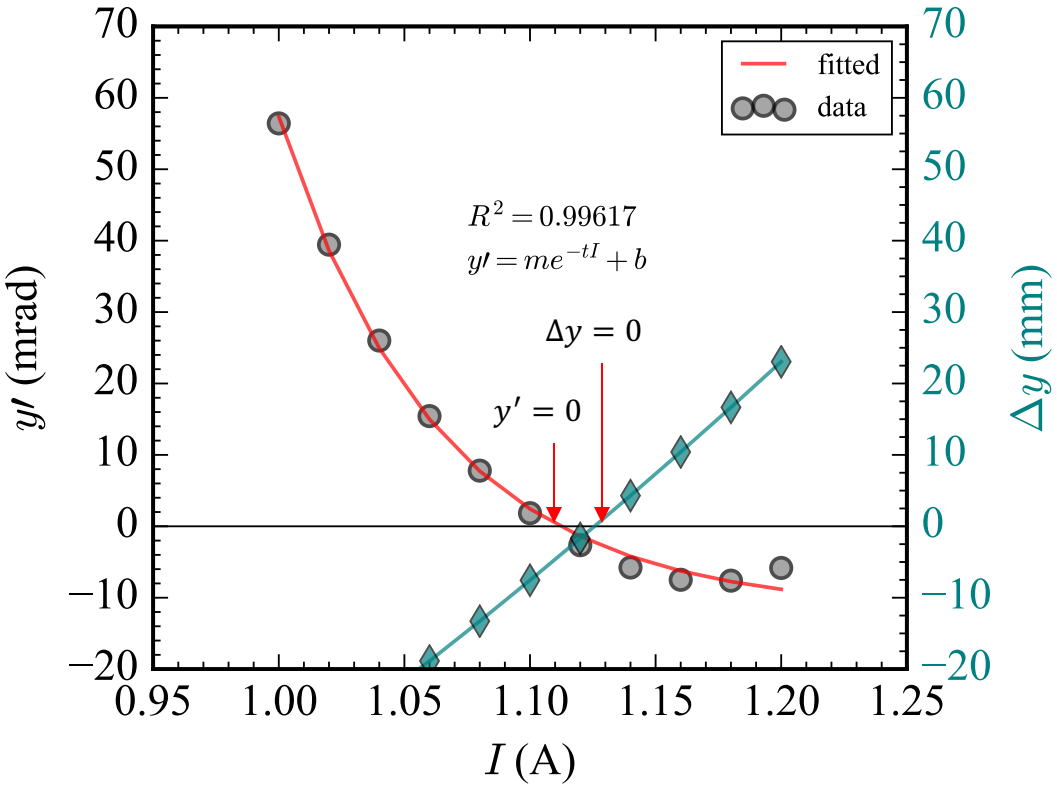
Beam Trajectory Simulation

1st Method: D1 = -D2 = -D3 = D4



Can't get $y' = 0$ and $\Delta y = 0$ by using identical currents for all dipoles.

ASTRA Screen at z = 20.408 m



e.g.,

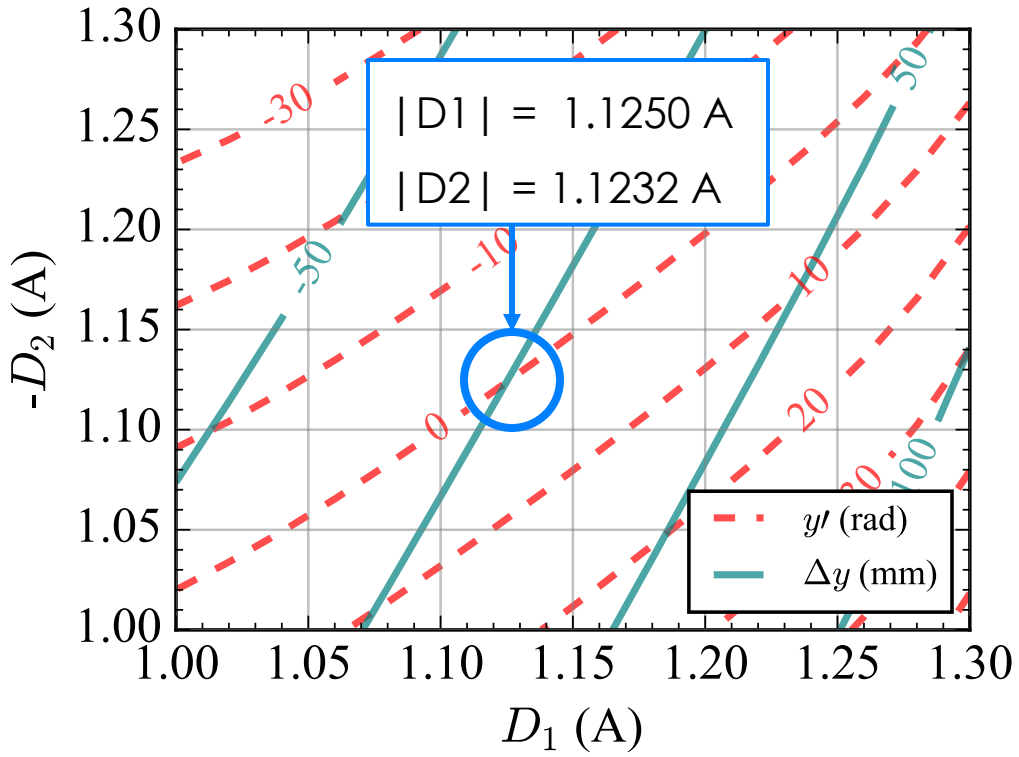
Optimum current for $y' = 0,\ I \approx 1.11\ A$

$\Delta y \approx -5\ mm$

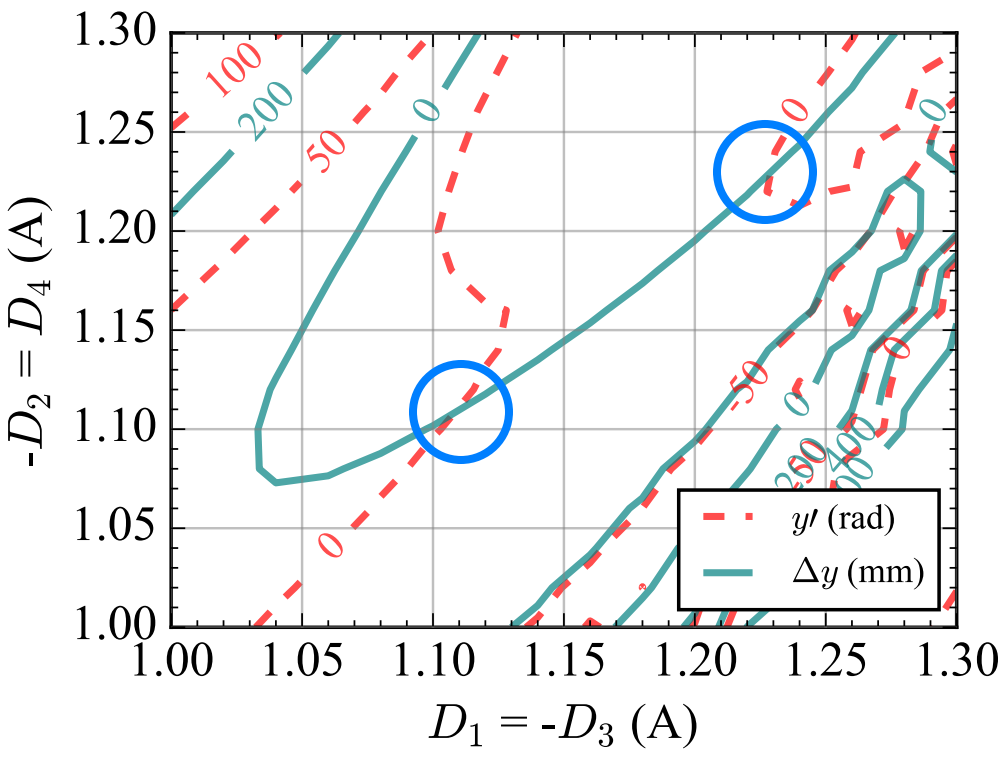
Beam Trajectory Simulation

2nd method : D1 = -D3 and -D2 = D4

Screen at the center between Dipole2 and Dipole3



Screen after Dipole4 (HIGH2 Scr3)

