Summary of HEDA2 dipole magnet analysis

Contents

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Introduction

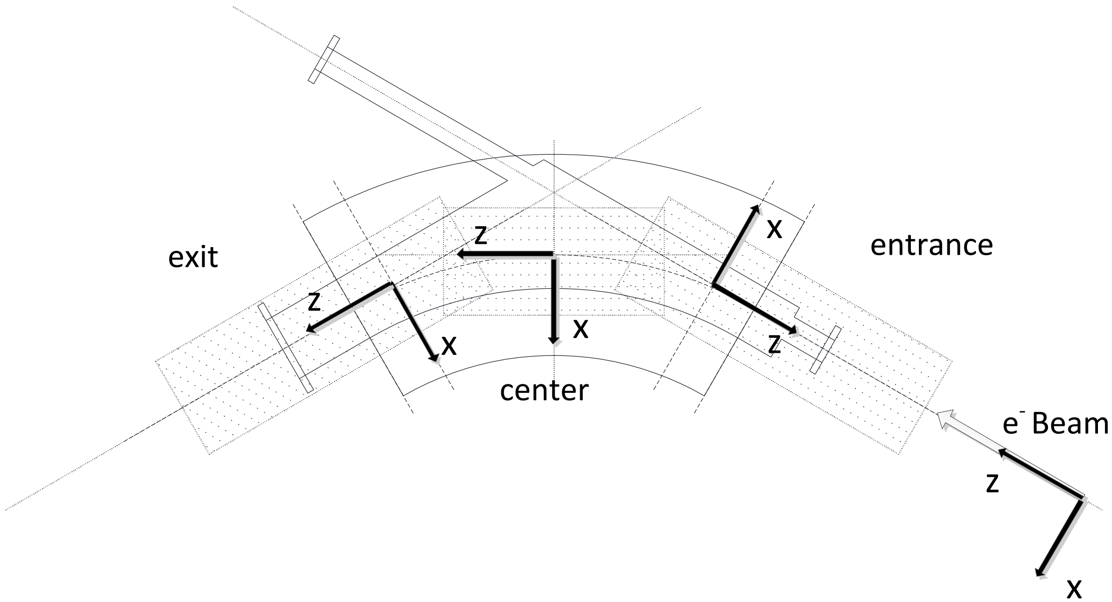
- Objective of the study
  - to analyze parameters of the HEDA2 magnets (e.g. effective length, excitation current) and compare to the designed specifications
  - to analyze the relations between electron momentum, magnetic field and excitation current
  - to find the behavior of the spectrometer (Disp3.D1)
  - to find the proper algorithm to transport the beam to the beam dump

Selected specifications

	DISP3.D1 (D1)	DISP3.D2 (D2)	DISP3.D3 (D3)
Maximum field (T)	0.23	0.34	0.34
Bending radius (mm)	600	400	400
Bending angle (°)	60	-120	60
Entrance angle (°)	0	0	0
Exit angle (°)	0	0	9

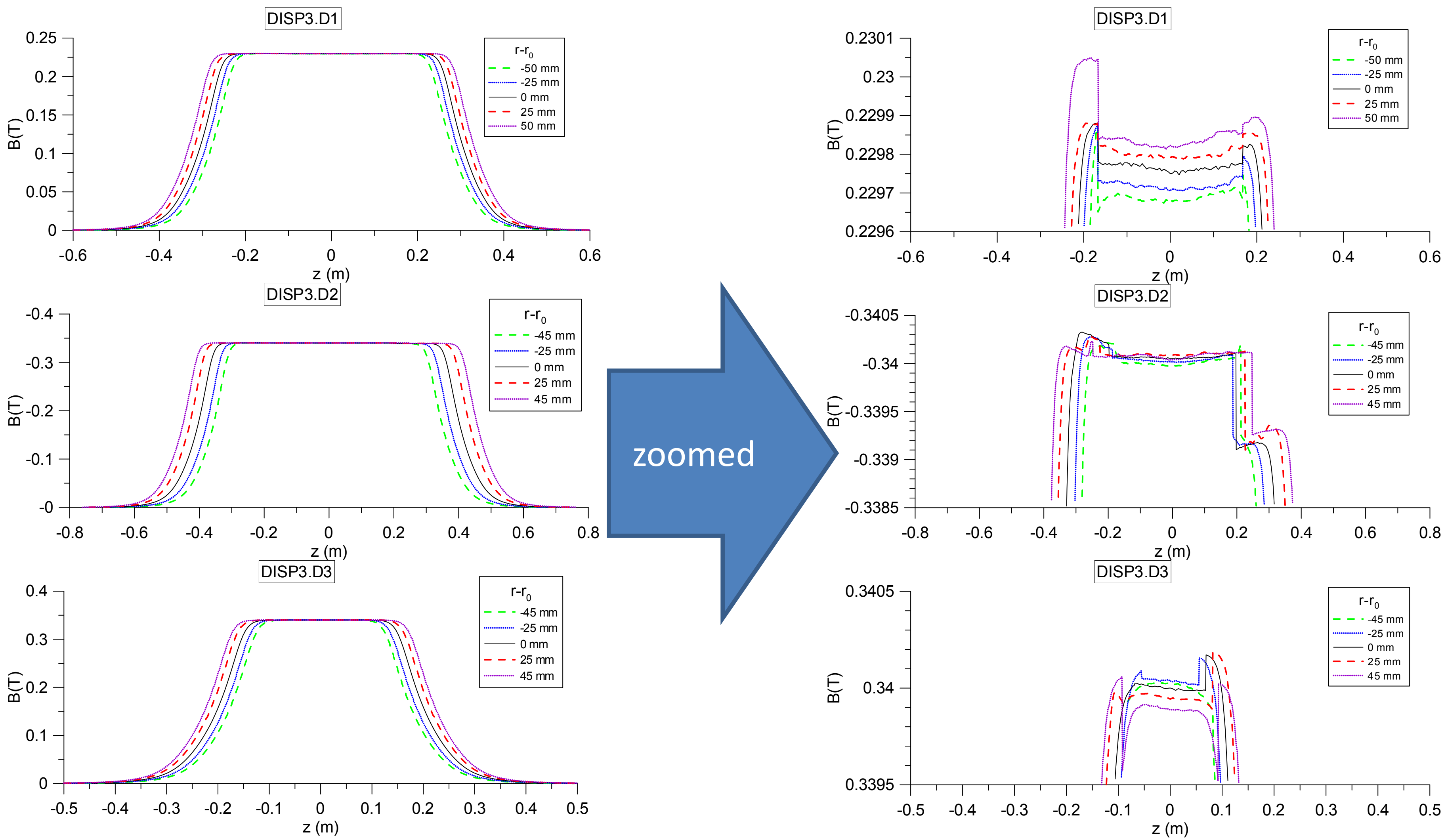
- Disp3.D1 is primarily used as spectrometer to measure longitudinal phase space.
- Disp3.D2 is designed to measure vertical slice emittance and to deflect the beam back to the straight section.
- Disp3.D3 is used to deflect the beam to the beam dump.

