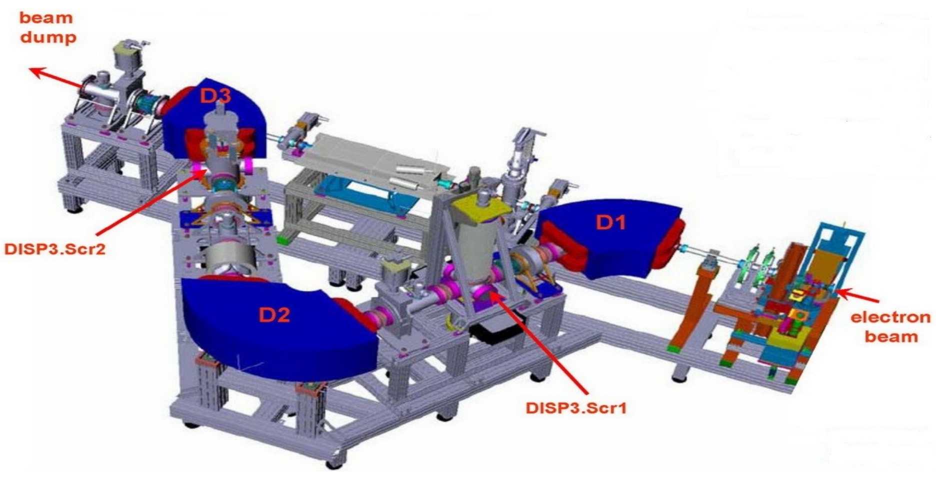
Fields and electron trajectories analysis for HEDA2 dipole magnets

Keerati Kusoljariyakul

Contents

HEDA2



Devices along the dispersive arm

- 3 dipole magnets
- 1 quadrupole magnets
- 2 ICTs
- 2 BPMs
- 2 screen stations

Question

- How different the field use in simulation code like ASTRA compare to the real measurement field?

Dipole magnet specification

Magnet	**D1**	**D2**	**D3**
[redacted]			
Bending angle (°)	60	120	60
[redacted]			
Exit angle (°)	0	9	0
[redacted]			
Homogeneity	$\pm5\times10^{-4}$	$\pm5\times10^{-4}$	$\pm5\times10^{-4}$
[redacted]			

Only specification that relate to this work is shown.

S.Rimjaem

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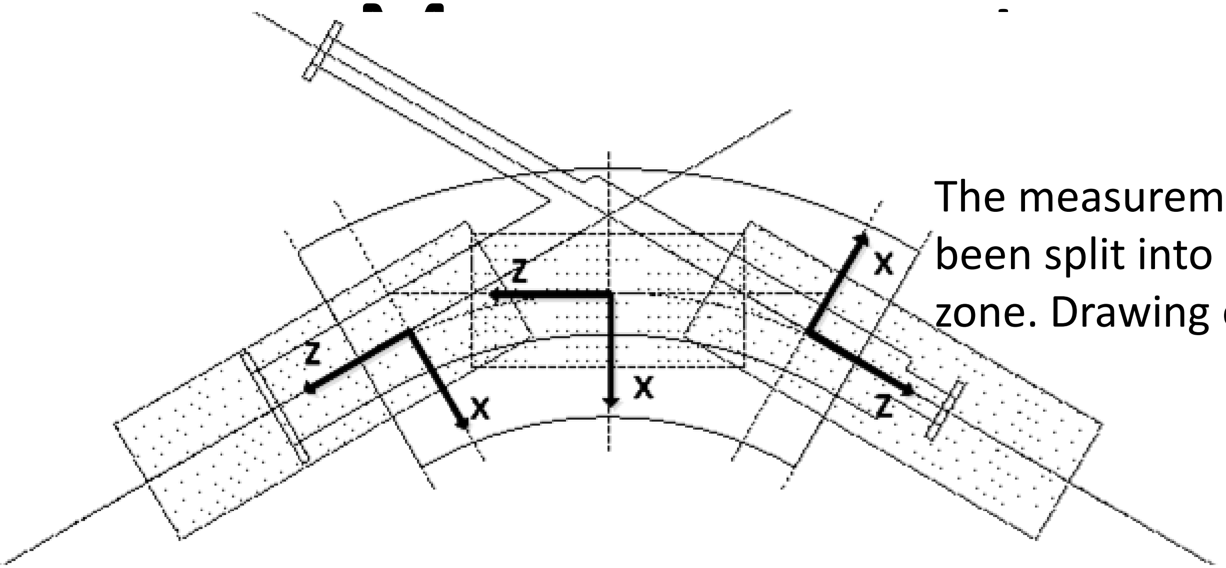


The measurement area have been split into 3 rectangular zone. Drawing on left is D1.

Magnet	zone	D1	D2	D3
x (mm)[from,to]*	1	[-80,80]	[-80,80]	[-60,60]
	2	[-80,80]	[-80,80]	[-60,60]
	3	[-70,90]	[-48,107]	[-60,50]
z (mm) [from,to]*	1	[-125,365]	[-145,360]	[-80,360]
	2	[-125,365]	[-145,360]	[-80,360]
	3	[-165,165]	[-250,250]	[-95,95]
z-axis angle (°)**	1	0	180	180
	2	180	0	180
	3	0	180	0

Zone1 = left
Zone2 = right
Zone3 = center

*5 mm step
**angle to ideal path, ideal path defined as path on center of dispersive arm beam line