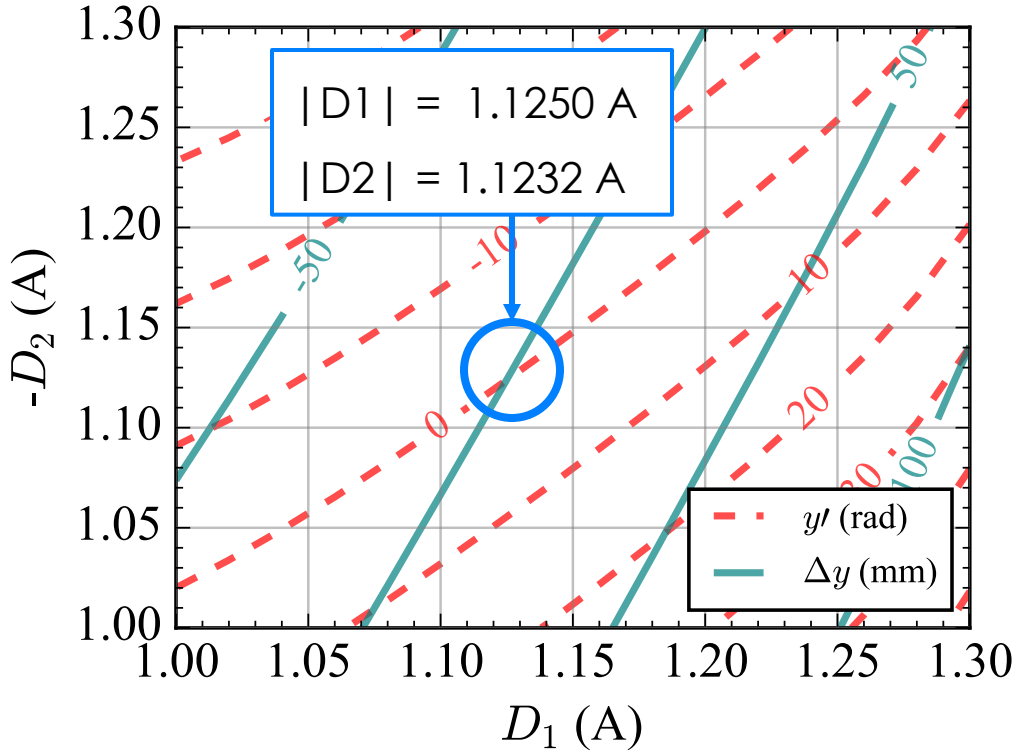


There is only one intersection between $y' = 0$ and $\Delta y = 0$ lines at the centre between Dipole2 and Dipole3.

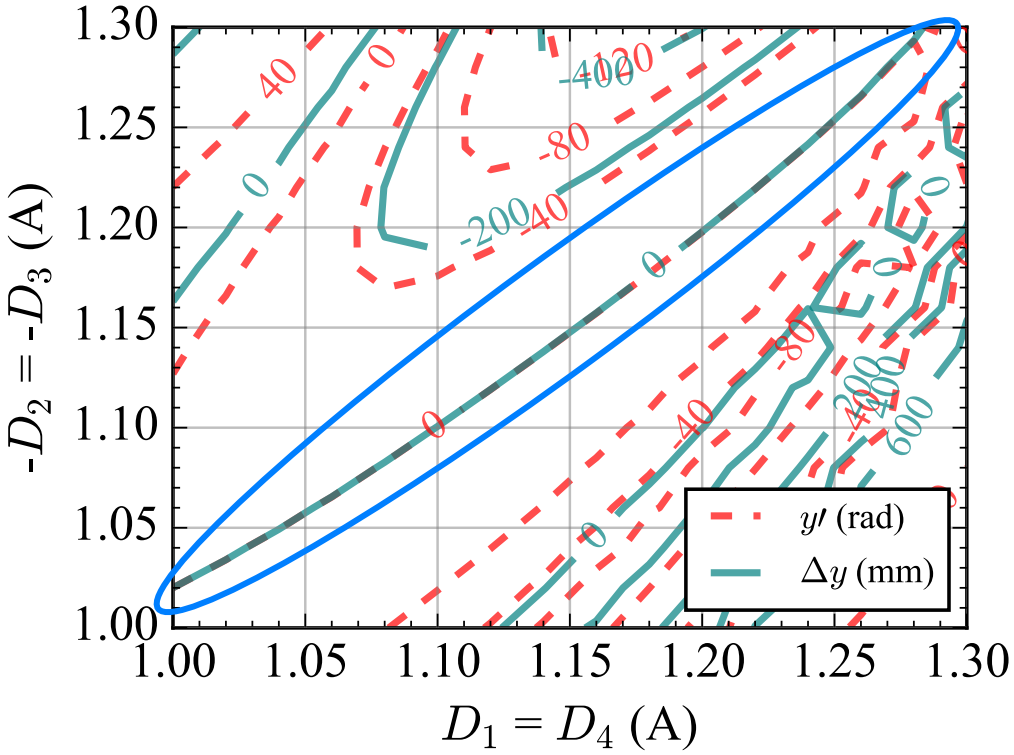
Beam Trajectory Simulation

3rd method : D1 = D4 and -D2 = -D3

Screen at the center between Dipole2 and Dipole3



Screen after Dipole4 (HIGH2 Scr3)

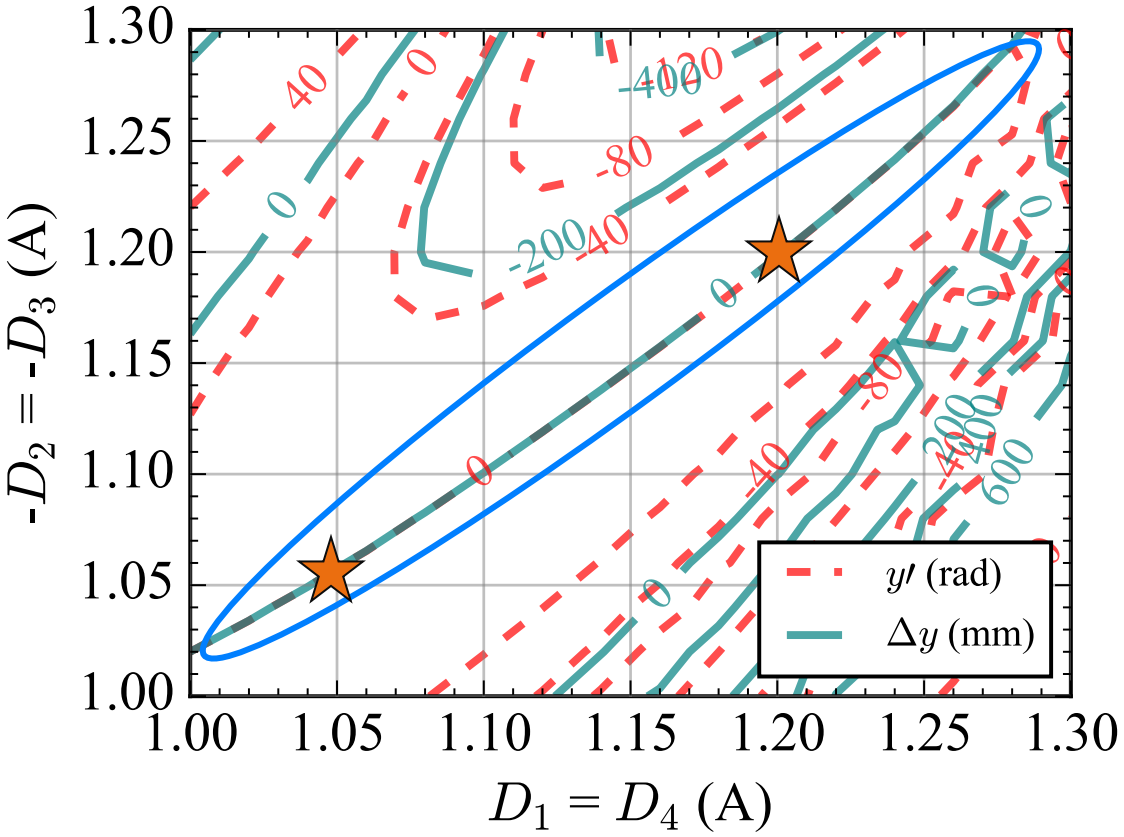


There is only one intersection point between $y' = 0$ and $\Delta y = 0$ lines at the centre between Dipole2 and Dipole3.