Field measurement



- Above picture shows the coordinate used in field measurement by the company Danfysik.
- Due to limitation of the equipment, the field has been measured in 3 separate zones.

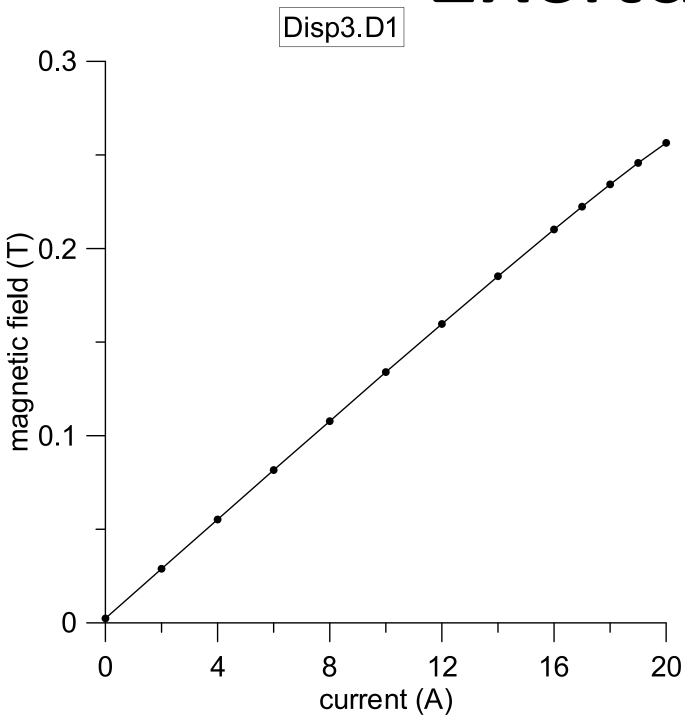
Field map

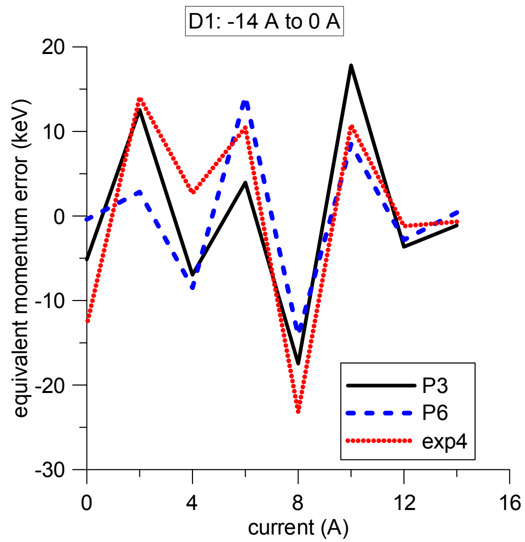

DISP3.D1
B(T)
z (m)
r-r0
-50 mm
-25 mm
0 mm
25 mm
50 mm
DISP3.D2
B(T)
z (m)
r-r0
-45 mm
-25 mm
0 mm
25 mm
45 mm
DISP3.D3
B(T)
z (m)
r-r0
-45 mm
-25 mm
0 mm
25 mm
45 mm
zoomed
DISP3.D1
DISP3.D2
DISP3.D3