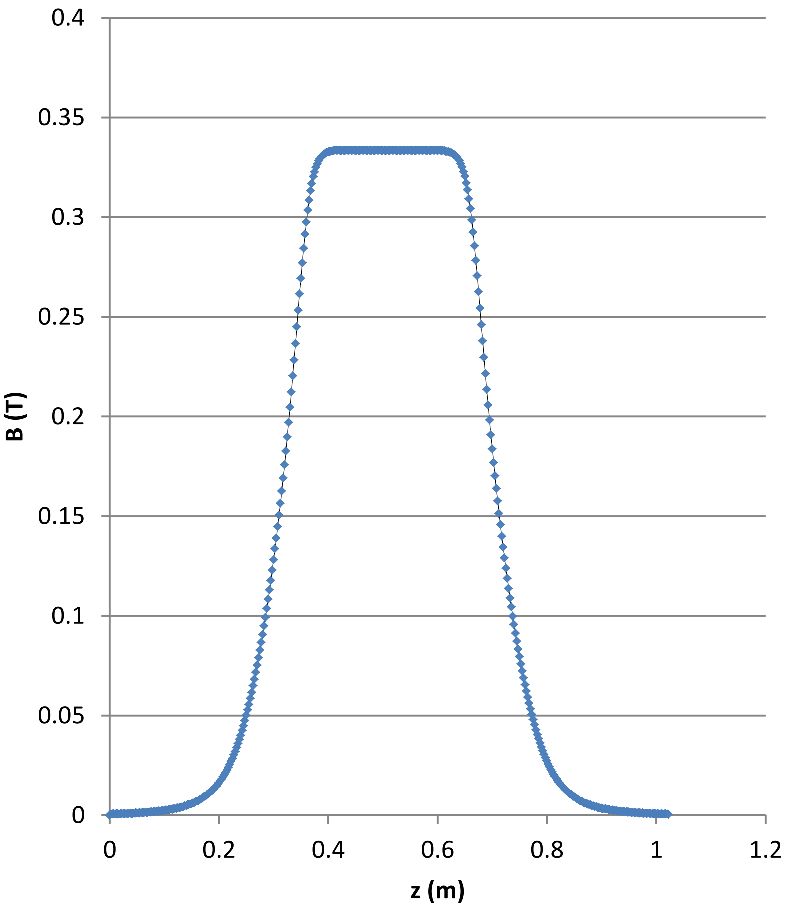
Information from DANFYSIK report

Field resampling

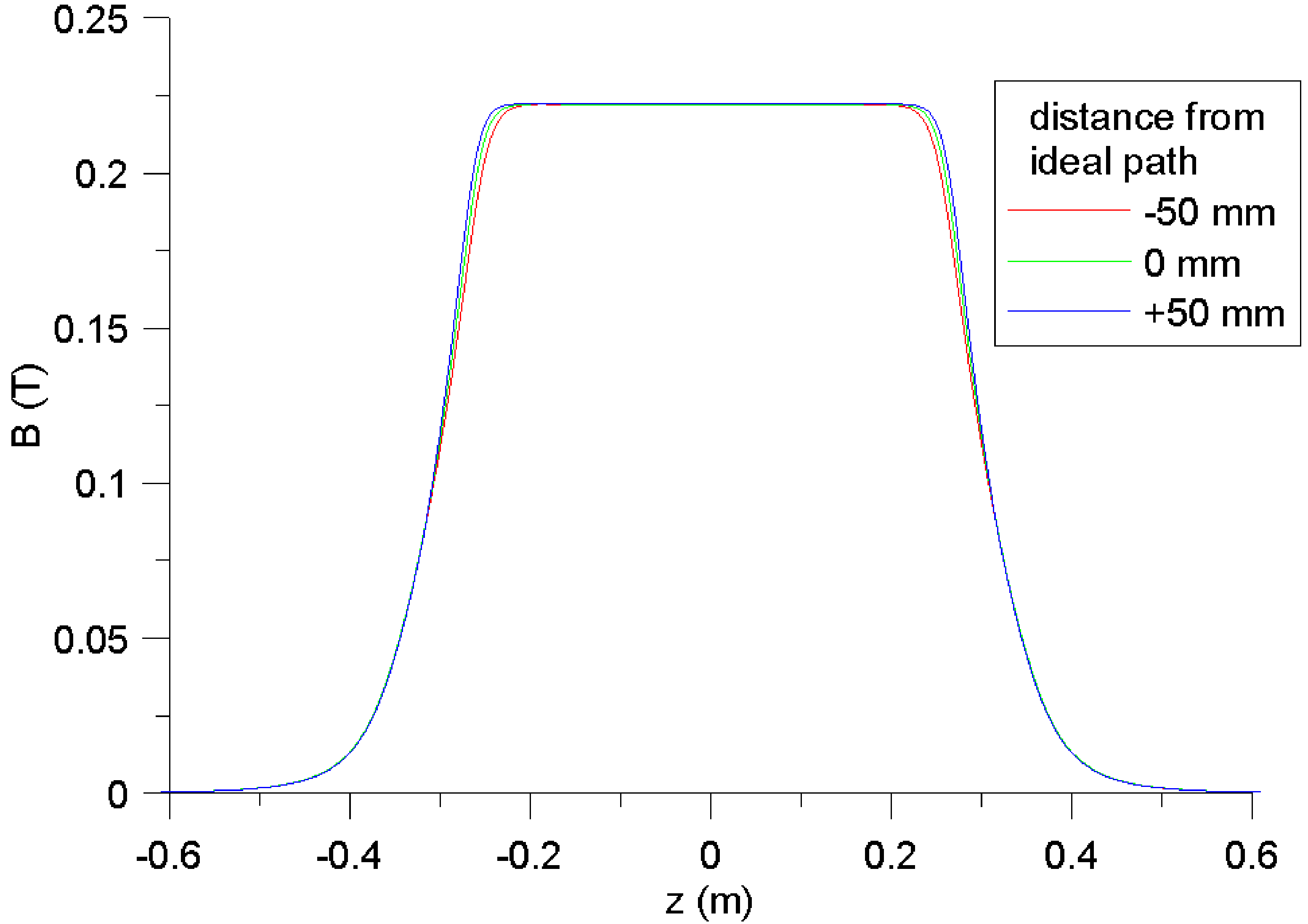
We need to know the field at points where electron will pass, which are mostly not cover in measurement. Thus, resampling is necessary.