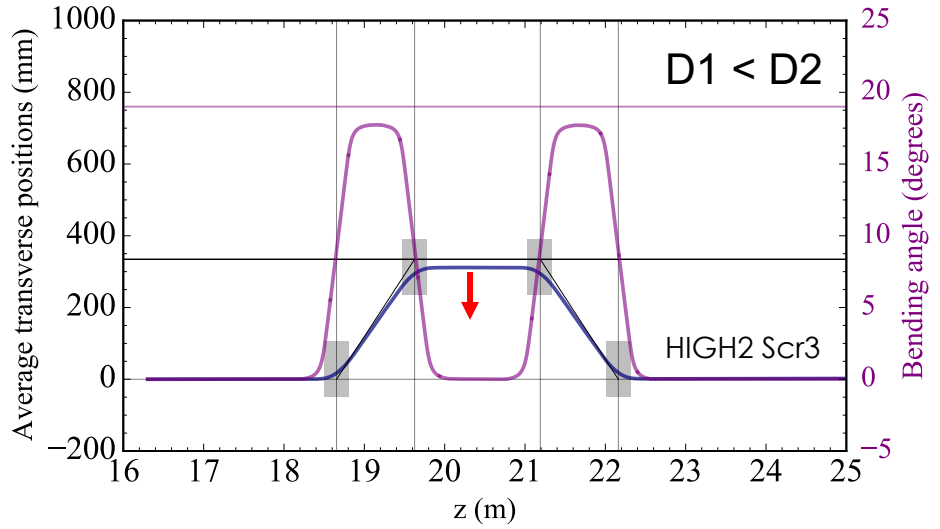
Beam Trajectory Simulation

3rd method : D1 = D4 and -D2 = -D3

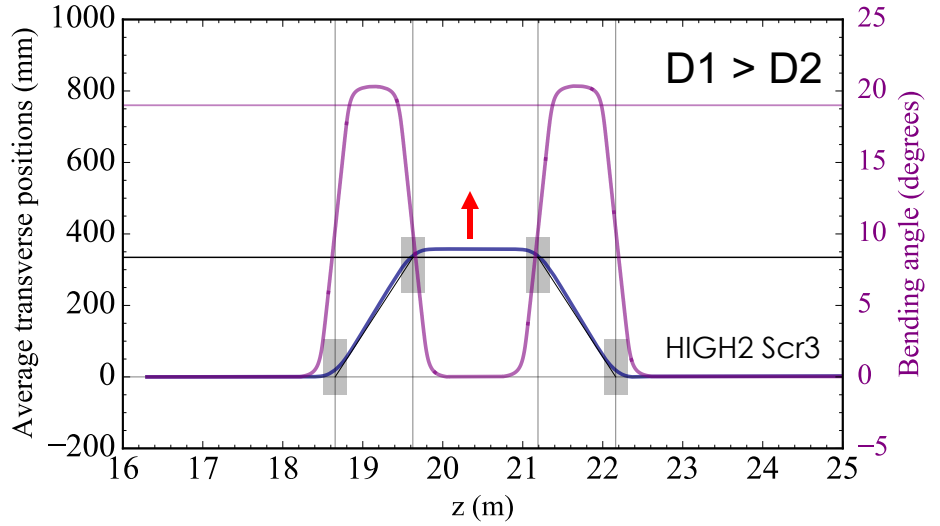
After Dipole4 at HIGH2 Scr3 (z = 23.450 m)



D1 = D4 = 1.05 A and -D2 = -D3 = 1.05611 A

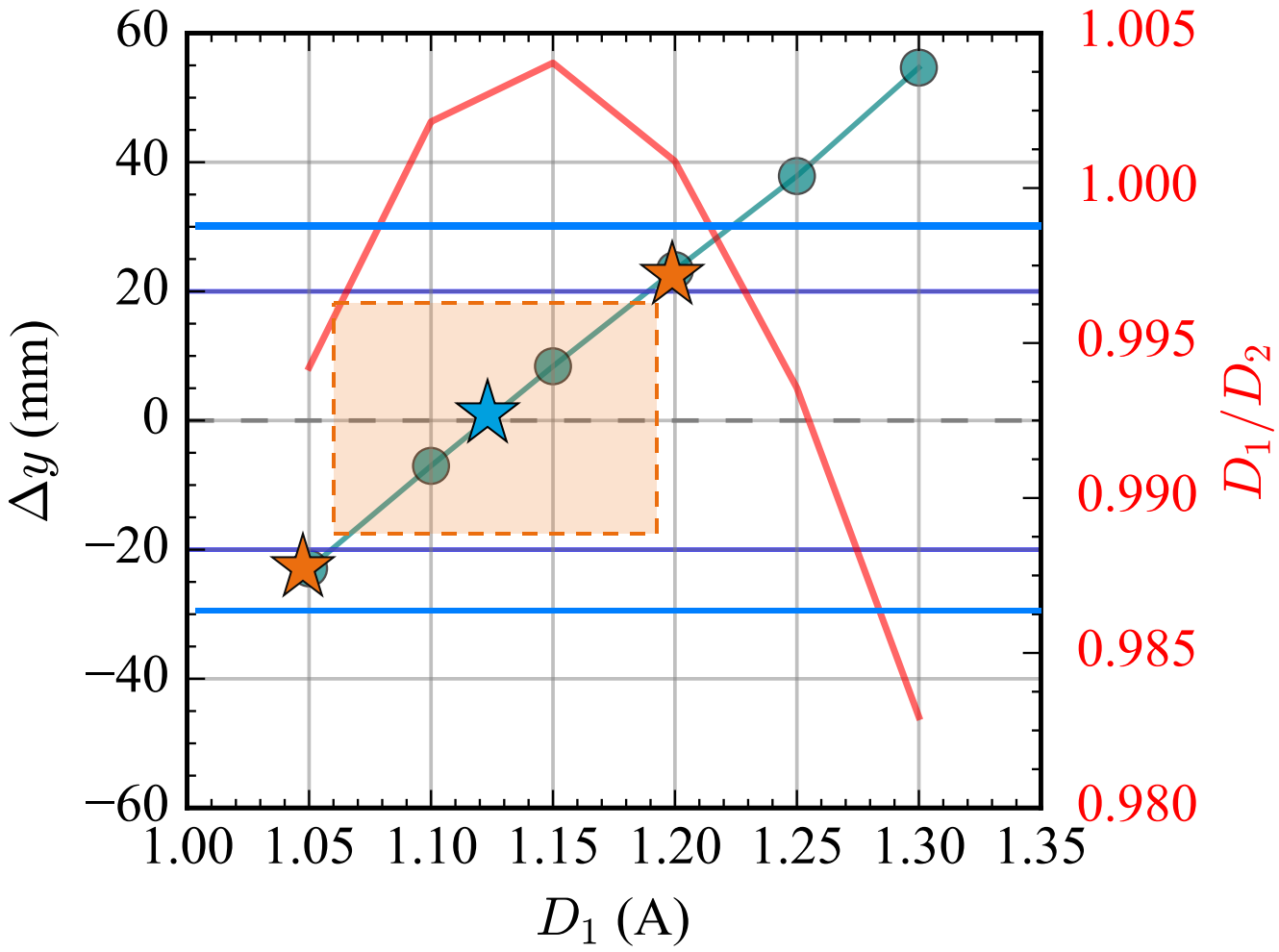


D1 = D4 = 1.20 A and -D2 = -D3 = 1.19896 A



Beam Trajectory Simulation

Offset beam position at the center between Dipole2 and Dipole3



Case : D1 = D4 and -D2 = -D3

Optimum ranges of D1 :