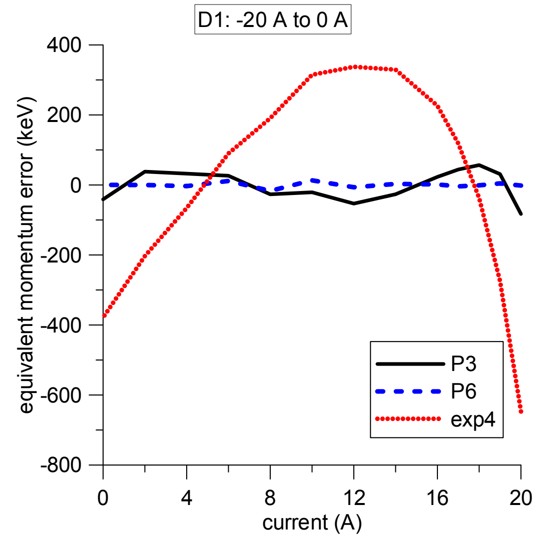
Effective length

DISP3.D1					
$r-r_0$ (mm)	-50	-25	0	25	50
l_{eff} (m)	0.569	0.598	0.625	0.653	0.680
l_{eff} (°)	59.32	59.54	59.72	59.87	59.98
DISP3.D2					
$r-r_0$ (mm)	-45	-25	0	25	45
l_{eff} (m)	0.726	0.773	0.832	0.891	0.948
l_{eff} (°)	117.21	118.18	119.23	120.12	120.71
DISP3.D3					
$r-r_0$ (mm)	-45	-25	0	25	45
l_{eff} (m)	0.364	0.387	0.416	0.445	0.472
l_{eff} (°)	58.67	59.14	59.59	59.53	60.10

Excitation current: D1







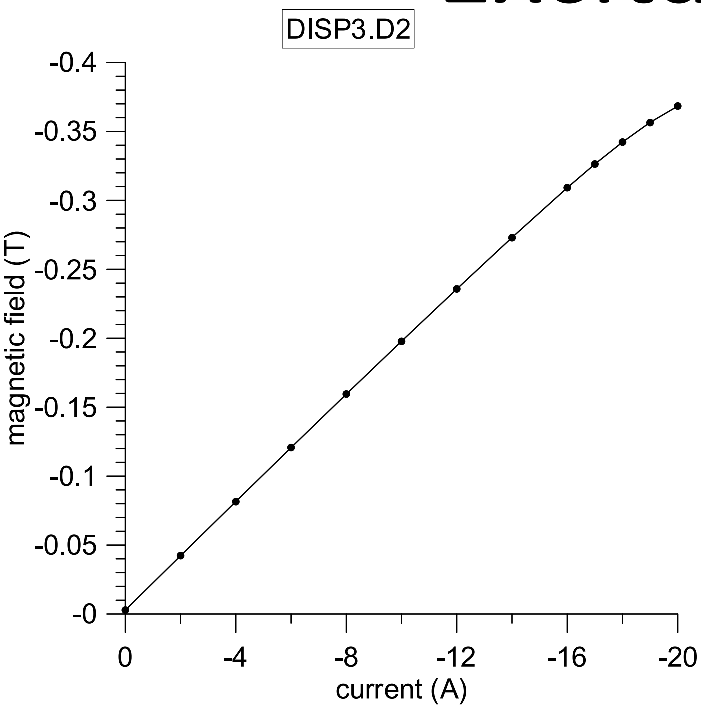
P3:

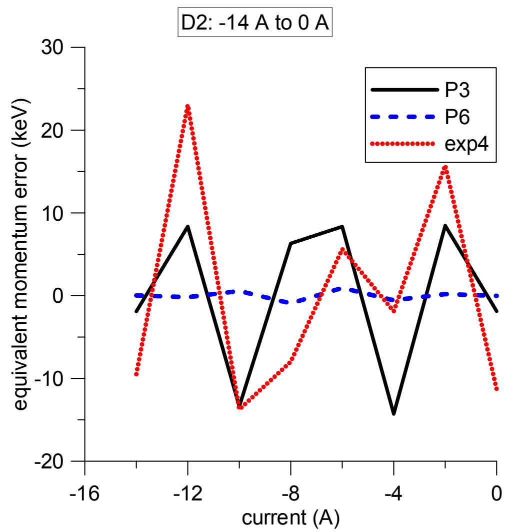
P6:

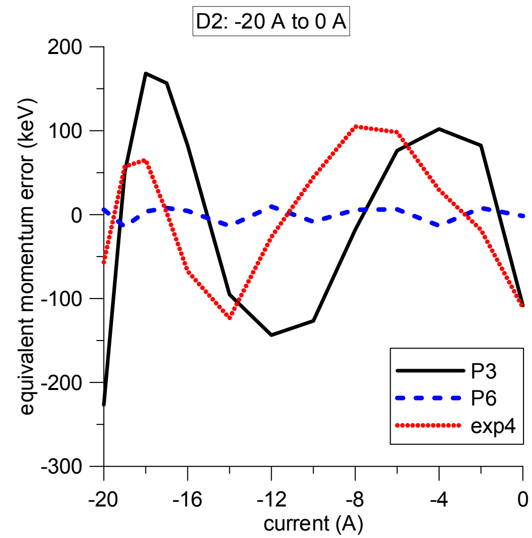
Exp4:

	20A P3	20A P6	20A exp4	14A P3	14A P6	14A exp4
A_0 or a	2.57901×10^{-3}	2.34905×10^{-3}	8.61661×10^{-1}	2.37859×10^{-3}	2.35225×10^{-3}	3.47465×10^{-1}
A_1 or b	1.29569×10^{-2}	1.34130×10^{-2}	-3.48652×10^{-1}	1.32093×10^{-2}	1.32490×10^{-2}	-1.83581×10^{-1}
A_2 or c	5.12914×10^{-5}	-1.11915×10^{-4}	2.60852×10^{10}	6.74892×10^{-6}	3.19593×10^{-5}	261.559
A_3 or d	-3.16716×10^{-6}	2.42747×10^{-5}	67.4284	-1.25158×10^{-6}	-1.97105×10^{-5}	26.3390
A_4		-2.56909×10^{-6}			3.49483×10^{-6}	
A_5		1.23642×10^{-7}			-2.62405×10^{-7}	
A_6		-2.31555×10^{-9}			6.91189×10^{-9}	

Excitation current: D2







P3:

P6:

Exp4:

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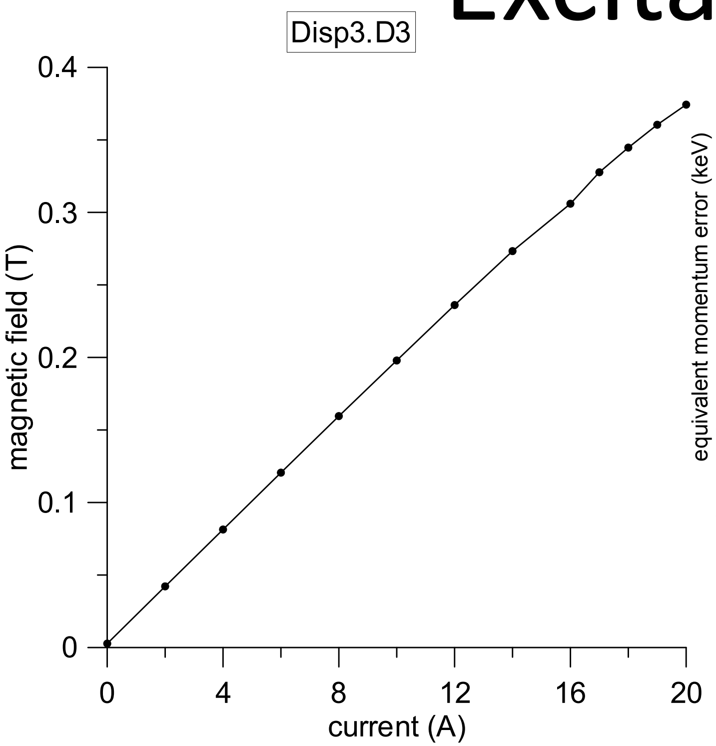
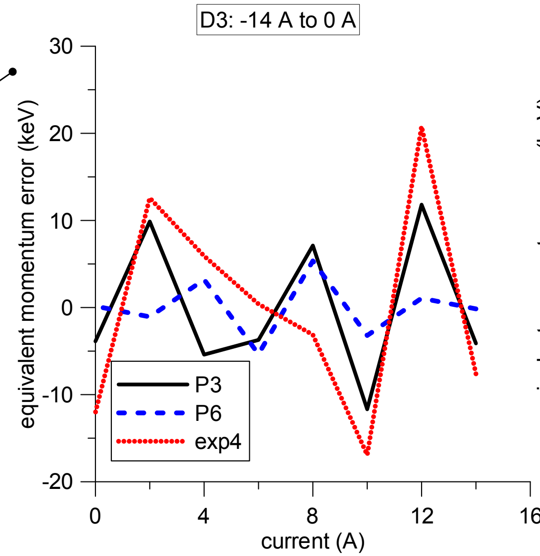
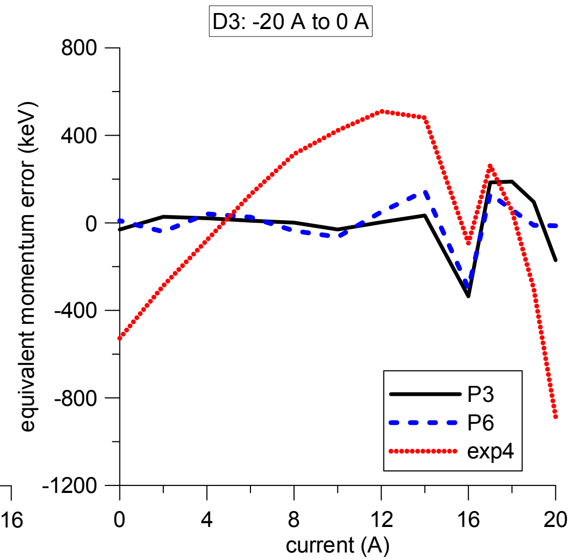
	20A P3	20A P6	20A exp4	14A P3	14A P6	14A exp4
A_0 or a	-3.72139×10^{-3}	-2.83156×10^{-3}	1.83627×10^{-2}	-2.83371×10^{-3}	-2.81822×10^{-3}	4.28924×10^{-1}
A_1 or b	1.86074×10^{-2}	1.97918×10^{-2}	1.93130×10^{-1}	1.97123×10^{-2}	2.03852×10^{-2}	1.48325×10^{-1}
A_2 or c	-1.94014×10^{-4}	7.14107×10^{-5}	1169.04	-1.20779×10^{-6}	5.84869×10^{-4}	191.285
A_3 or d	-1.03958×10^{-5}	2.08078×10^{-5}	9.48302×10^{-1}	-2.22128×10^{-6}	1.76323×10^{-4}	2.18436
A_4		3.23287×10^{-6}			2.45443×10^{-5}	
A_5		2.05485×10^{-7}			$1.55798\times10_{-6}$	
A_6		4.82016×10^{-9}			3.71202×10^{-8}	

