

KoBRA Magnet Control for Beam Tuning with Ion Optics

2022. 07. 20.

Low Energy Experimental System Team

Hanyang University, Ph. D Candidate

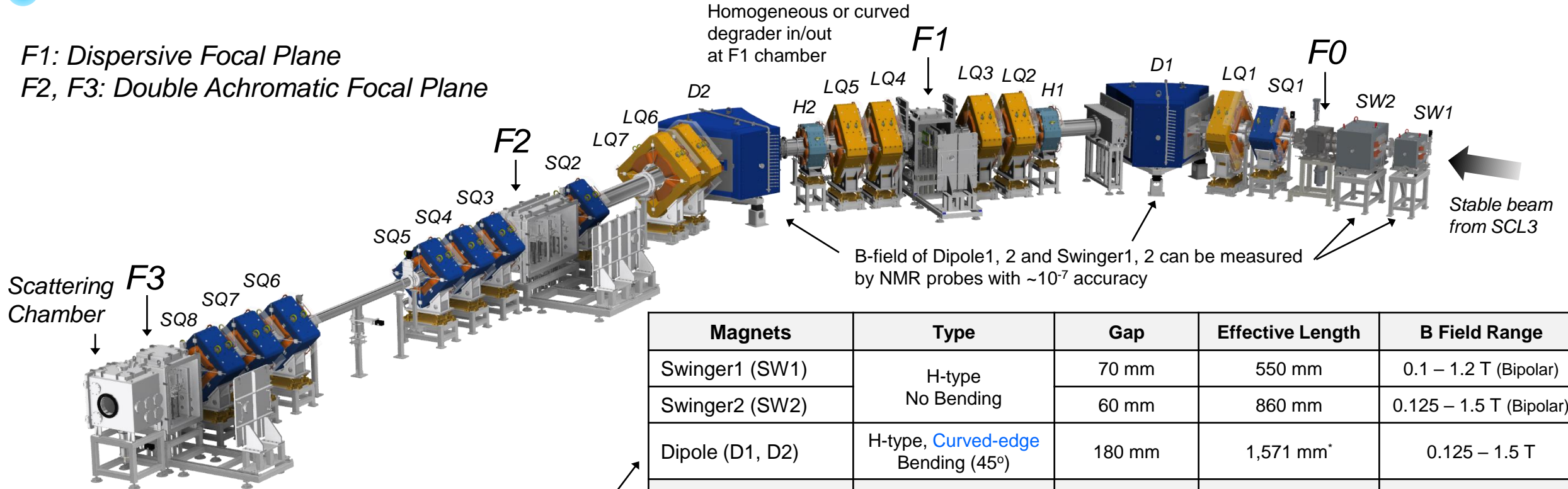
Dong Geon Kim

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KoBRA Stage1

F1: Dispersive Focal Plane

F2, F3: Double Achromatic Focal Plane



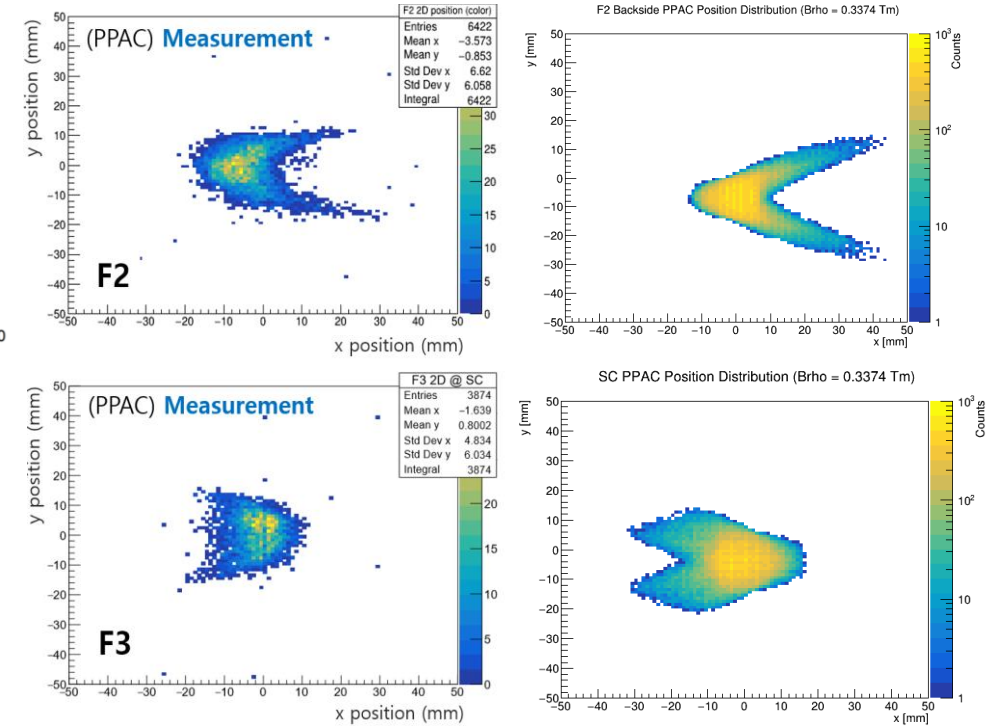
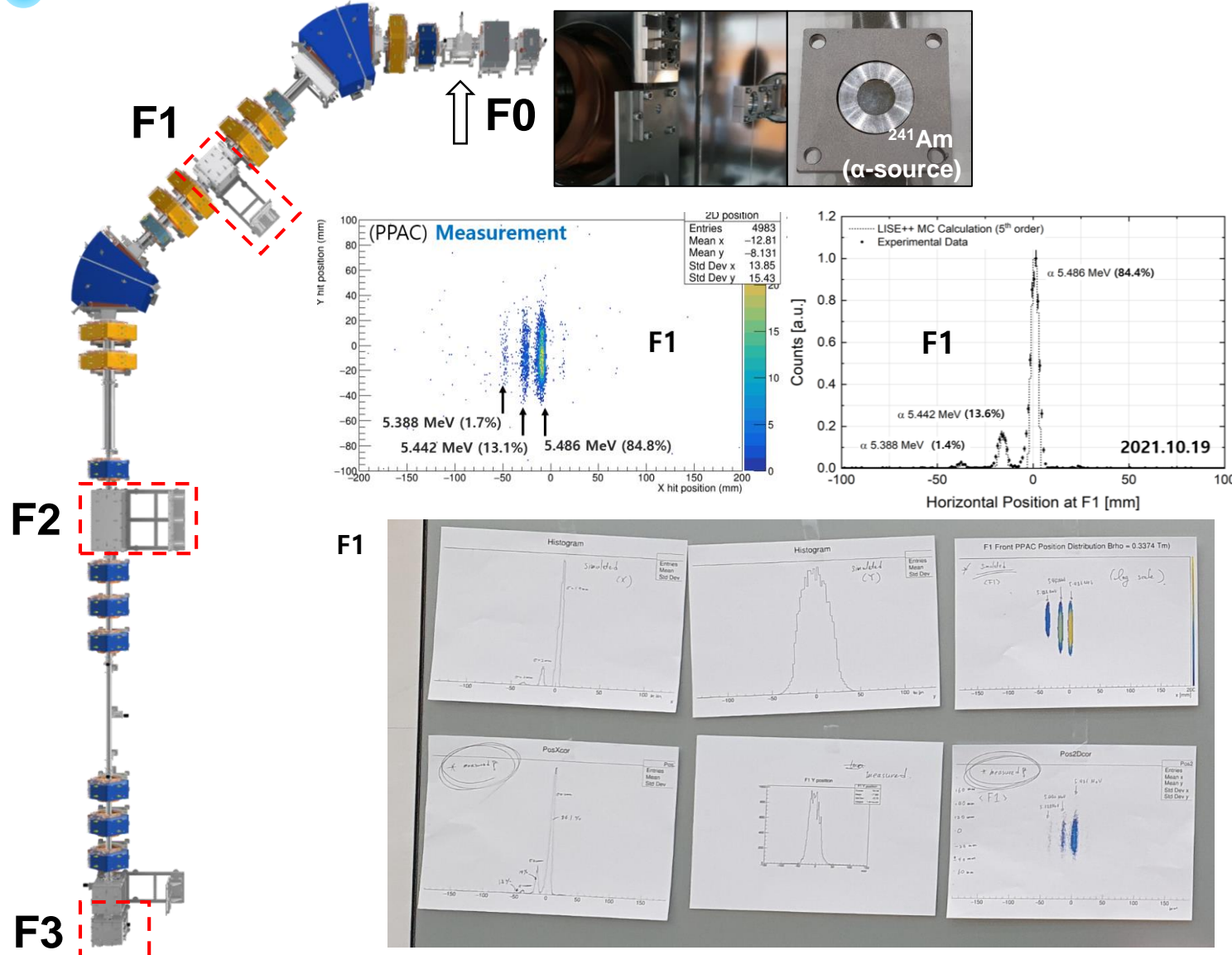
Magnets	Type	Gap	Effective Length	B Field Range
Swinger1 (SW1)	H-type No Bending	70 mm	550 mm	0.1 – 1.2 T (Bipolar)
Swinger2 (SW2)		60 mm	860 mm	0.125 – 1.5 T (Bipolar)
Dipole (D1, D2)	H-type, Curved-edge Bending (45°)	180 mm	1,571 mm*	0.125 – 1.5 T