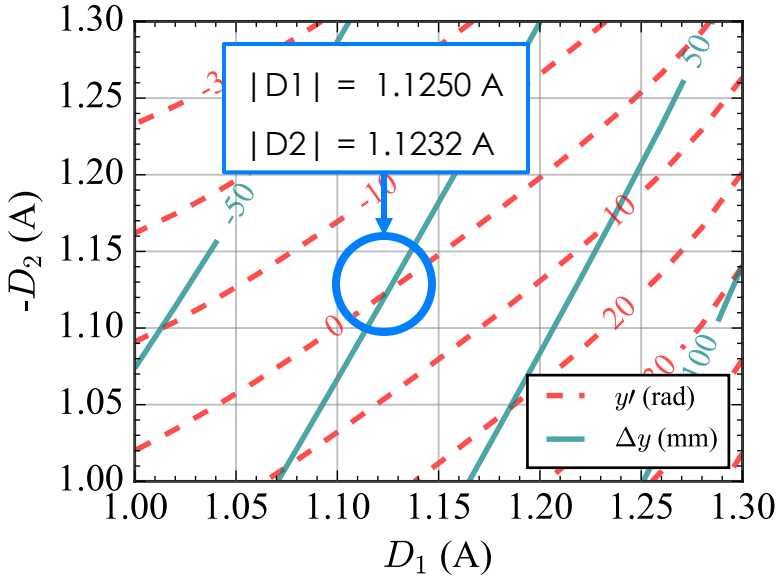
D1 : 1.06 → 1.18 A

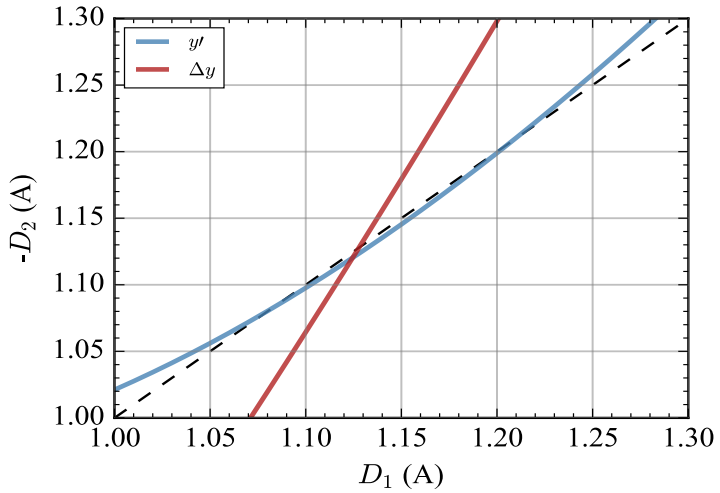
D1 > D2

Vacuum tube between Dipole2 and Dipole3 is NW63CF type, which has the **inner radius of 30 mm.**

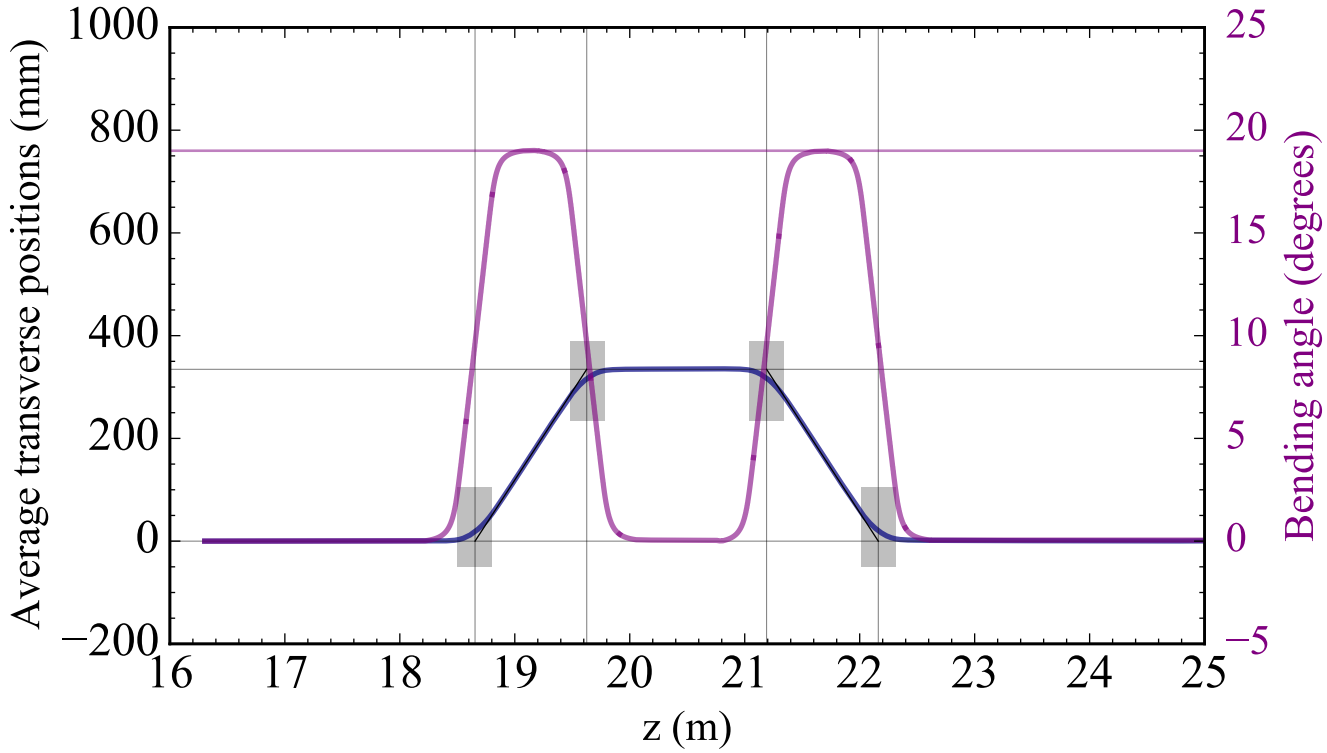
Beam Trajectory Simulation

Optimum current





Screen at the center between Dipole2 and Dipole3



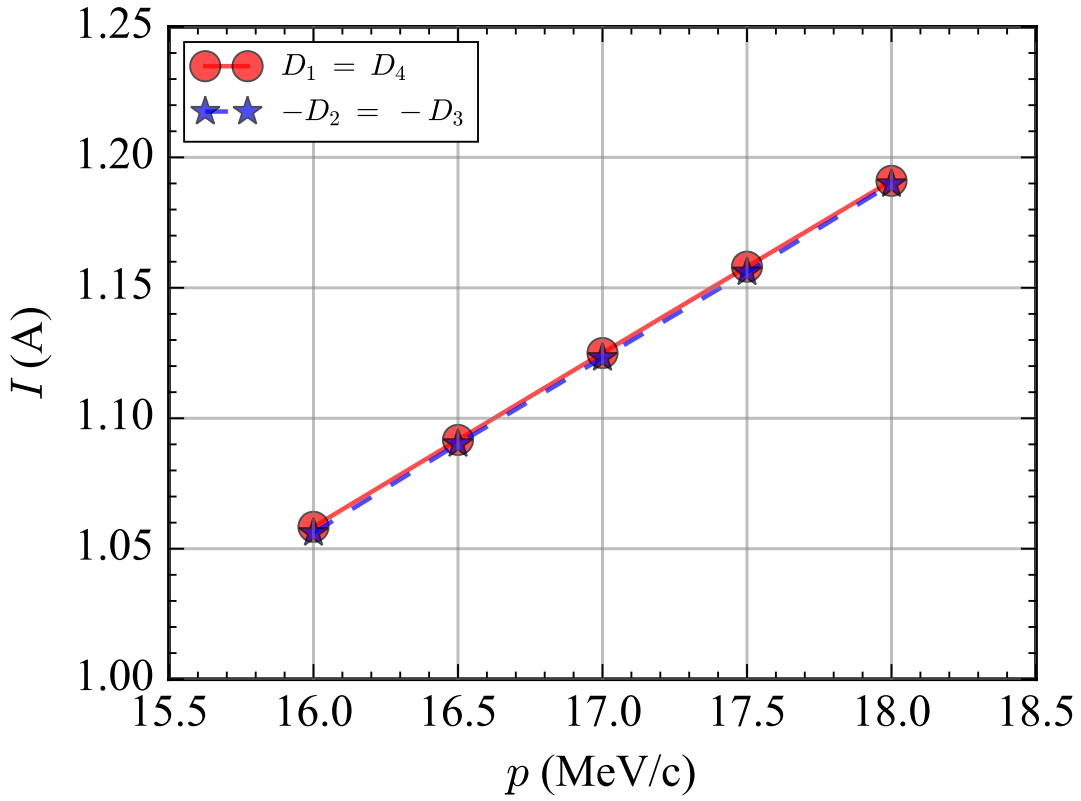
D1 = D4 = 1.1250 A and -D2 = - D3 = 1.1232 A