Excitation current: D3







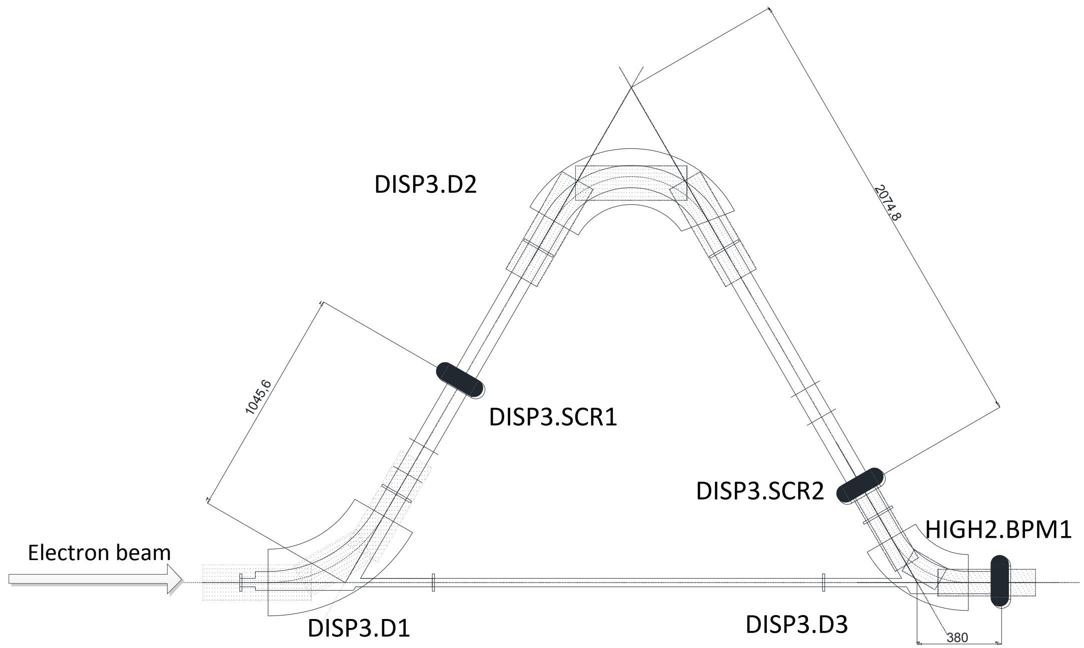
P3:

P6:

Exp4:

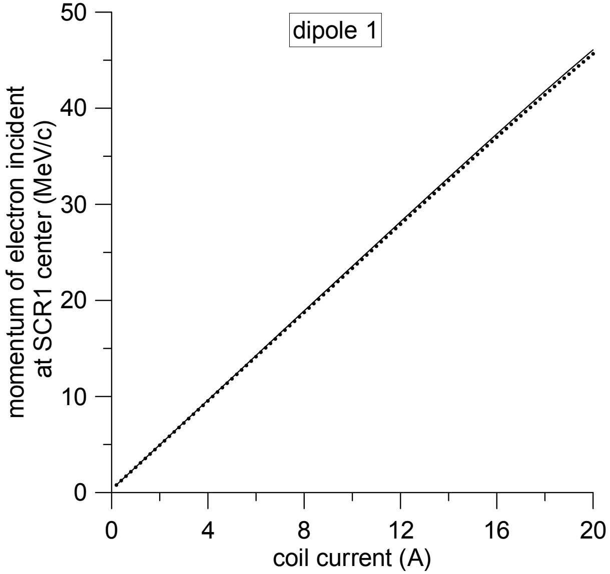
	20A P3	20A P6	20A exp4	14A P3	14A P6	14A exp4
A_0 or a	2.9581×10^{-3}	2.6219×10^{-3}	-8.1733	2.7363×10^{-3}	2.7027×10^{-3}	4.0011×10^{-1}
A_1 or b	1.9374×10^{-2}	2.1283×10^{-3}	-3.7936×10^{-1}	1.9656×10^{-2}	2.0208×10^{-2}	-1.4289×10^{-1}
A_2 or c	6.6165×10^{-5}	-1.0782×10^{-3}	2.2529×10^{5}	1.3350×10^{-5}	-4.2838×10^{-4}	232.26
A_3 or d	-5.1485×10^{-6}	2.4996×10^{-4}	-436.40	-2.6184×10^{-6}	1.2629×10^{-4}	20.386
A_4		-2.5934×10^{-5}			-1.7354×10^{-5}	
A_5		1.2142×10^{-6}			1.0923×10^{-6}	
A_6		-2.1225×10^{-8}			-2.5987×10^{-8}	