Magnets	Aperture diameter	Physical Length	Effective Length	B Field Range
Small Quadrupole(LQ1-8)	210 mm	592 mm	668.5 mm	0.0027 – 0.8 T
Large Quadrupole(SQ1-7)	410 mm	496 mm	640.5 mm	0.009 – 0.7 T
Sextupole(H1, H2)	410 mm	428 mm	527.5 mm	0.005 – 0.25 T

*Effective length of dipole magnet is considered in optics tuning depending on B-field

For large acceptance and minimization of high order aberrations

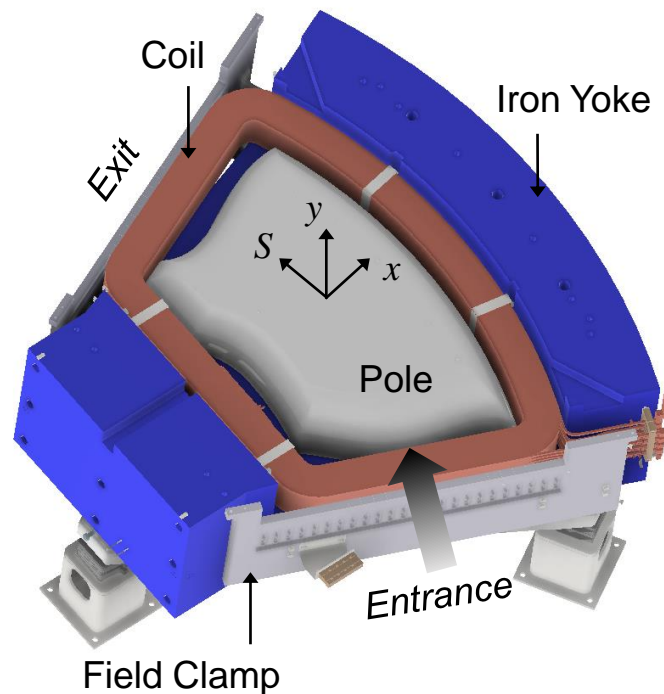
- ✓ Angular acceptance = 80 mrad (H), 200 mrad (V)
- ✓ Momentum acceptance = 8%
- ✓ Magnetic rigidity ($B\rho$) = 0.25 – 3.0 Tm
- ✓ High order correction = up to 5th order

(First) Alpha Beam Commissioning at 2021.10.