Details

- Bilinear interpolation
- No extrapolation
- Can sampling everywhere

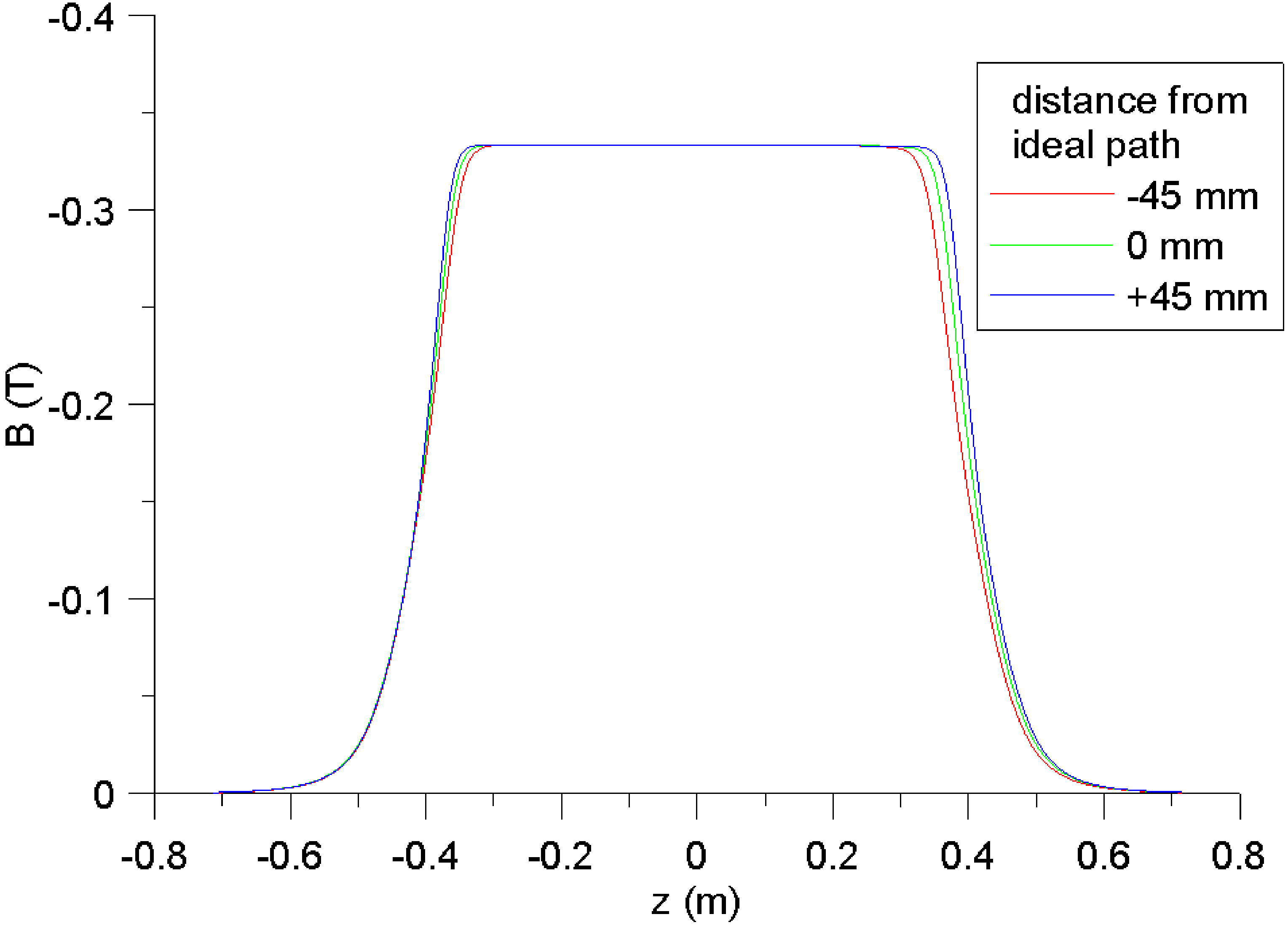


D1



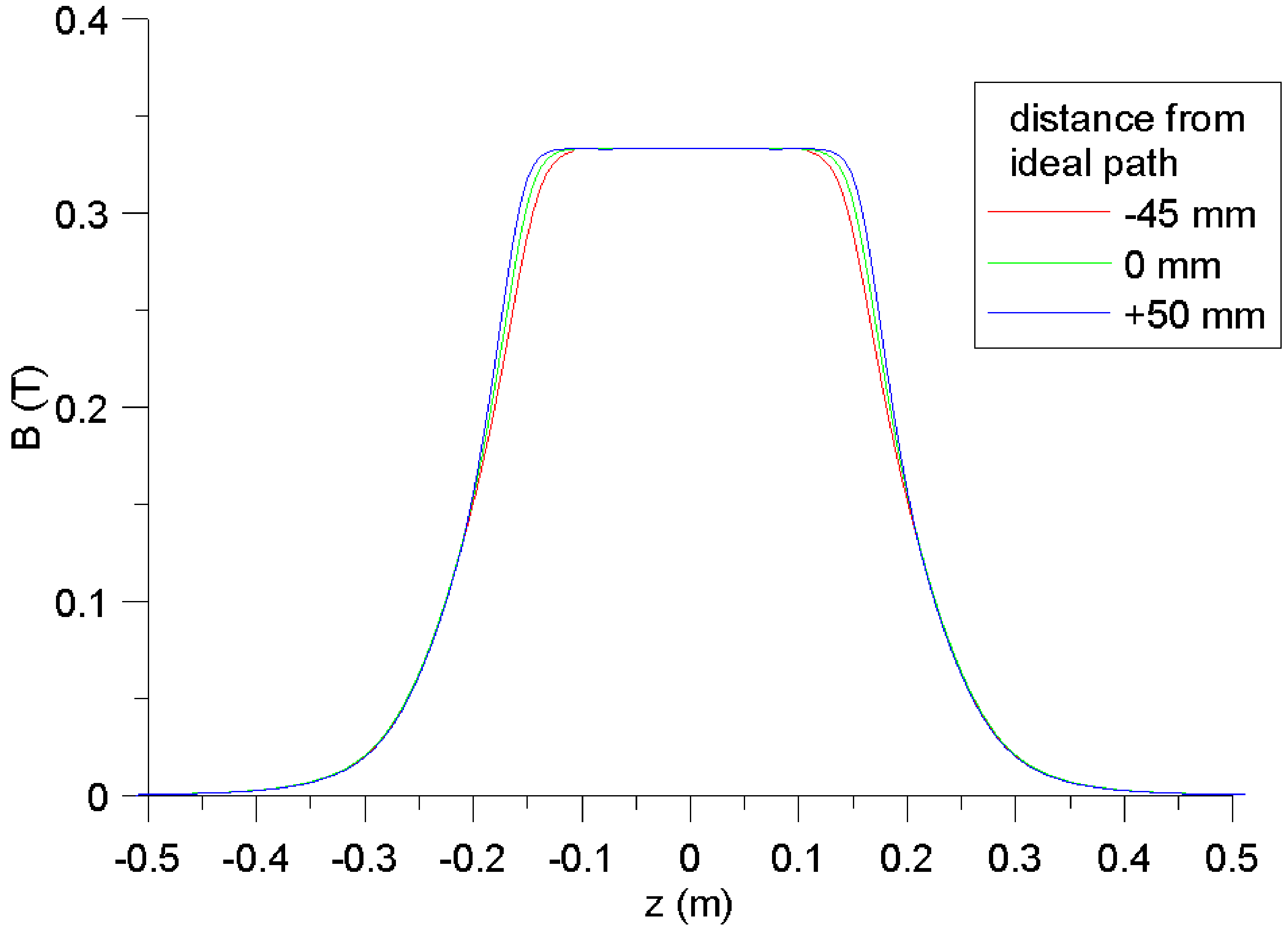
z is measured on ideal path

D2



z is measured on ideal path

D3

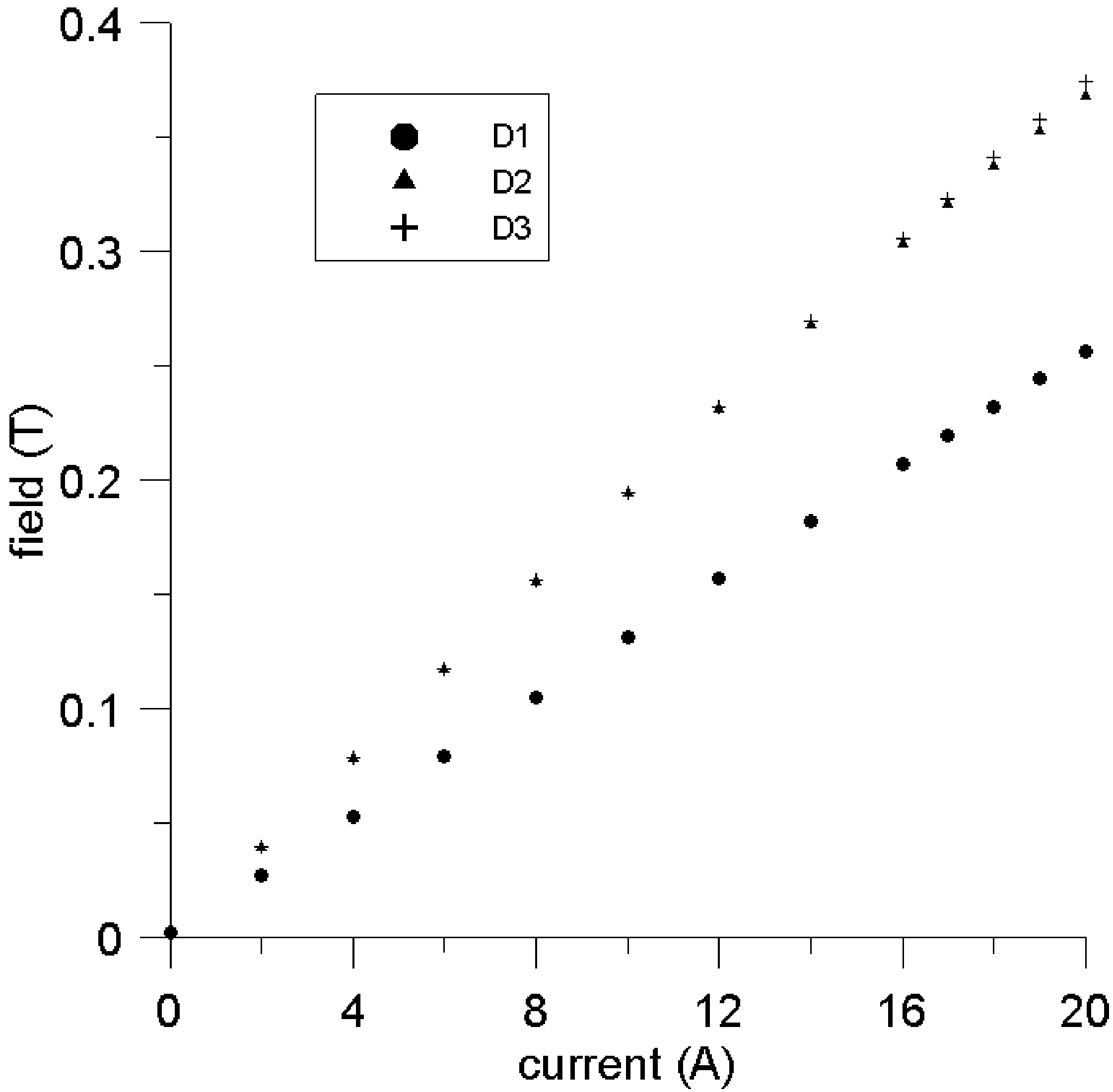


z is measured on ideal path

Effective length

x =	-45 mm	-25 mm	0 mm	25 mm	45 mm
D1 (mm)/(°)	621.4	623.4	625.4	627.0	628.1
	59.34	59.53	59.72	59.87	59.98
D2 (mm) /(°)	818.1	825.2	832.6	838.8	842.7
	117.19	118.20	119.25	120.14	120.71
D3 (mm) /(°)	409.7	412.9	416.0	418.3	419.4
	58.69	59.15	59.59	59.91	60.07

Excitation