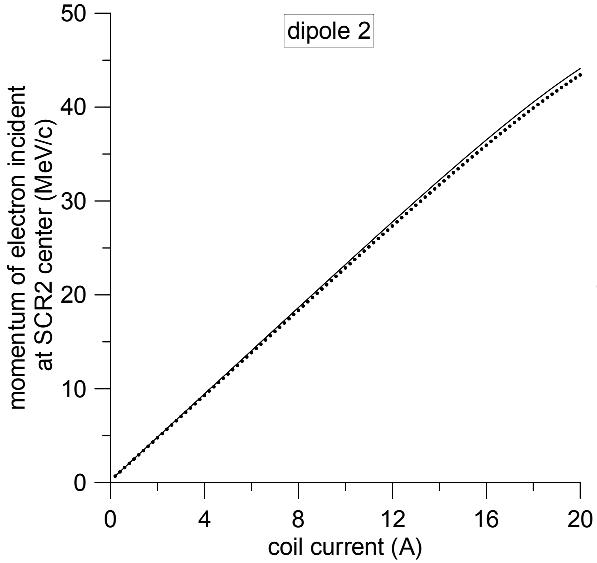
Simulation method and setup

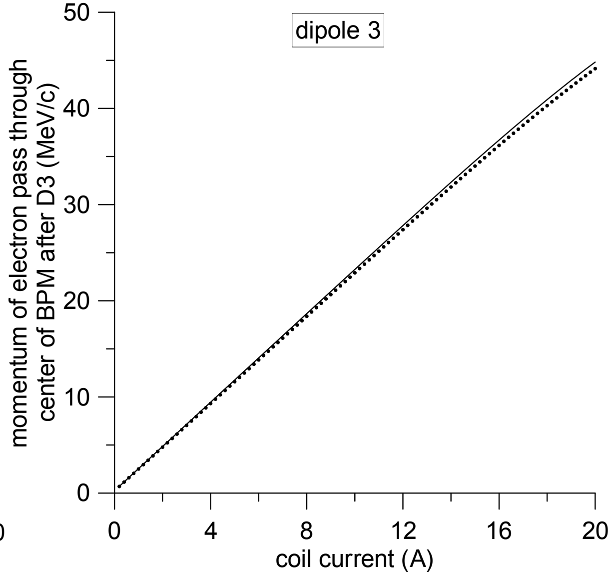


To solve: with Range-Kutta 4th order method

Momentum calibration







- Momentum simulated by the measured fields are less than momentum calculated by hard-edge field due to present of the fringe field

	criteria	A_0	A_1	10^{-6}cr
D1	center	-2.5116×10^{-6}	178.43	179.98
	parallel	-7.7331×10^{-6}	178.41	179.98
D2	center	-6.0606×10^{-7}	117.99	119.92
	parallel	5.9211×10^{-6}	117.67	119.92
D3	center	1.4700×10^{-5}	118.09	119.92
	parallel	-1.0936×10^{-6}	117.70	119.92

Momentum calibration:

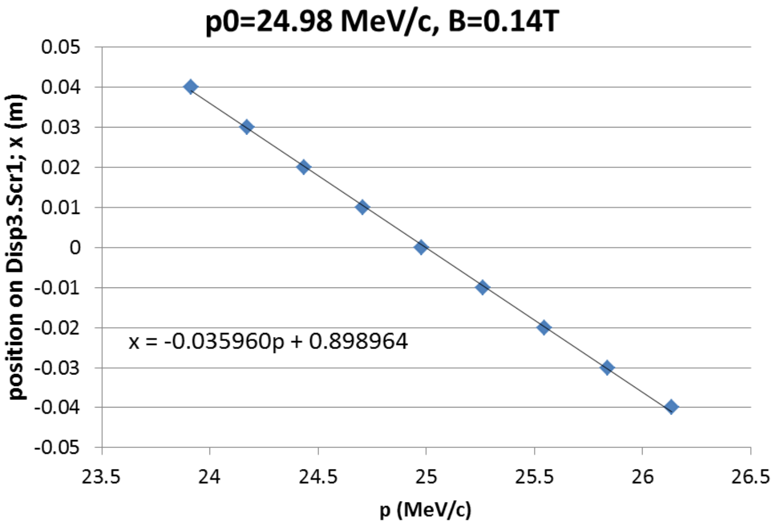
The equation and coefficients required to calculate momentum

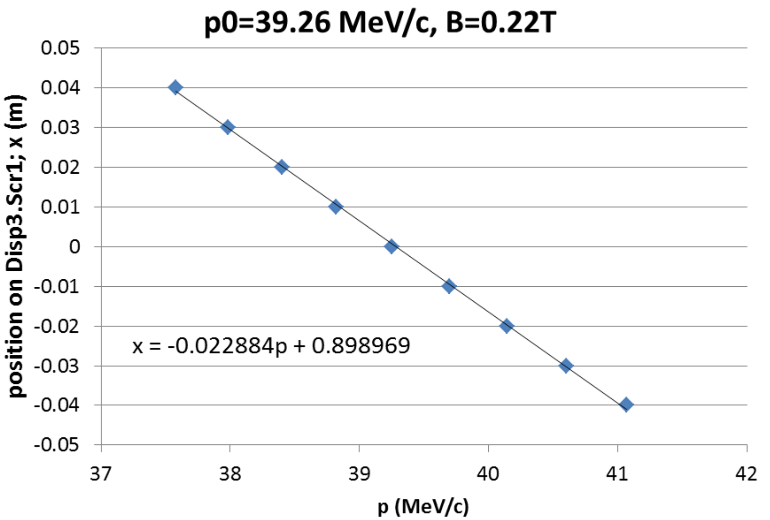
The momentum of the electron that incident at screen center / leave the magnet parallel to the ideal path as a function of the coil current of a dipole magnet can be calculated with this equation and these coefficients.