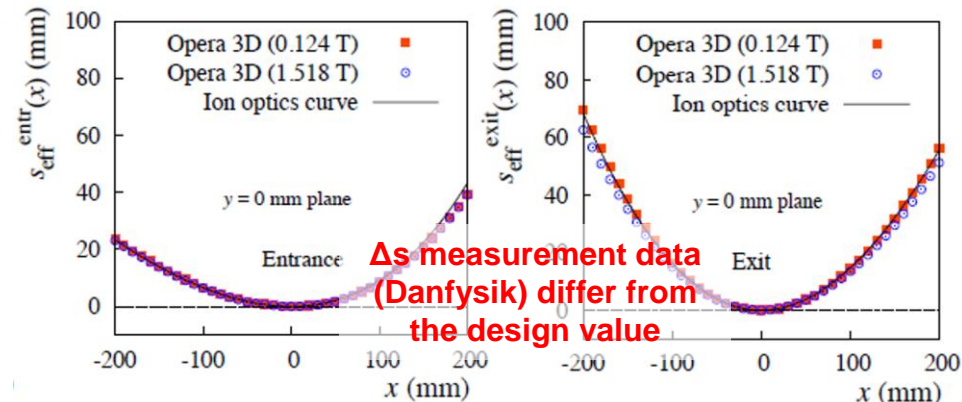
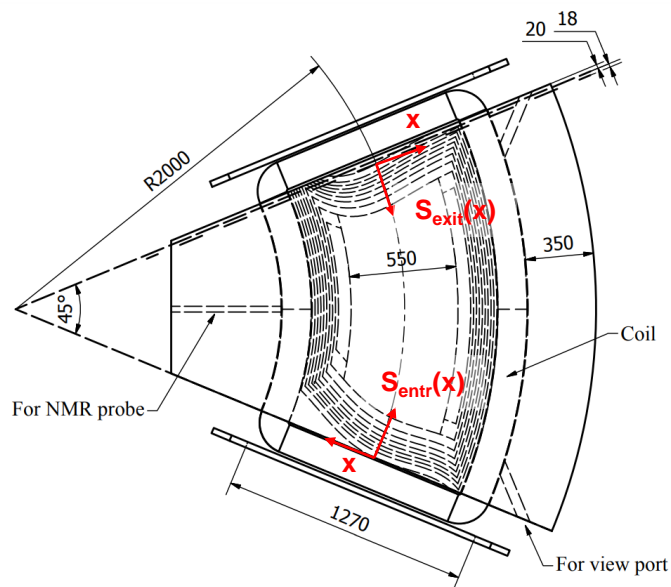


✓ The results of the position distributions were consistent with each other

KoBRA Ion Optics Calculation

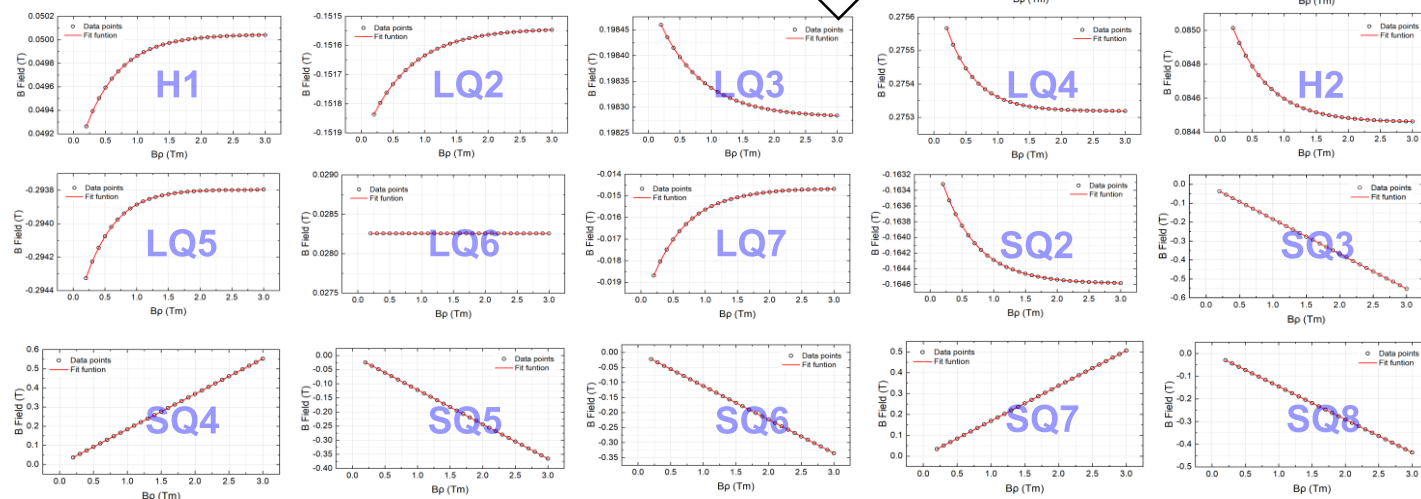


Curved Boundary Bending Magnet



Effective field boundary curves at entrance and exit

Optical tuning
for dipole B_p range
(0.2 to 3.0 Tm)