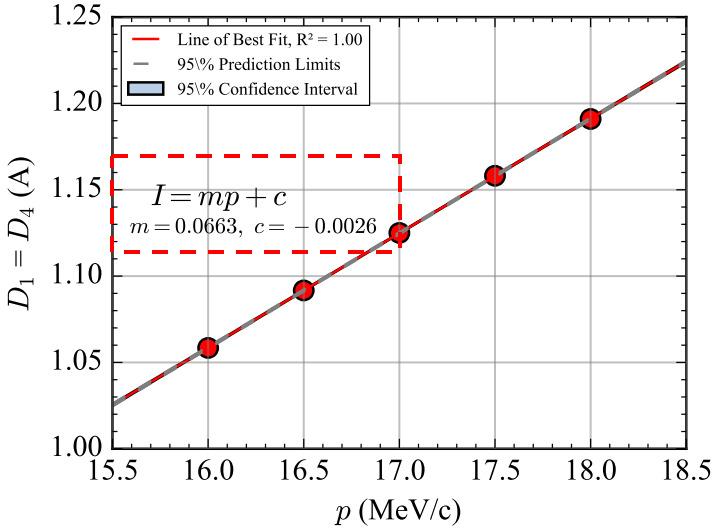
It is posible to use the optimum current from screen at the center between Dipole2 and Dipole3 to define the optimum current for screen after Dipole4.

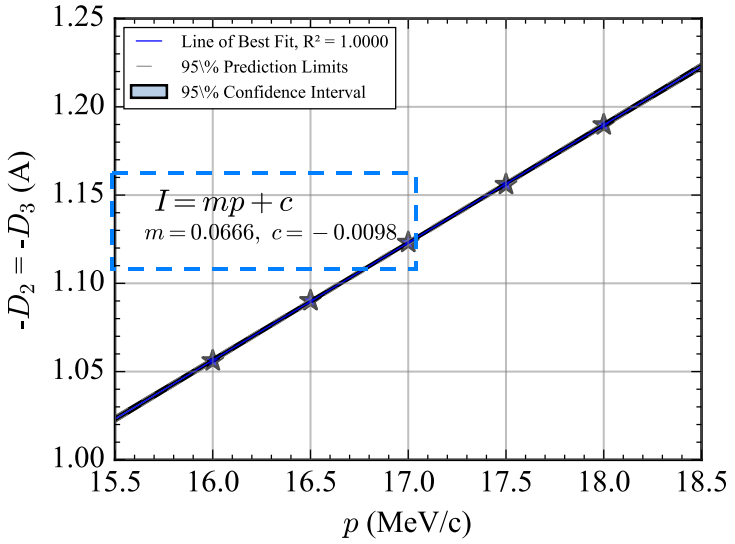
Beam Trajectory Simulation

Optimum currents of each beam momentums

Optimum currents for beam momentum of 16 → 18 MeV/c







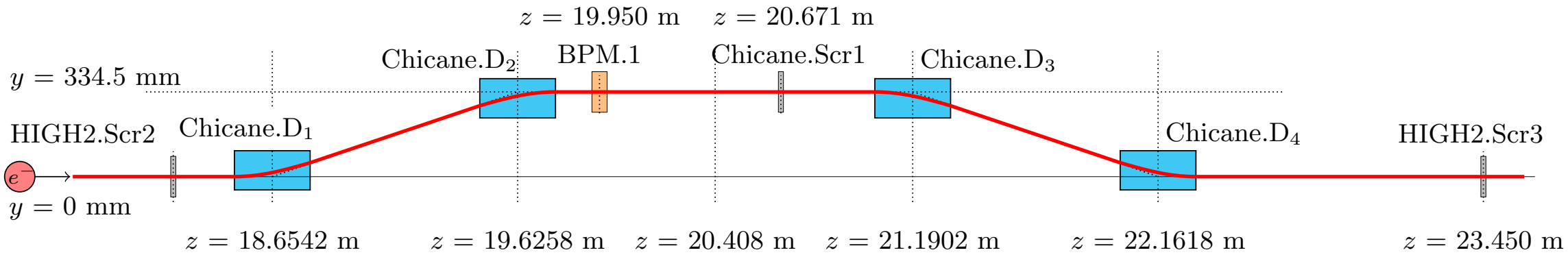
Applied current :

D1 > D2 for beam momentum of 16 → 18 MeV/c

Beam Transportation Through BC

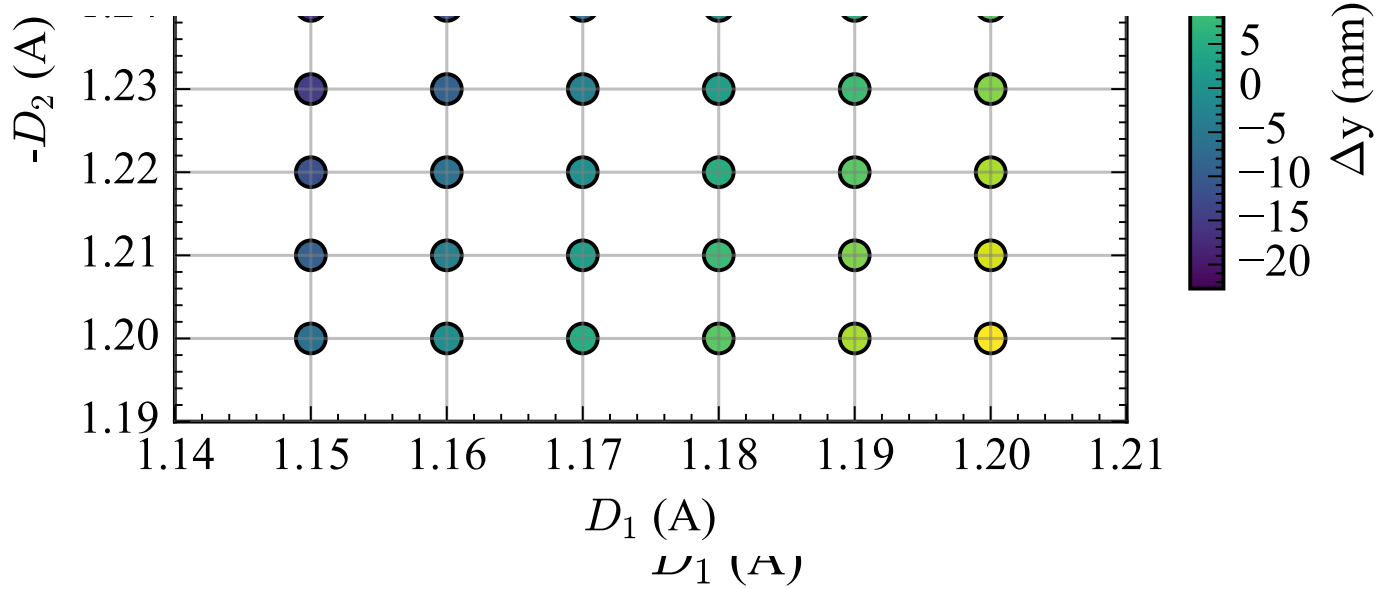
Results from 3 December 2022

At Chicane Scr.1 (z = 20.671 m)