	D1 center	D1 parallel	D2 center	D2 parallel	D3 center	D3 parallel
A0	3.262×10^{-1}	3.262×10^{-1}	2.468×10^{-1}	2.462×10^{-1}	2.409×10^{-1}	2.401×10^{-1}
A1	2.303	2.303	2.266	2.261	2.269	2.261
A2	1.116×10^{-6}	-2.585×10^{-8}	1.153×10^{-6}	-1.477×10^{-5}	7.839×10^{-6}	1.979×10^{-7}
A3	-3.258×10^{-7}	1.203×10^{-7}	-2.753×10^{-7}	3.254×10^{-6}	-2.155×10^{-6}	1.759×10^{-7}
A4	3.983×10^{-8}	-1.987×10^{-8}	2.788×10^{-8}	-3.318×10^{-7}	2.415×10^{-7}	-3.228×10^{-8}
A5	-2.126×10^{-9}	1.097×10^{-9}	-1.253×10^{-9}	1.559×10^{-8}	-1.183×10^{-8}	1.931×10^{-9}
A6	-1.133×10^{-8}	-1.139×10^{-8}	-3.337×10^{-8}	-3.359×10^{-8}	-2.285×10^{-8}	-2.302×10^{-8}

Please refer to the full report for more information.

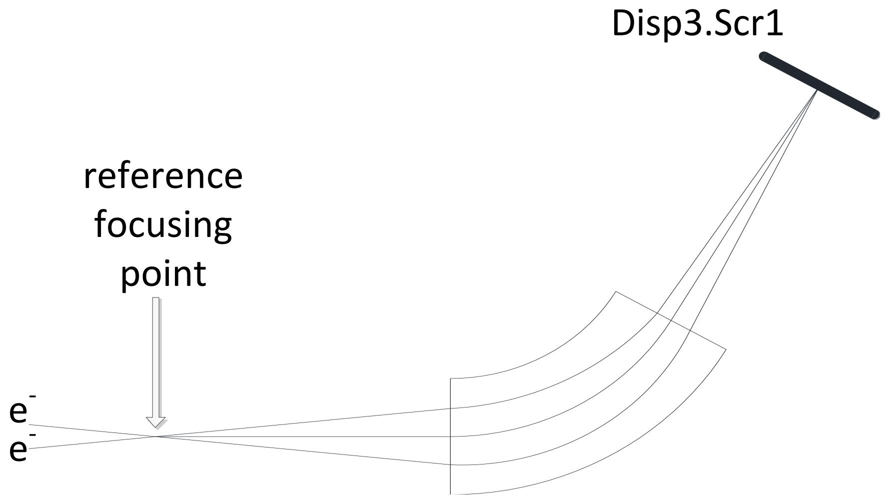
Momentum spread simulation





First order dispersion *D* = 0.898976 m from the simulation compare to 0.905 m from transport metrix.

Optimum focal point for Disp3.D1

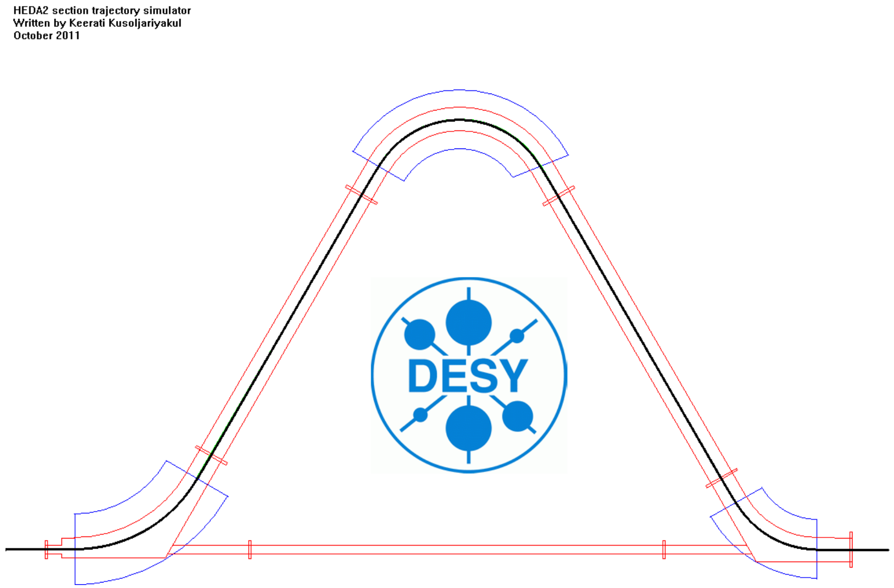


If the beam has finite size, the dipole magnet will focus the beam on bending plane.