✓ Polynomial functions for the entrance and exit

$$s_{entr}(x) = -0.03334x + 1.109x^2 + 2.32716x^3 + 3.49304x^4$$

$$s_{exit}(x) = -0.06761x + 1.61773x^2 + 2.18264x^3 - 10.4334x^4$$

KoBRA Ion Optics Calculation (1st order)

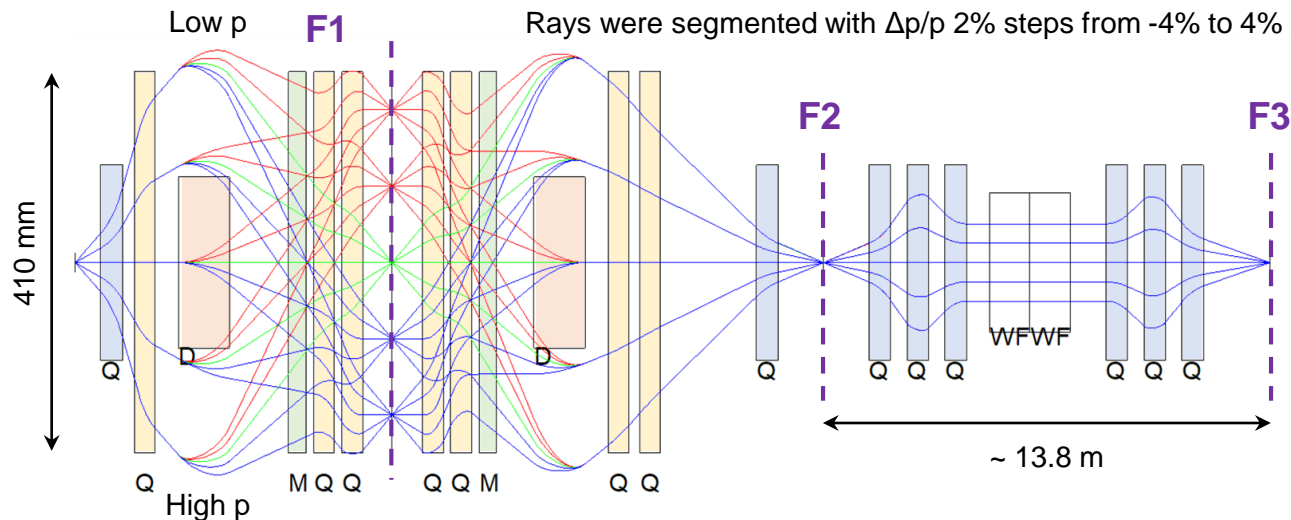
- ✓ B Field Optical Tuning of SQ, LQ, SX for dipole Bp range (0.2 to 3.0 Tm)
- ✓ Optical tuning observes KoBRA optics design parameters
 - F1: Dispersive Focal Plane (Momentum dispersion at F1 = 4.1 cm/%)
 - F2, F3: Double Achromatic Focal Plane (Angle & momentum dispersion = 0)

KoBRA Ion Optics Design Parameters

	F1	F2	F3
(x x)	0.96	2.7	3.2
(x θ)	0	0	0
(y y)	10.7	3.0	3.9
(y Φ)	0	0	0
(x δ)	4.1	0	0
(θ δ)	0	0	0