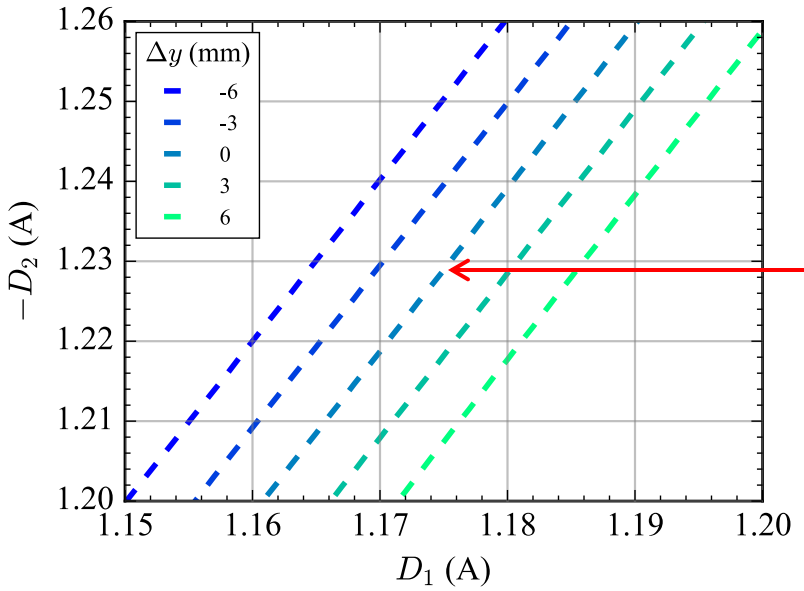
- 2D current scan for D1 and D2.
- Positive current for D1 and Negative current for D2.
- Data was recorded at Chicane.Scr1.

Scanned ranges : |D1| 1.15 → 1.20 A
|D2| 1.19 → 1.26 A



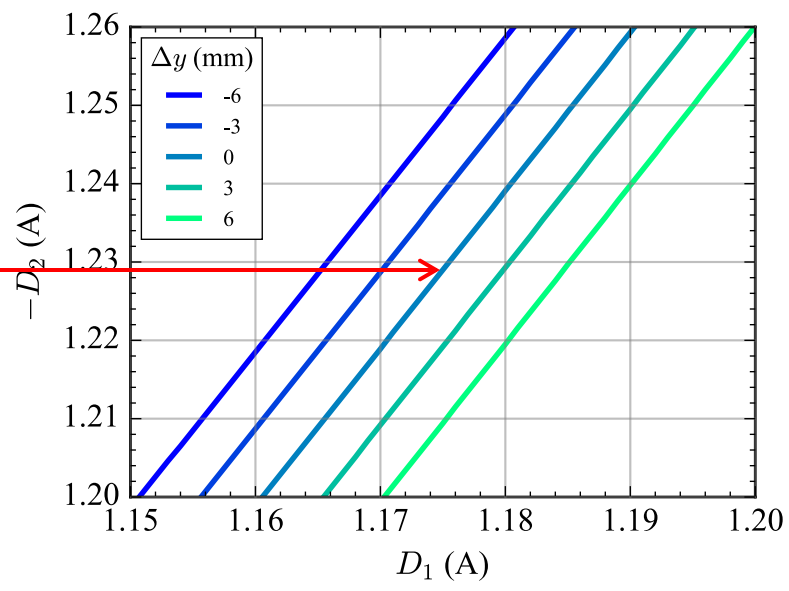
Beam Transportation Through BC

Matching beam vertical position with simulation



Measurement result at Chicane screen

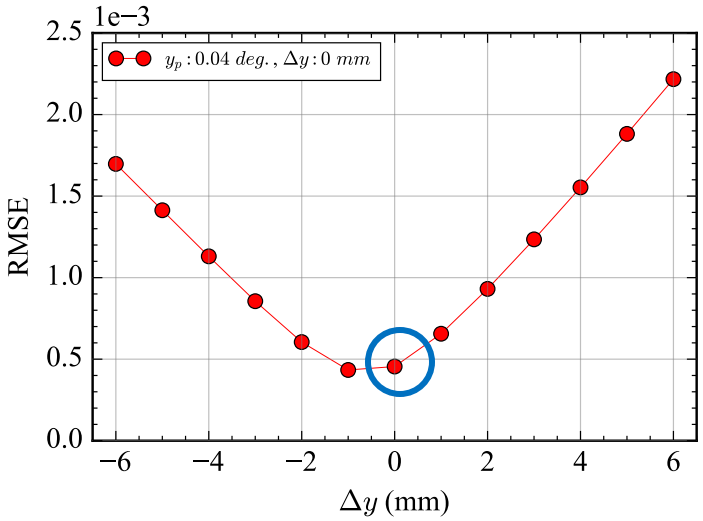
Beam momentum : 17.057 MeV/c



Simulation result at Chicane screen

Beam momentum : 17.057 MeV/c

Vertical angle = + 0.04 deg.
= + 0.698 mrad



- Just trajectory traking!
- Zero momentum spread
- Without
  - Space charge effect
  - CSR effect
- Dipole current from CST need to be corrected by experiment.

Summary and Discussion

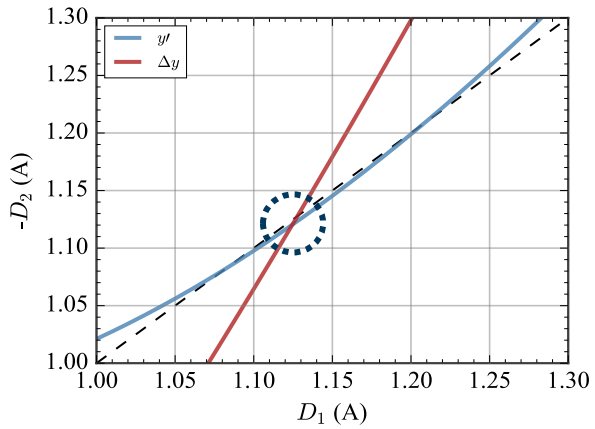
Beam trajectory simulation

- Optimum method : D1 = D4 and -D2 = -D3
- Optimum current range for D1 : 1.06 → 1.18 A
- Optimum current for on-axis trajectory for beam momentum 17 MeV/c:

  D1 = D4 = 1.1250 A

  -D2 = -D3 = 1.1232 A

Optimize D1/D2 to be 1 by moving Chicane dipole 2 and Chicane dipole 3 in the vertical direction.



Screen at the center between Dipole2 and Dipole3

Beam momentum 17 MeV/c

$y' = 0 \; and \; \Delta y = 0$

D1 = 1.1250 A and -D2 = 1.1232 A

D1/D2 = 1.0146 → 1

Summary and Discussion

Next.. Future works

- Beam vertical positions at the Chicane BPM and Chicane Screen are requirement for correcting dipole current from simulation.
- D1, D2, D3, and D4 → Zero dispersion at HIGH2. Scr3 and maximum THz energy by CTR measurement.