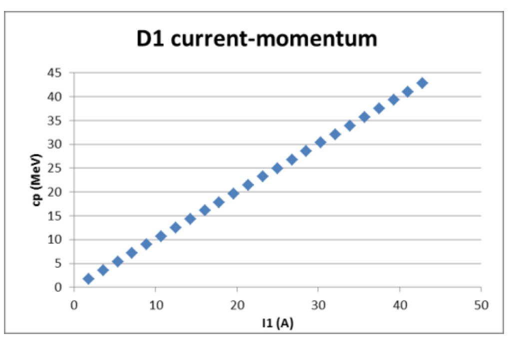
The beam should be focused somewhere to compensate the focusing effect of the dipole.

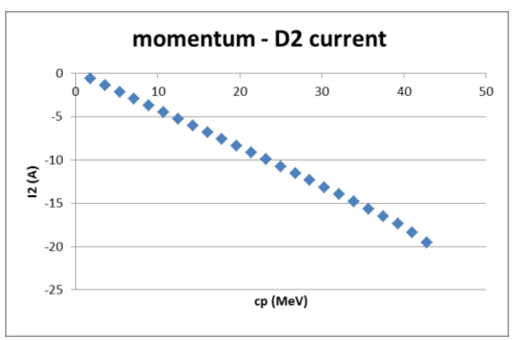
	PITZ position (m)	beam size (radius) at magnetic field entrance (envelop) (mm)	divergence at magnetic field entrance (envelop) (mrad)	beam size (radius) at the screen (µm)	equivalent momentum error	equivalent momentum error at p_0=25 MeV/c (keV/c)
optimum	15.657	0.5	0.3799 (diverse)	0.836	-1.21×10^{-6}	-0.030
PST.Scr5	15.318	0.5	0.3023 (diverse)	53.847	-6.09×10^{-5}	-1.523
High2.Scr2	18.262	0.5	-0.3799 (converse)	539.913	-6.08×10^{-4}	-15.203

Coupled mode



- Objective is to find the operating currents of all magnets that transport the beam through HEDA2 to the beam dump.
- First, consider the ideal trajectory in the picture. We need to find the field of each magnet that make the electron at various momenta move on this ideal path.
- Next, the fields will be converted to currents of corresponding magnet.
- Finally, we can find the current of a magnet as a function of the current of a former magnet that provide this ideal trajectory.





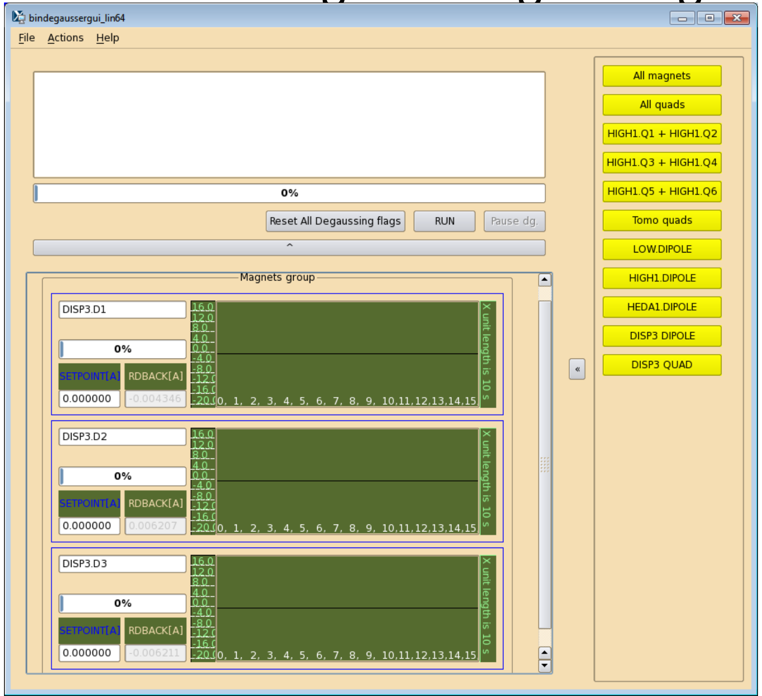
Coupled mode

The Deviation(%) is the percentage value deviate from the value from above equations that operator can set (in limited mode). They are obtain from simulation by finding the maximum deviation that the electron still be able to reach the beam dump.

Addition information

- The reports and field data can be accessed at /afs/ifh.de/group/pitz/doocs/measure/Magnets/Dipoles/HEDA2
- The coupled mode fitting has been verify up to Disp3.Scr2 with noticeable off center. One needs to verify or recalibrate the coefficients with real experiment.
- The degaussing procedure has been implemented using new degaussing GUI.

	Field at 20A (T)	Field after degaussed (μT)
D1	0.2583	70
D2	0.3707	7.6
D3	0.3748	58



Conclusion

- Magnetic field of the dipole magnets have been processed and available at /afs/ifh.de/group/pitz/doocs/measure/Magnets/Dipoles/HEDA2
- The relation between momentum of the electron travel on the ideal path and the magnet coil current has been established.
- The behavior of the magnet Disp3.D1 as a spectrometer has been reported. The optimum focusing position has been suggested.
- The calculation method for the coupling mode and the result have been presented.

I would like to thank all friends and colleagues, you give me an amazing and invaluable experience here at PITZ. Thank you very much.