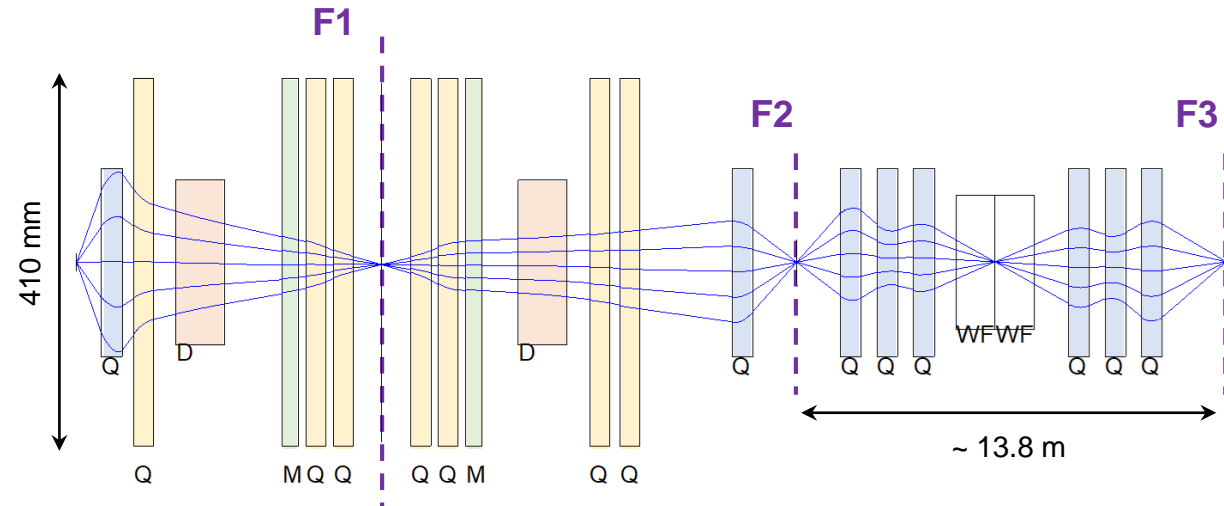
※ Degradar not use

Horizontal Ray Plot



$x, y = 0$ mm, $\theta = \pm 40$ mrad, $\Phi = 0$ mrad, $D_p = 4\%$

Vertical Ray Plot



$x, y = 0$ mm, $\theta = 0$ mrad, $\Phi = \pm 100$ mrad, $D_p = 4\%$

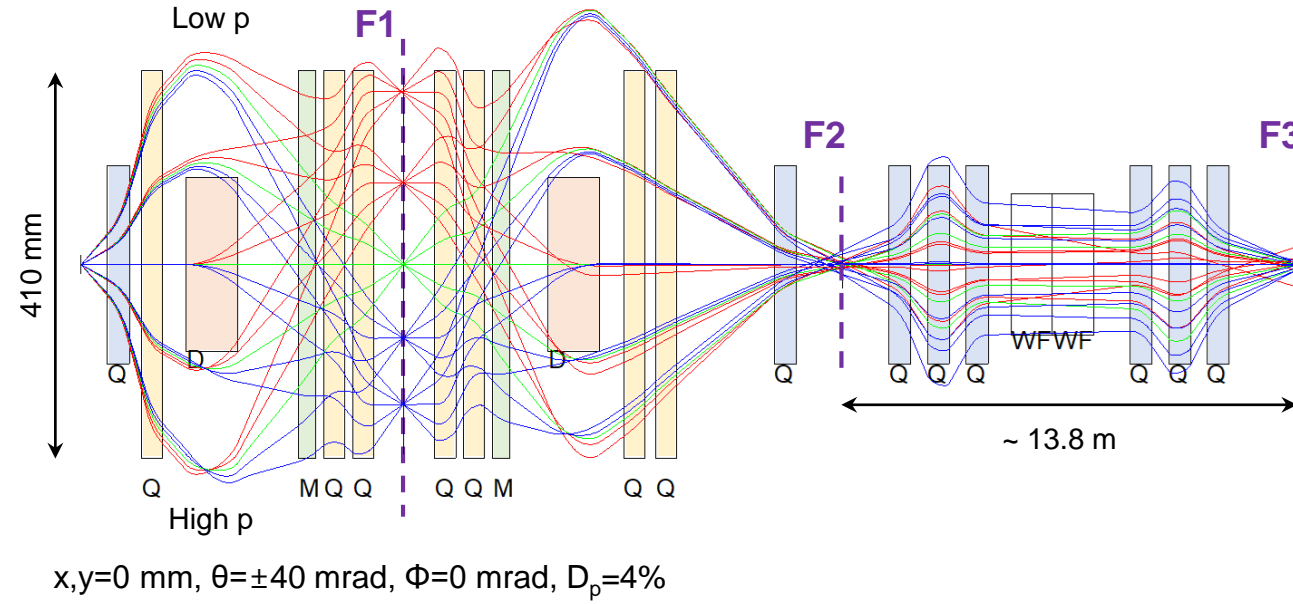
Dipole
 LQ
 SX
 SQ

KoBRA Ion Optics Calculation (5th order)

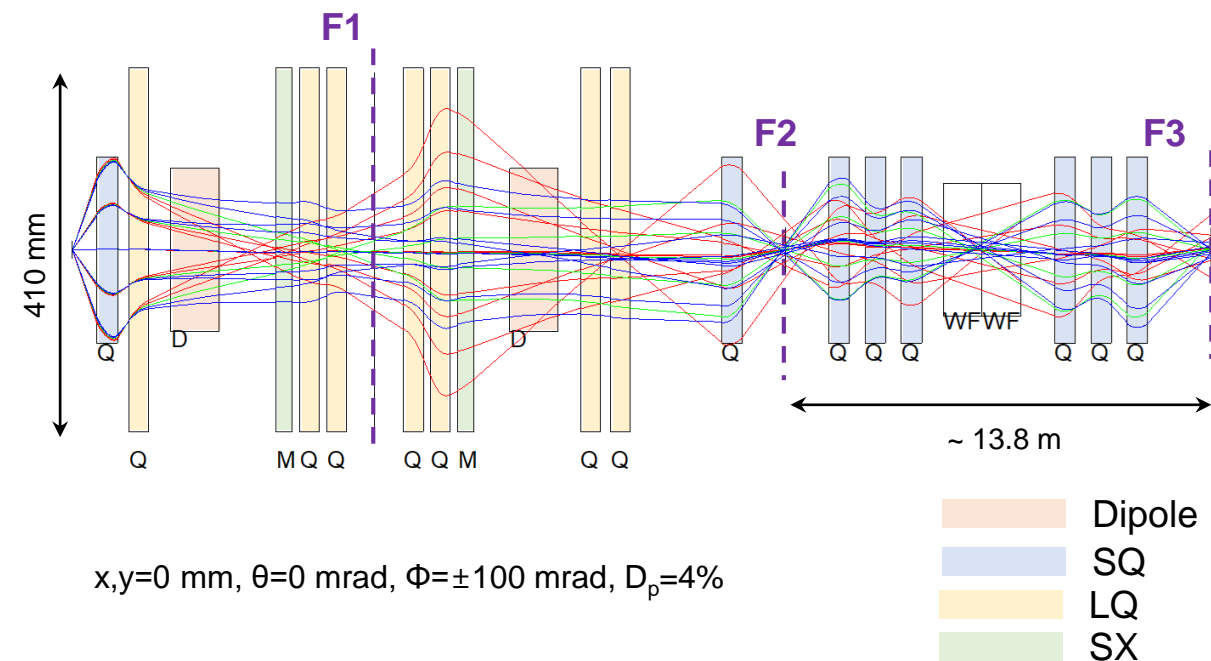
- ✓ (SQ, LQ, SX) B Field Optical Tuning for dipole B_p range (0.2 to 3.0 Tm)
- ✓ Curved boundary bending magnet and sextupole magnets minimize high order aberrations