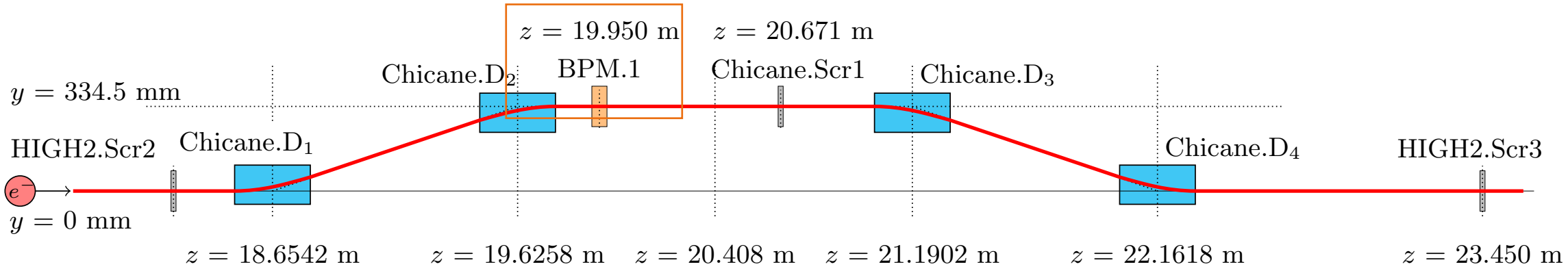
- Trajectory tracking by using CST particle studio.

- Beam dynamics simulation to find optimum currents for magnetic by considering :
  - Beam momentum spread
  - Beam emittance
  - Space charge effect
  - CSR effect

- Study compression conditions for SASE, seeded, super radiant techniques.
  - Beam momentum : 16, 17, 18 MeV/c
  - Bunch charge

Next BC commissioning

Plan for next BC commissioning 2023 January



Objectives

- To verify the vertical centroid position at BPM.1 (in this time) and Chicane.Scr1 from simulation with experiment.
- To find the optimum currents for D1, D2, D3, D4 for electron beam transportation through PITZ bunch compressor for electron beam momentum of 16, **17**, 18 MeV/c.
  - On-axis trajectory for electron beam.
  - Monitor at HIGH2 Scr3.

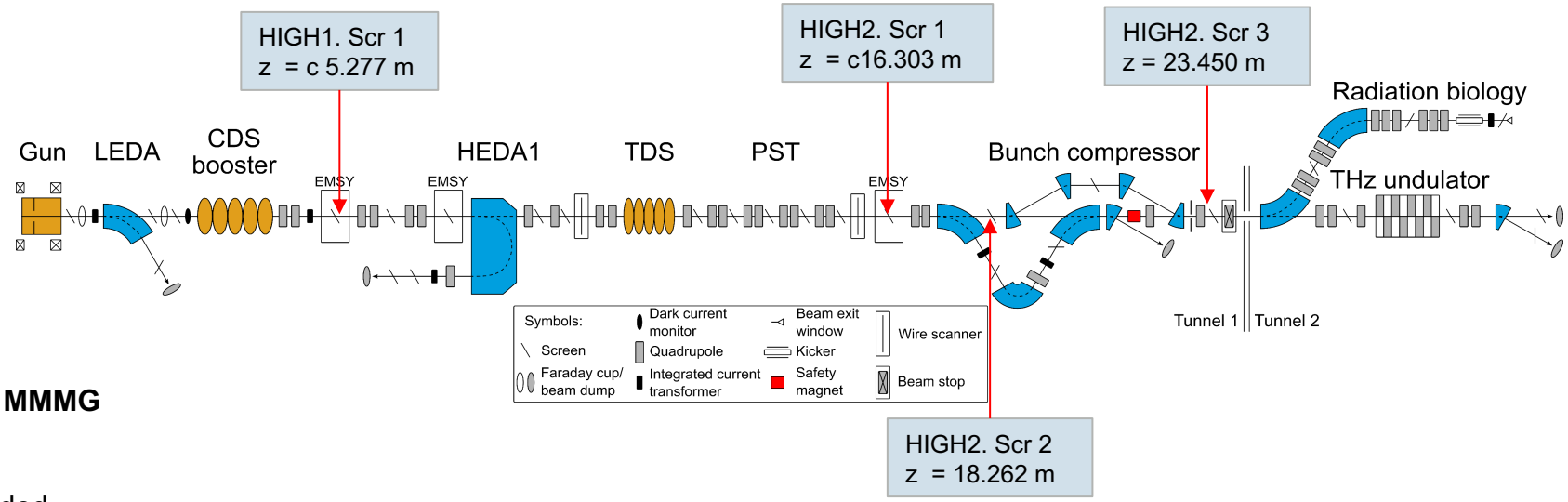
Bunch compressor commissioning

Next commissioning : Beam transportation at HIGH2. Scr3

Beam parameters for beam transportation through chicane

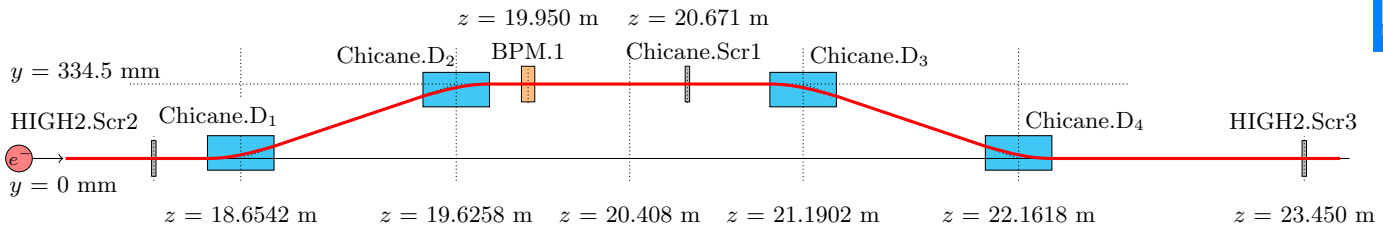
Beam preparation

- Laser (FWHM): > 8 ps
- BSA : 1 mm
- Bunch charge : maximum of 200 pC at Low.FC1
- Beam momentum at LEDA: 6.3 MeV/c for gun phase **MMMG**
- Beam monitor at HIGH1.Scr1
  - Transverse profiles (sig x, sig y) must be recorded.
- Beam momentum measurement at HEDA1 (e.g. Booster amplitude : 11 MV , Momentum : 17.0843 MeV/c)
  - Beam momentum **17** MeV/c at **MMMG**
  - Do BBA at HIGH1. Scr1 in the range from MMMG to +10 degrees, step +5 degrees
    - BBA should be lower than 0.1 mm
- Center **vertical** beam at HIGH2.Scr1, HIGH2.Scr2, HIGH2.Scr3
  - Use script to save beam image