6th order polynomial fitting

	D1	D2	D3
A0	2.213E-03	2.229E-03	2.218E-03
A1	1.238E-02	1.816E-02	1.831E-02
A2	1.104E-04	4.063E-04	3.047E-04
A3	-4.540E-06	-5.730E-05	-3.395E-05
A4	-3.275E-07	3.879E-06	1.596E-06
A5	2.626E-08	-1.329E-07	-3.225E-08
A6	-5.121E-10	1.618E-09	5.531E-11

	designed field at (spec=19A) (linear approx.)
D1	17.81
D1	18.08
D3	17.91

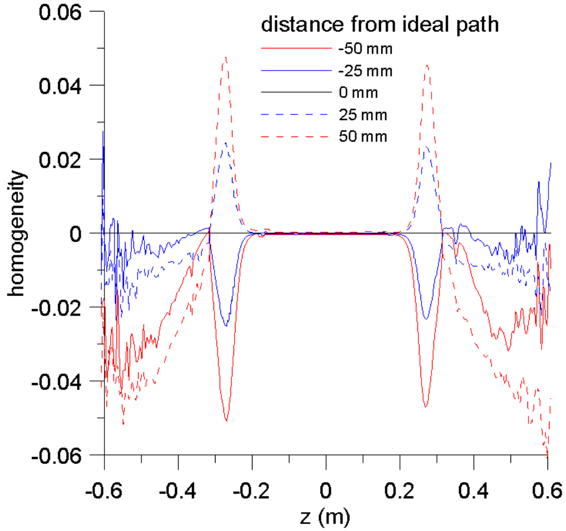
This table show how much current need to produce field amplitude in specification

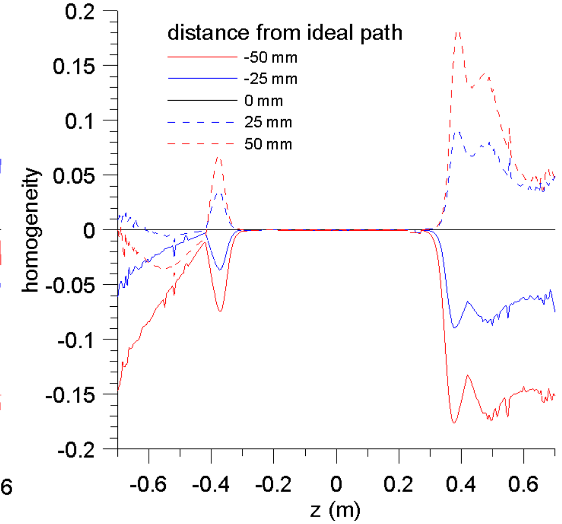
Homogeneity

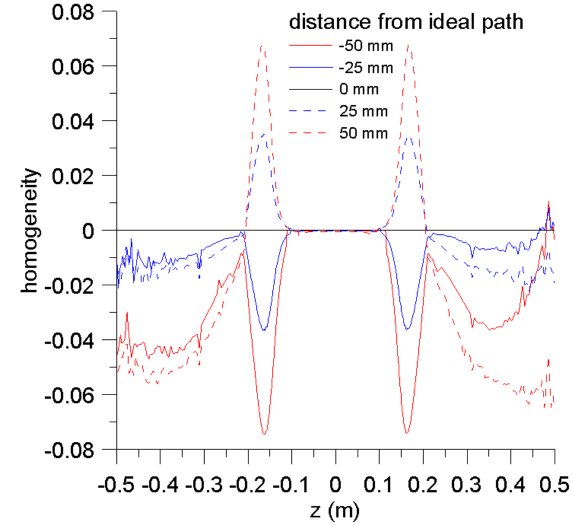
Spec : $5x10^{-4}$ at 2-3 gaps (120-180 mm) from pole edge