Horizontal Ray Plot

Rays were segmented with $\Delta p/p$ 2% steps from -4% to 4%



Vertical Ray Plot

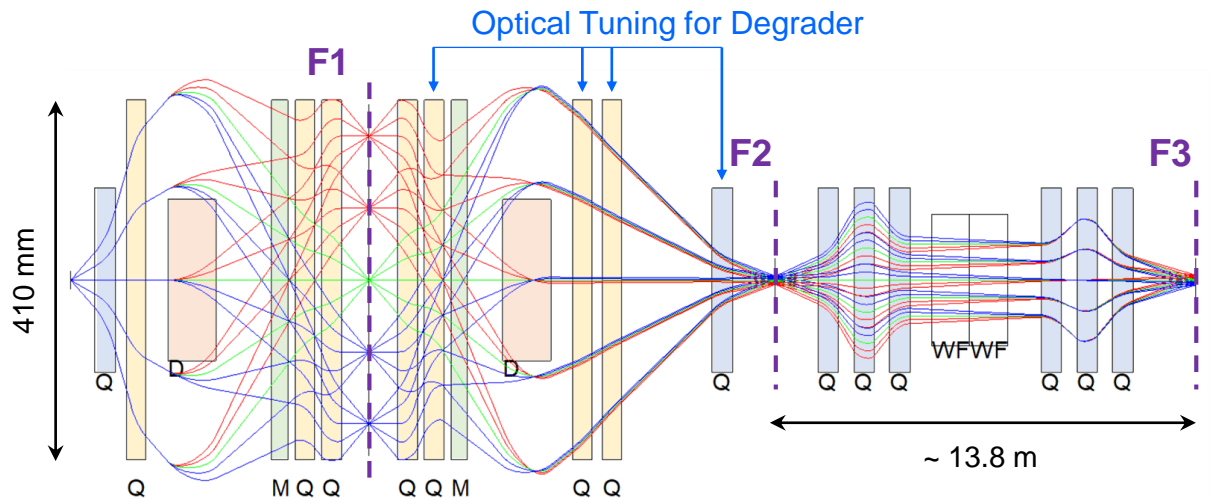


KoBRA Ion Optics Calculation – Degrader

- ✓ Homogeneous(flat) or curved degrader can be installed in F1 chamber
- ✓ **Quadrupole (LQ6-8, SQ2)** B Field Optical Tuning for dipole Bp range (0.2 to 3.0 Tm) and d/R range (0.01 to 0.2)