Bunch compressor commissioning

Next commissioning : monitor beam at HIGH2. Scr3

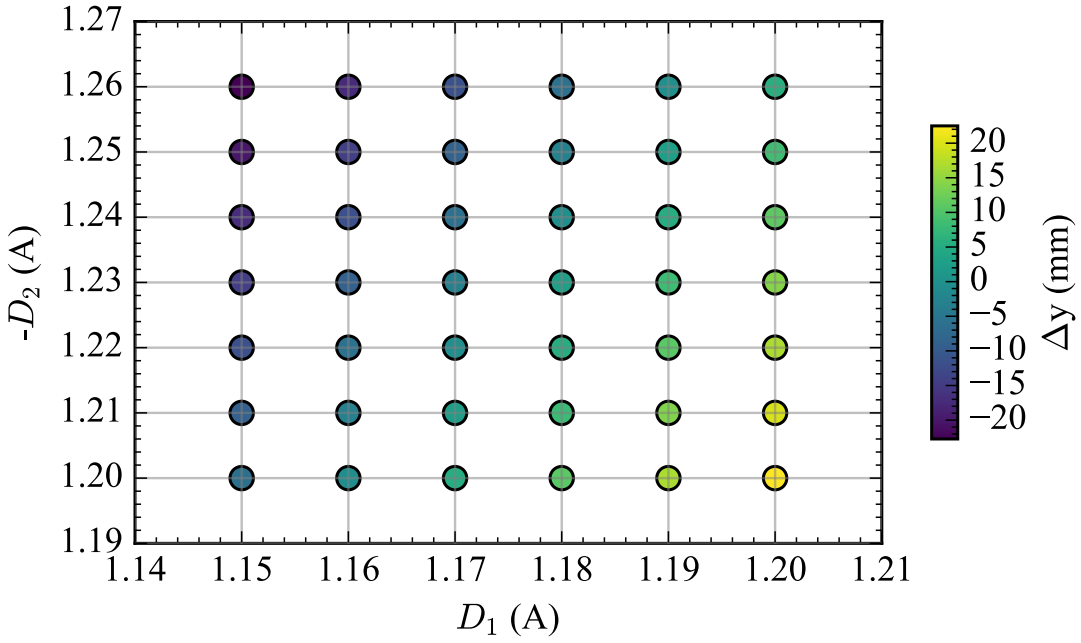


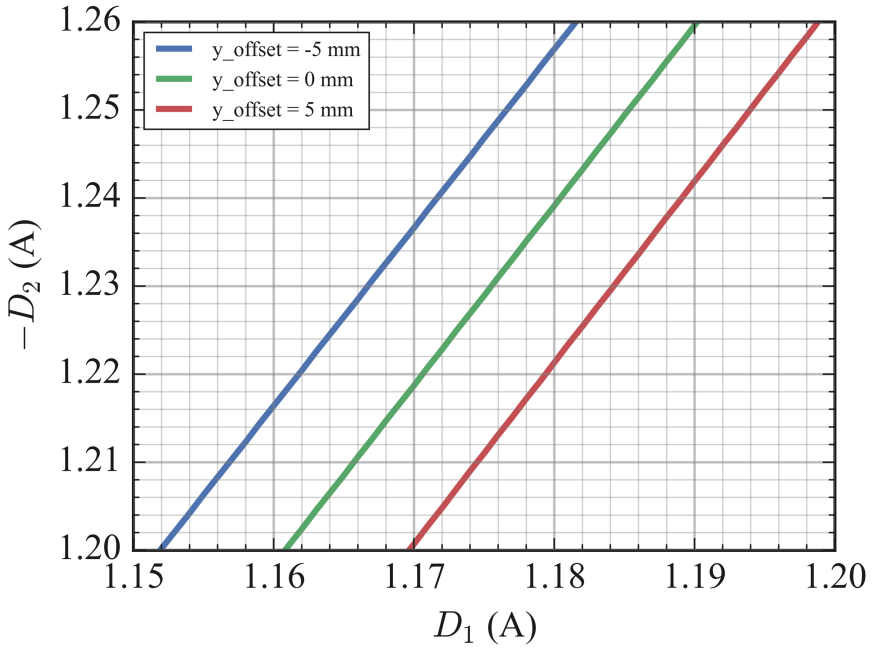
Beam Transportation

1st Step D1 and D2 Scan (Positive for D1 and Negative for D2)

1. Finding the ranges of scan for D1 and D2 manually.
2. Using MATLAB script “Current Scan2Dtest.m”.
3. Monitor beam at BPM.1 and CHICANE.Scr1.

e.g.,





Bunch compressor commissioning

Next commissioning : monitor beam at HIGH2. Scr3

2nd Step **Scan y offset** at CHICANE.Scr1 and **monitor beam HIGH.2 Scr3**.

1. Run python script “Calculate_current_D1andD2.py”
2. Give y offset input at Console ex. 5 mm then enter.
3. Using ratio (slope) between D2 and D1 as an input for next step.
4. Using D1 = D4 and -D2 = -D3 to transport beam.
5. Using MATLAB script “Current Scan2Dtest.m” to scan current for D1 = D4 and -D2 = -D4 by choosing scan ranges from no.2 .

Y offset (mm)	Scan range for D1 and –D3	Scan range for -D2 and D4
-5	e.g. 1.17 – 1.20	e.g. 1.20 – 1.26
5	:	:

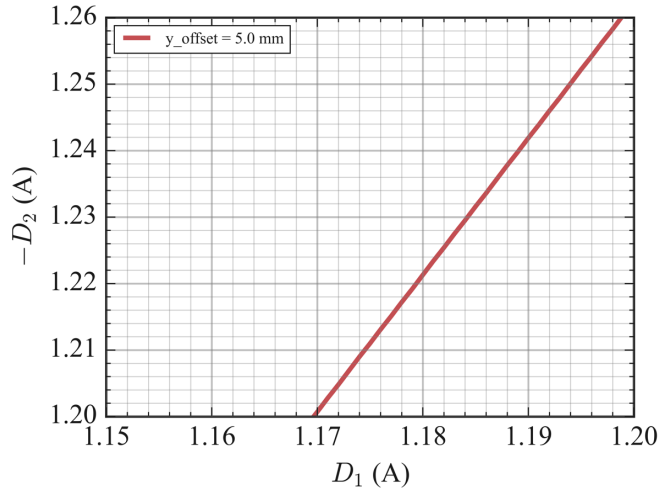
Note: Step y = 1 mm

Step scan = 0.01 A

1

```
In [262]: runfile('C:/Users/kongmone/.spyder-py3/Scripts/For_experiment/
Calculate_current_D1andD2.py', wdir='C:/Users/kongmone/.spyder-py3/Scripts/
For_experiment')
-------------------------------------------
RMSE_p:0.08032
R-squared_p:0.99995
-------------------------------------------
y_offset (mm) :

5
```

2



3

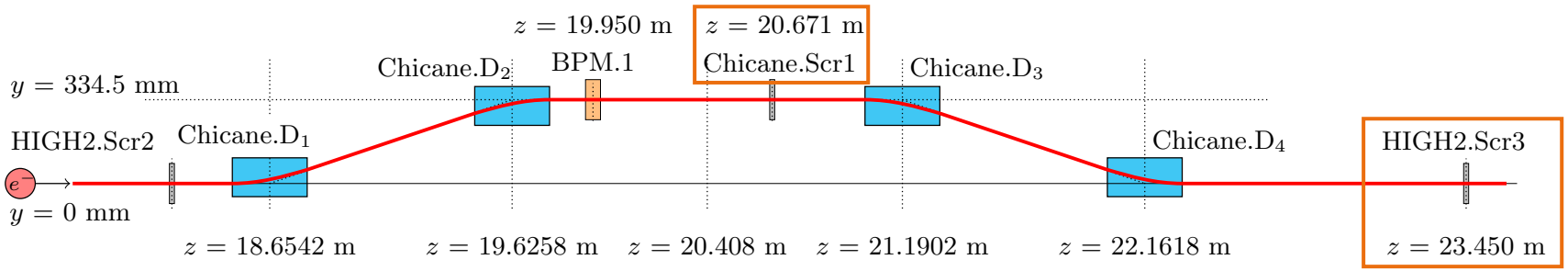
```
In [262]: runfile('C:/Users/kongmone/.spyder-py3/Scripts/For_experiment/
Calculate_current_D1andD2.py', wdir='C:/Users/kongmone/.spyder-py3/Scripts/
For_experiment')
-------------------------------------------
RMSE_p:0.08032
R-squared_p:0.99995
-------------------------------------------
y_offset (mm) :

5
-------------------------------------------
Ratio D2/D1 : 1.0304955663091626
-------------------------------------------
D1 (A):  Please choosing D1 from graph

1.18

-------------------------------------------
y offset = 5.0 mm, D1 = -D3 = 1.18 A, -D2 = D4 = 1.2213 A

Use ranges from graph for D1, D2, D3, D4.
-------------------------------------------
```

Bunch compressor commissioning

Next commissioning : monitor beam at HIGH2. Scr3 by setting offset vertical position of beam at CHICANE.Scr1

Beam parameters

- Bunch charge : 200 pC at Low.FC1
- Beam momentum : 16, **17**, 18 MeV/c
  (minimum momentum spread)



Beam momentum : 16, **17**, 18 MeV/c → **17** MeV/c → D1 and D2 scan, Monitor beam at CHICANE.Scr1 BPM.1

Minimum momentum spread

Step scan current : 0.01 A

Vertical offset (y offset): 5 mm
:
Vertical offset (y offset): 0 mm
:
Vertical offset (y offset): -5 mm

Step y offset : 1 mm

D1 = -D3 and –D2 = D4 scan
Monitor beam at HIGH2. Scr3

D1 = -D3 and -D2 = D4 scan
Monitor beam at HIGH2. Scr3

D1 = -D3 and -D2 = D4 scan
Monitor beam at HIGH2. Scr3

1st Step

2nd Step

Thank you for your attention