D1 D2 D3

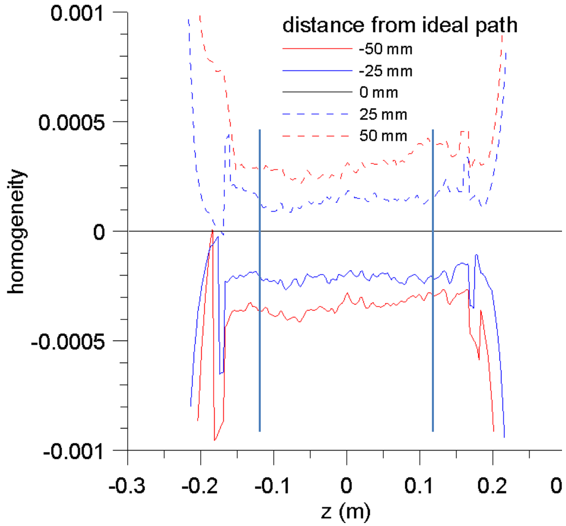
Overall magnet

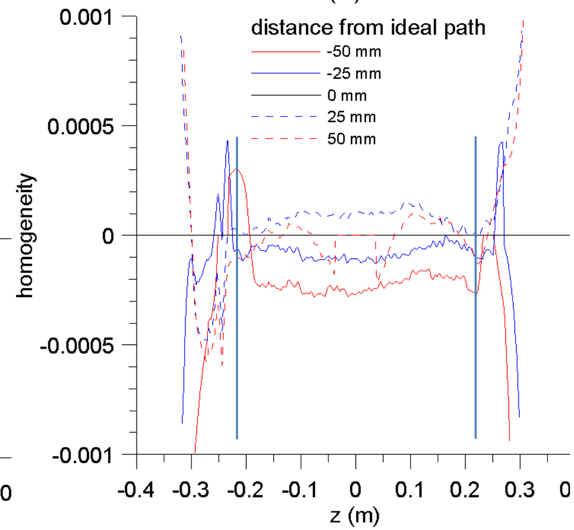


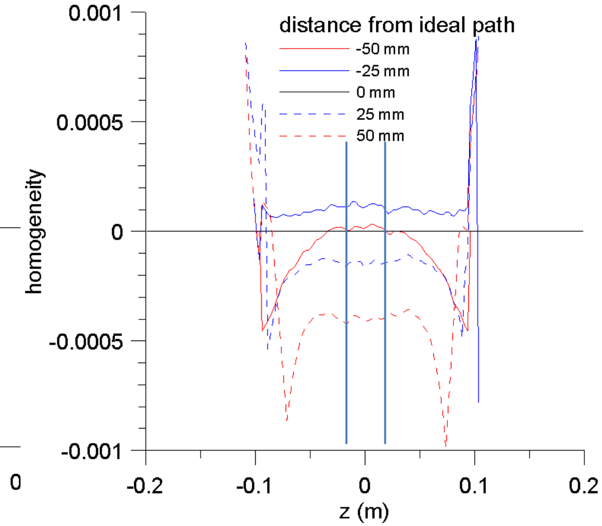




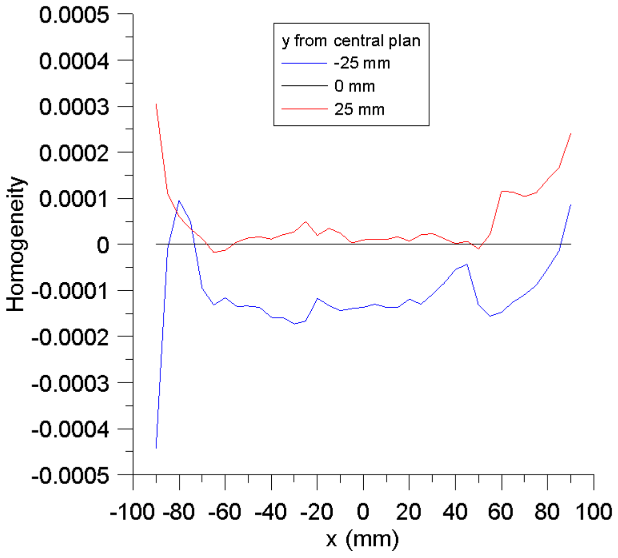
Inside magnet poles (bars show 3 gaps boundary)



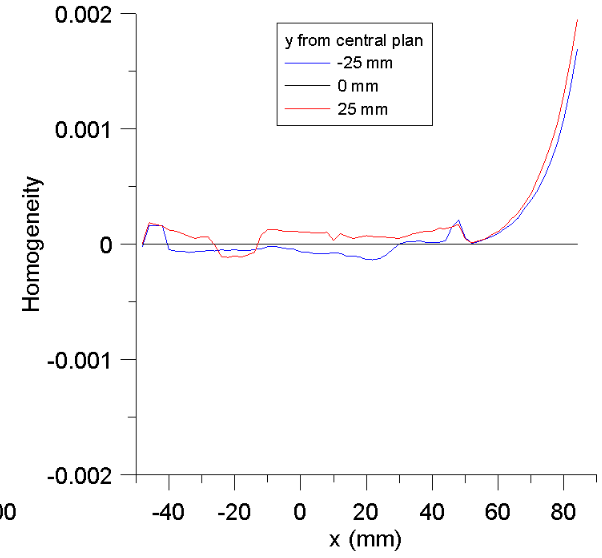




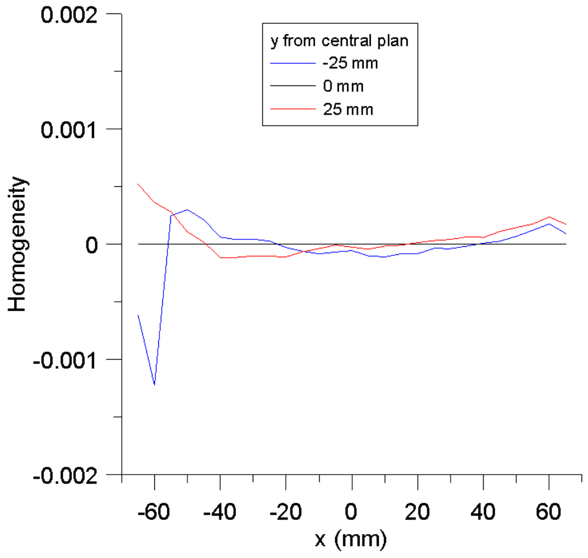
Vertical homogeneity



D1



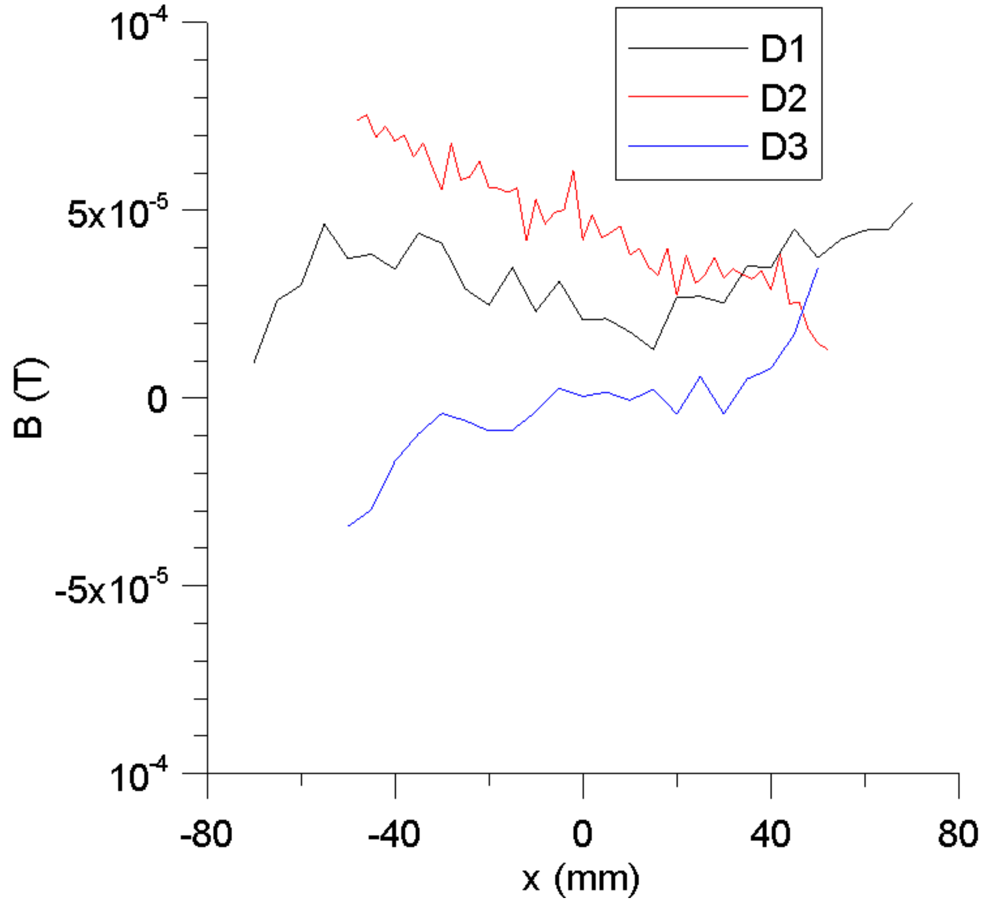
D2



D3

spec: 5×10^{-4} over vertically +/- 25 mm

Horizontal field



DANPYSIK also provides horizontal field measurement .
The field has been measured on horizontal plane.