※ (Ray plot) Optical component of F1 degrader does not considered

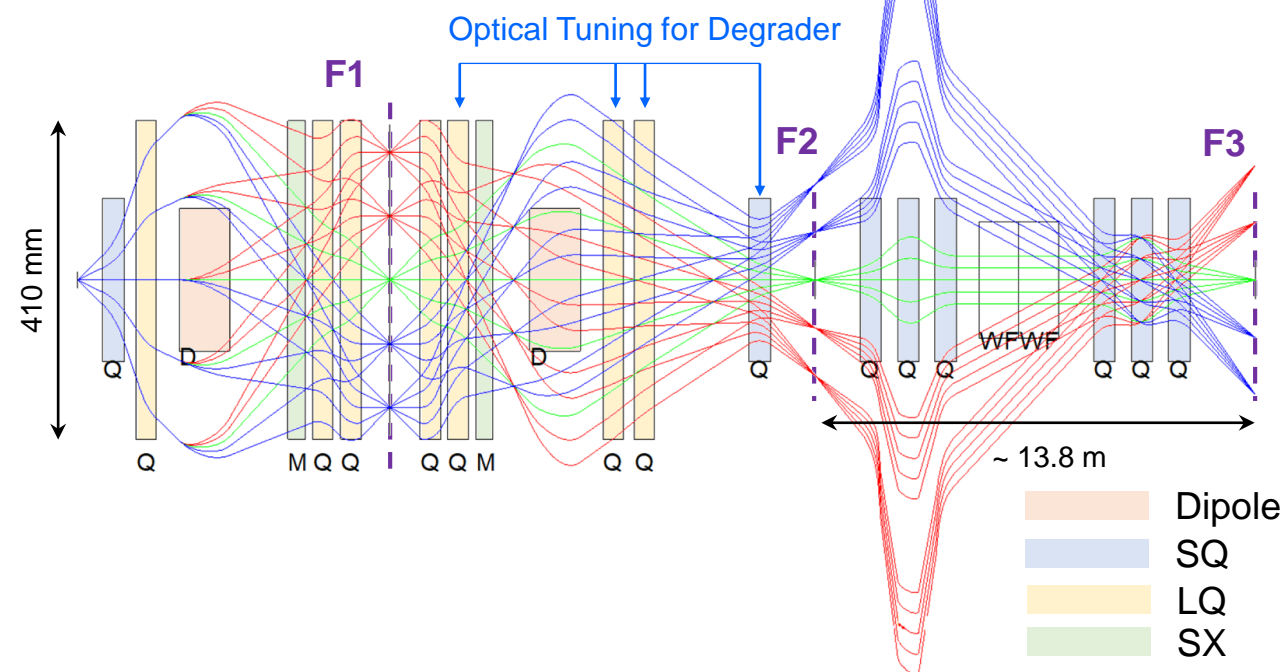
Horizontal Ray Plot – d/R=0.01



Rays were segmented with $\Delta p/p$ 2% steps from -4% to 4%

$x, y = 0$ mm, $\theta = \pm 40$ mrad, $\Phi = \pm 100$ mrad, $D_p = 4\%$

Horizontal Ray Plot – d/R=0.2

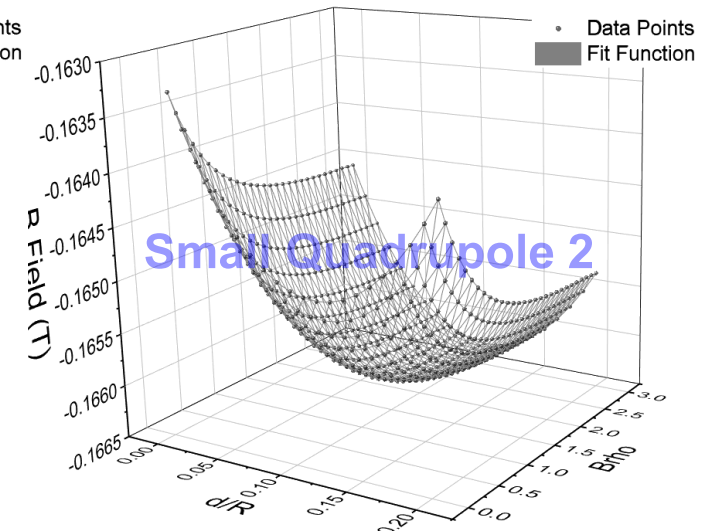
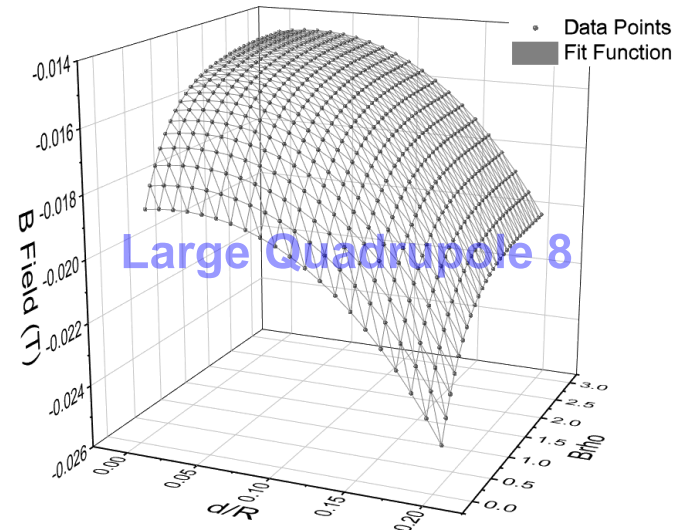
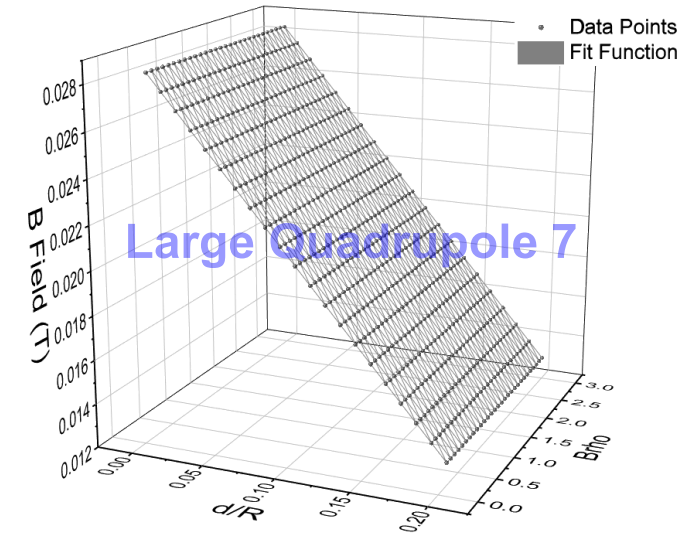
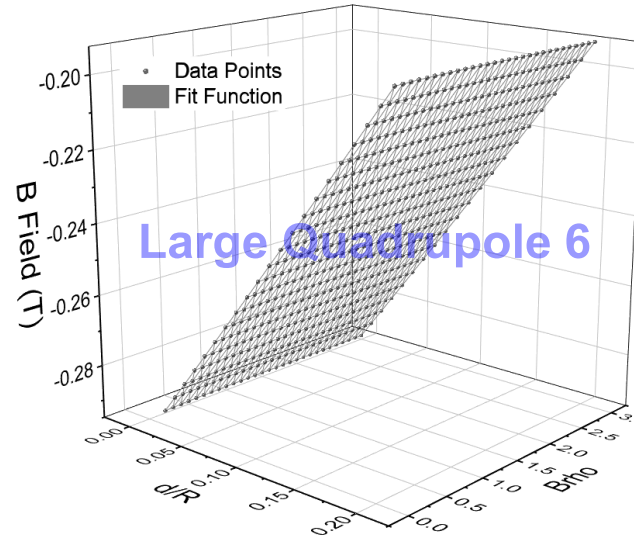


KoBRA Ion Optics Calculation – Degrader (Cont.)