ASTRA dipole field

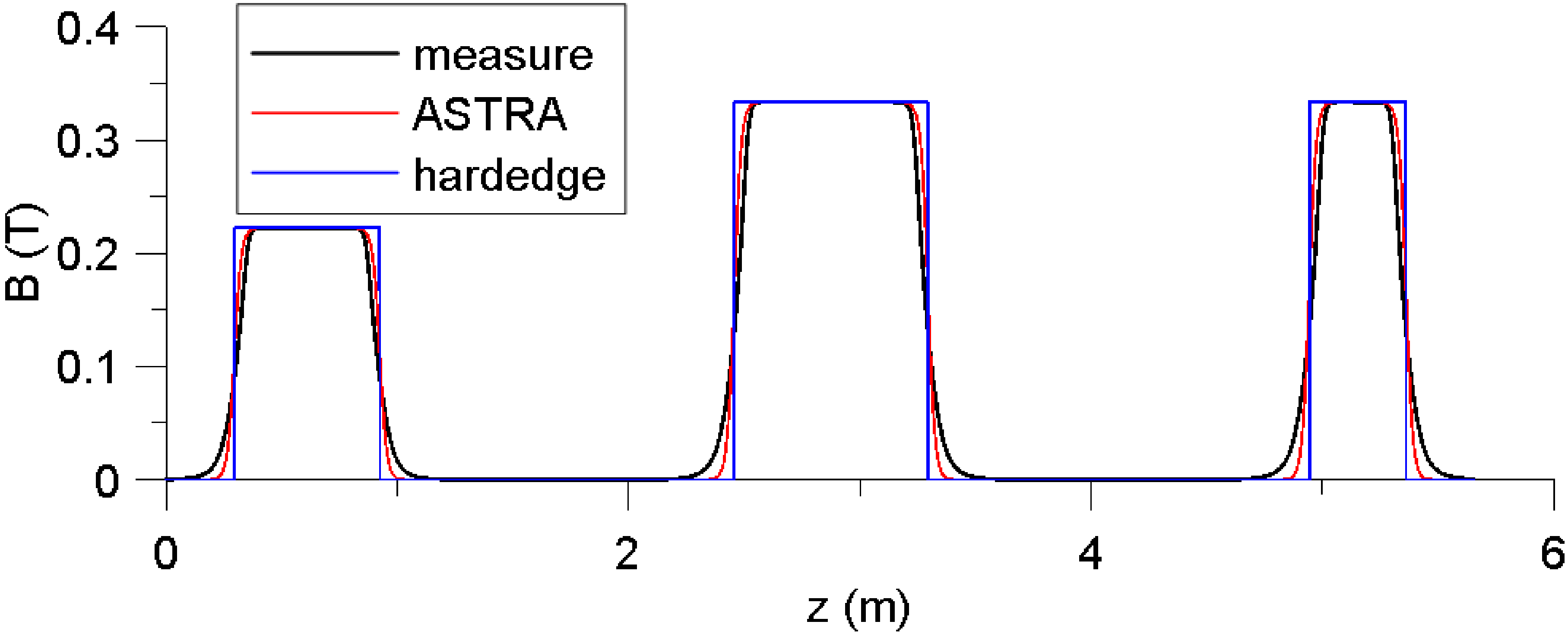
In ASTRA the field of a dipole magnet is calculated from the equation

From ASTRA manual V2.0 p.77

where *d* is normal distance from magnet edge

G is gap between pole

Comparison of fields



Field	L_{eff} D1/D2/D3 (mm)
measurement	624.7/832.4/415.4
ASTRA	628.3/837.2/418.2
hardedge	628.0/837.0/418.0

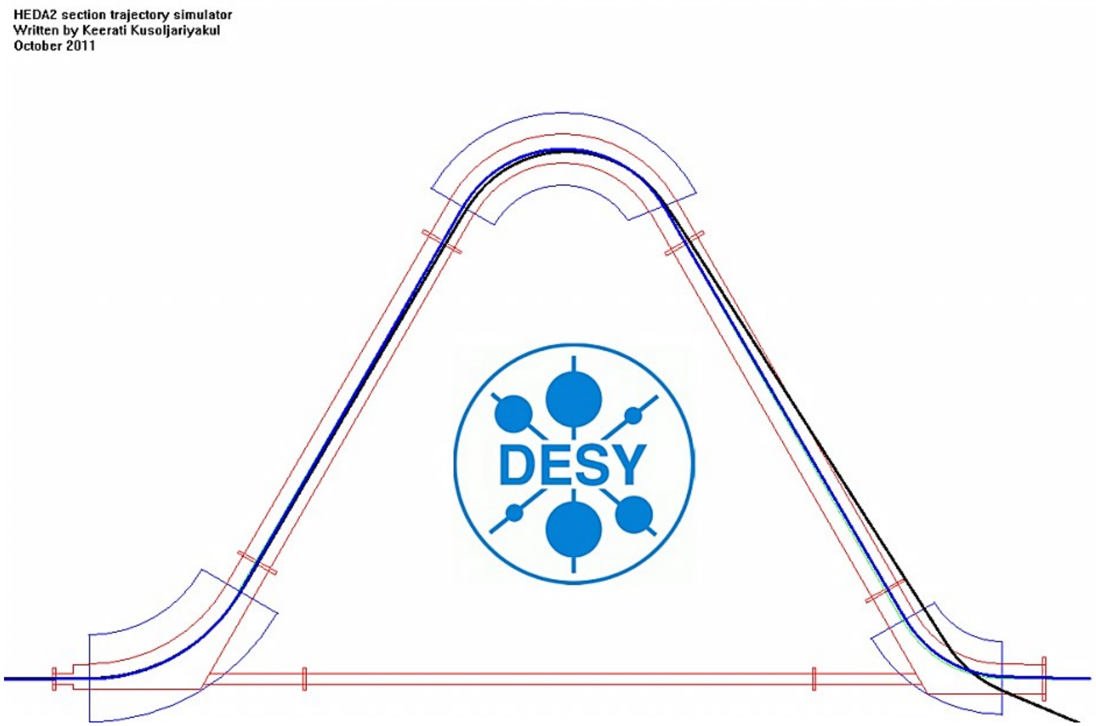
Hard edge field is defined as a field with rectangular field profile with length equal to length of magnet edge.

Trajectory analysis : algorithm

- Using adaptive step size Runge-Kutta 4th order method
- Try to solve the Lorentz force equation

- The Cartesian coordinate is used
- The field can be measurement, ASTRA or hard edge field

Comparison : Trajectories under field



D1 field = 222.358 mT
D2 & D3 field = 333.537 mT

- blue line = ASTRA field.
- black line = field.
- energy = 40 MeV.
- Both fields use same maximum field (field calculated from bending equation).
- Electron move as expected in ASTRA field.
- In measurement field, electron move off the ideal path a little bit after D1 then D2 amplify the effect, make the electron hit chamber before entering D3

Optimized trajectory : parallel to ideal path at D3 exit

25 MeV

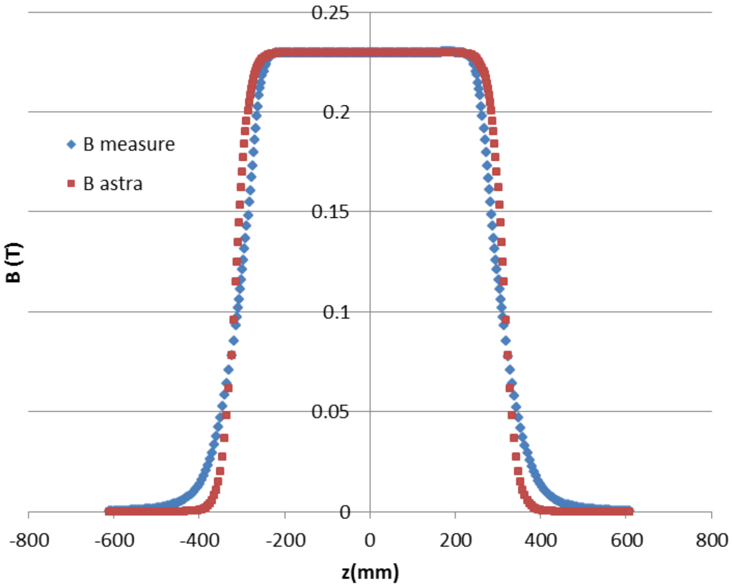
	Measurement	ASTRA	Hardedge	Ideal
D1 field (mT)/(A)	140.167/10.72	138.956	138.956	138.956
D2 field (mT)/(A)	212.264/10.96	208.434	208.434	208.434
D3 field (mT)/(A)	210.180/10.85	208.729	208.437	208.434
x at D3 exit (m)	-2.91×10^{-3}	3.09×10^{-4}	-2.25×10^{-6}	0
x' at D3 exit (°)	1.17×10^{-5}	1.09×10^{-5}	4.03×10^{-6}	0

40 MeV

	Measurement	ASTRA	Hardedge	Ideal
D1 field (mT)/(A)	224.295/17.36	222.585	222.538	222.358
D2 field (mT)/(A)	339.665/18.09	333.490	333.531	333.537
D3 field (mT)/(A)	336.329/17.71	334.009	333.549	333.537
x at D3 exit (m)	2.91×10^{-3}	0	1.48×10^{-5}	0
x' at D3 exit (°)	4.71×10^{-6}	9.08×10^{-6}	-6.86×10^{-6}	0

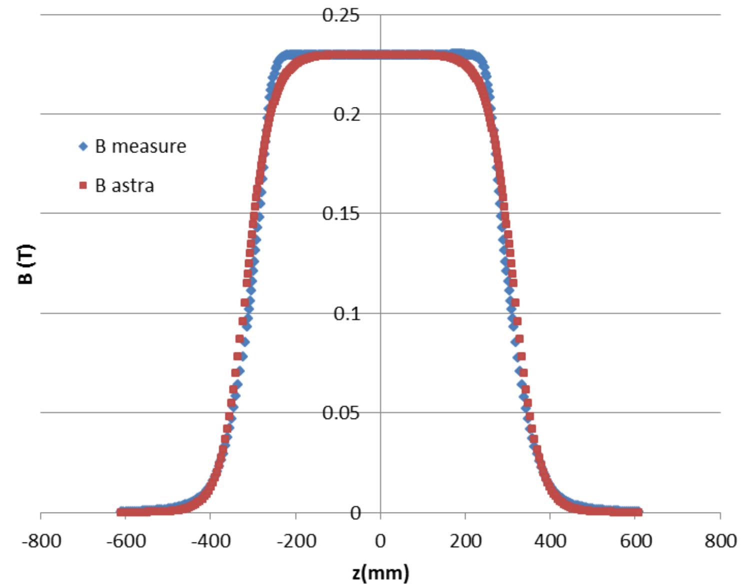
ASTRA field : magnet gap test

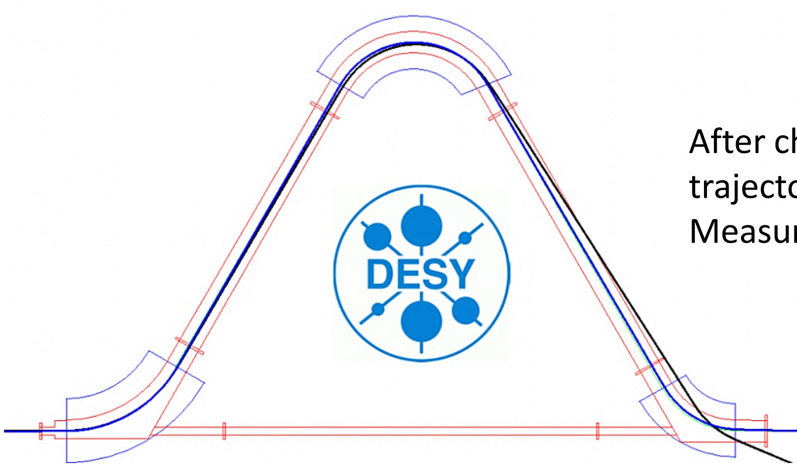
60 mm (actual value)



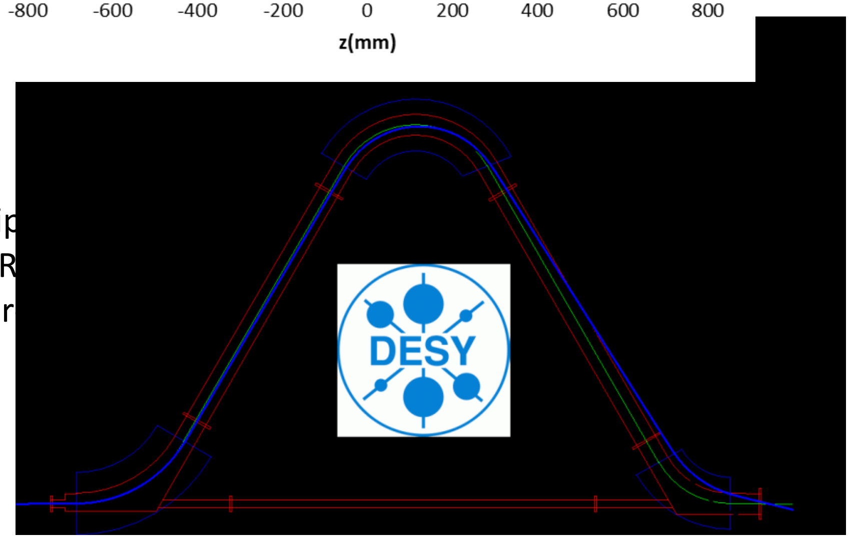
e dipole g
RA

120 mm

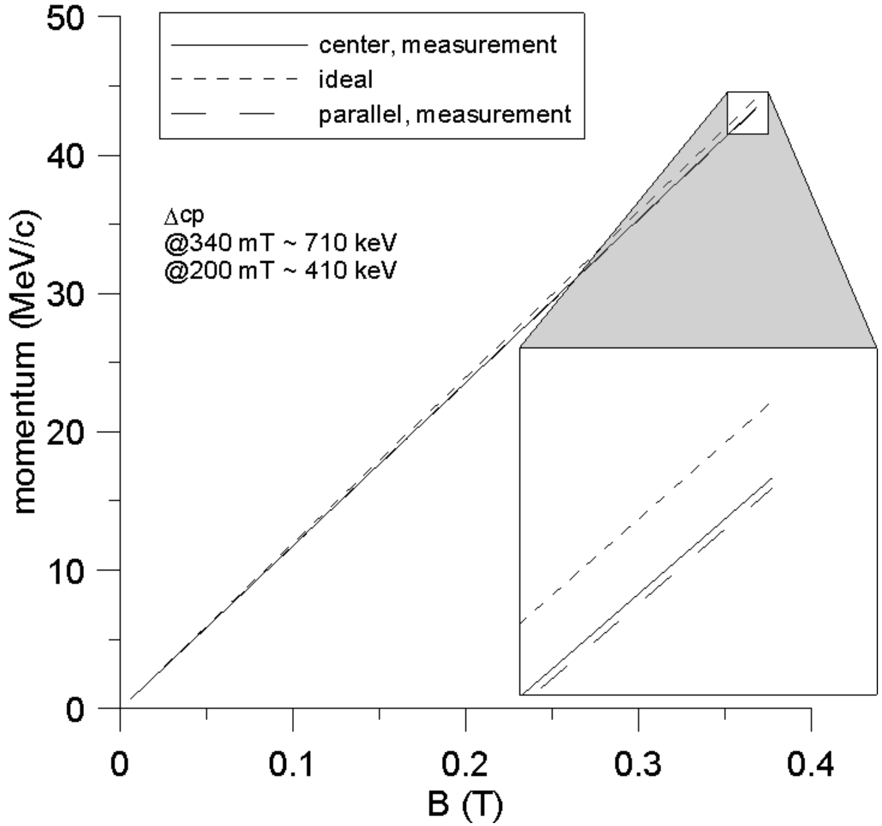


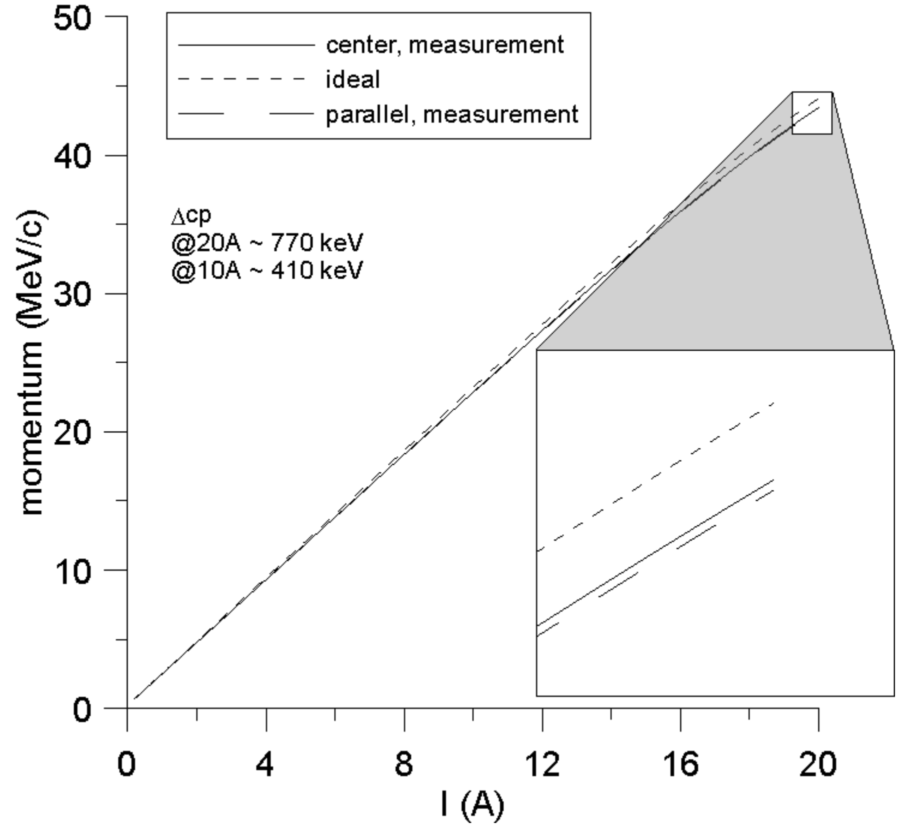


After changing the dip
trajectory under ASTR
Measurement field ar



Energy calibration





Example plot when electron moving on ideal path entering dipole 2, traverse pass dipole 2 and then observed at SCR2. Center meaning that the electron incident at SCR2 center. Parallel mean the electron exit dipole 2 parallel to ideal path.

Energy calibration equations

Center of SCR1/SCR2/BPM

	A0	A1	A2	A3	A4	A5	A6
D1	0.322	2.303	1.116E-06	-3.257E-07	3.982E-08	-2.126E-09	-1.133E-08
D2	0.247	2.266	1.15E-06	-2.752E-07	2.787E-08	- 1.252E-09	-3.337E-08
D3	0.241	2.268	7.838E-06	-2.155E-06	2.415E-07	-1.183E-08	-2.285E-08

Parallel to the ideal path

	A0	A1	A2	A3	A4	A5	A6
D1	0.326	2.303	-2.651E-08	1.205E-07	-1.988E-08	1.097E-09	-1.139E-08
D2	0.246	2.261	- 1.477E-05	3.255E-06	-3.319E-07	1.559E-08	-3.359E-08
D3	0.240	2.261	1.969E-07	1.761E-07	-3.229E-08	1.932E-09	-2.302E-08

Energy calibration comparison

Ideal case

Calibration equation

[SI]

	A0	A1
D1 ideal	0	179.87
D1 center	1.24E-06	178.25
D1 parallel	1.38E-06	178.23
D2 ideal	0	119.92
D2 center	3.76E-07	118.07
D2 parallel	-7.07E-05	117.82
D3 ideal	0	119.92
D3 center	1.04E-05	118.09
D3 parallel	-1.09E-06	117.70

Effect of energy offset at D1

E_0	Energy offset	B (mT)	ΔB (mT)
6.72 MeV	-20 keV	37.4774	-0.1127
	0	37.5901	0.0000
	+20 keV	37.7023	0.1122
25 MeV	-20 keV	140.1084	-0.1122
	0	140.2207	0.0000
	+20 keV	140.3328	0.1122
40 MeV	-20 keV	224.2694	-0.1140
	0	224.3834	0.0000
	+20 keV	224.4938	0.1104

If the beam has energy offset of 20 keV, how much field different to guide the beam incident on center of SCR1?

Summary

- The company provide us the field information we need but we have to process it.
- Effective length of the D1,D2,D3 on ideal trajectory are 59.72, 119.25, 59.59 degree.
- To achieve specify field, the current need for D1,D2,D3 are 17.81, 18.08, 17.91.
- Field homogeneity is in specification.
- ASTRA field with correct gap is stronger than the measurement field, but we may able to adjust the gap or pole edge to mimic measurement field.
- The dipole magnet current-electron momentum relation has been study.

TODO

- Energy spread measurement on the screen
- Ability to measure sliced beam parameters
- Use ASTRA output as input to compare the result with ASTRA