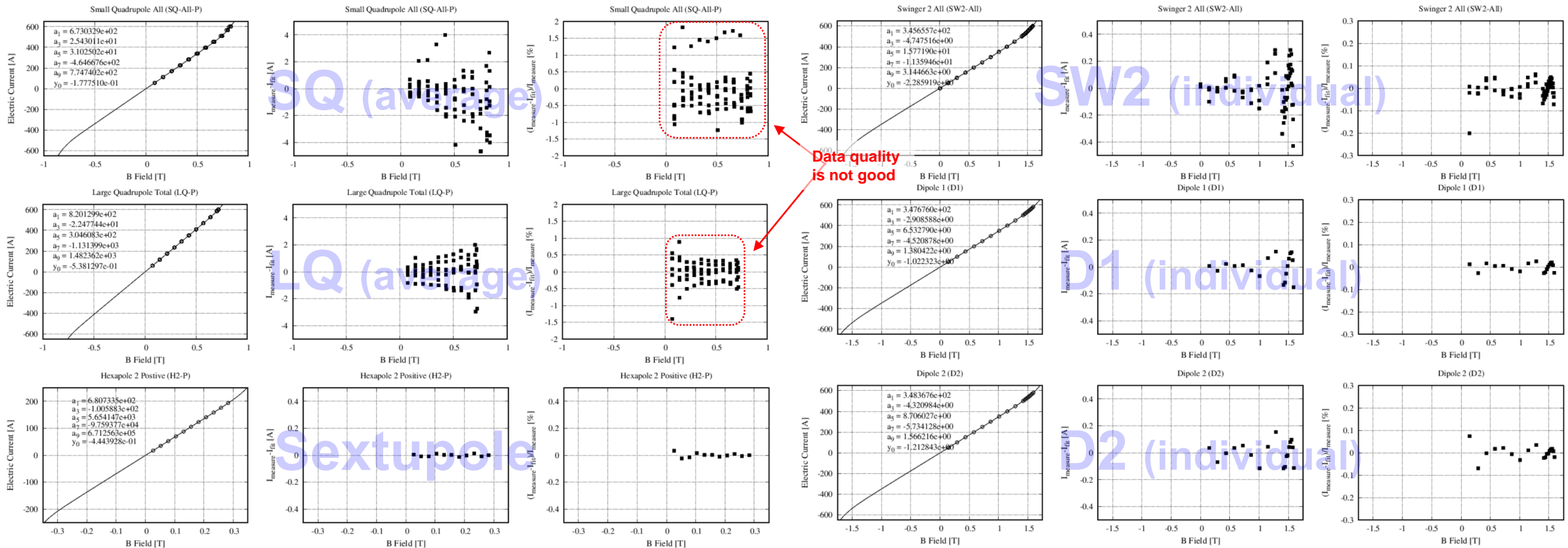
- ✓ LQ6, LQ8, SQ2: surface function
- ✓ LQ7: linear function without Bp dependence

KoBRA Ion Optics Parameters (Degrader Use)

	F1	F2	F3
(x x)	0.96	2.7 ~ 3.6	3.2 ~ 4.3
(x θ)	0	0	0
(y y)	10.7	1.8 ~ 3.0	2.3 ~ 3.9
(y Φ)	0	0	0
(x δ)	4.1	0	0
(θ δ)	0	0	0



- ✓ Fit function: $I(B) = a_1 B + a_3 B^3 + a_5 B^5 + a_7 B^7 + a_9 B^9 + y_0$



Remote Magnet Control with CSS

Beam Tune Magnet PS Interlock of magnet NMR Probe

Magnet Remote/Local All Remote Control All Local Control All Magnet Power On/Off All Magnet Power ON All Magnet Power OFF All Auto Set B-field Optics valve (Manual)

Korea Broad acceptance Recoil Spectrometer & Apparatus **KoBRA**

F3 Water OFF Q15 Water OFF Q14 Water OFF Q13 WF1 Water OFF Q12 Water OFF Q11 Water OFF Q10 Local Local Remote REM REM REM OFF OFF OFF OFF OFF

F2 Water OFF Q9 Water OFF Q8 Water OFF Q7 D2 Water OFF H2 Water OFF Q6 Water OFF Q5 Local Local Local Local Local Local REM REM REM REM REM REM OFF OFF OFF OFF OFF OFF

F1 Water OFF Q4 Water OFF Q3 Water OFF H1 Beam Dump D1 Water OFF Q2 Water OFF Q1 Local Local Local Local Local Local REM REM REM REM REM REM OFF OFF OFF OFF OFF OFF

F0 Water OFF SW2 Water OFF SW1 Local Local REM REM OFF OFF OFF OFF OFF OFF

Magnetic Rigidity (Tm): Ramping U/D

Bending Magnet Gaussmeter Control 1 Mode AutoFlat Mode Display Manual Disp.

Swinger Magnet Gaussmeter Control 1 Mode AutoFlat Mode Display Manual Disp.

Real-time Measurement of B-field with NMR Probe

D2 NMR probe Lock 0.20703 (T) Out

D1 NMR probe UnLock 1.83928 (T) In

Swinger1 NMR probe UnLock 0.110166 (T) In

Swinger2 NMR probe UnLock 0.490178 (T) In

Magnetic Flux Densities of Magnets (T) Manual

	Q15	Q14	Q13	WF	Q12	Q11	Q10	Q9	Q8	Q7	D2	H2	Q6	Q5	Q4	Q3	H1	D1	Q2	Q1	SW2	SW1
Setting values	-0.00497	0.00497	-0.00497		-0.00497	0.00497	-0.00497	-0.00500	-0.00931	0.01959	0.50116	0.01000	-0.19755	0.18517	0.13338	-0.10265	0.03346	0.30000	0.16710	-0.00497	-0.04563	0.04000
Optics values: (Auto/Manual)	-0.00500	0.00500	-0.00500		-0.00500	0.00500	-0.00500	-0.00500	-0.00923	0.01891	0.50116	0.01000	-0.19581	0.18352	0.13219	-0.10103	0.03347	0.30000	0.16710	-0.00500	-0.04563	0.04000
Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D		Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D	Ramp U/D

B-Field Correction Factors (manually corrected values)

	Q15	Q14	Q13	WF	Q12	Q11	Q10	Q9	Q8	Q7	D2	H2	Q6	Q5	Q4	Q3	H1	D1	Q2	Q1	SW2	SW1
Reset All	0.9943	0.9943	0.9943		0.9942	0.9943	0.9942	1	1.0089	1.0361	1	1	1.0089	1.009	1.009	1.016	0.9997	1	1	0.9943	1	1

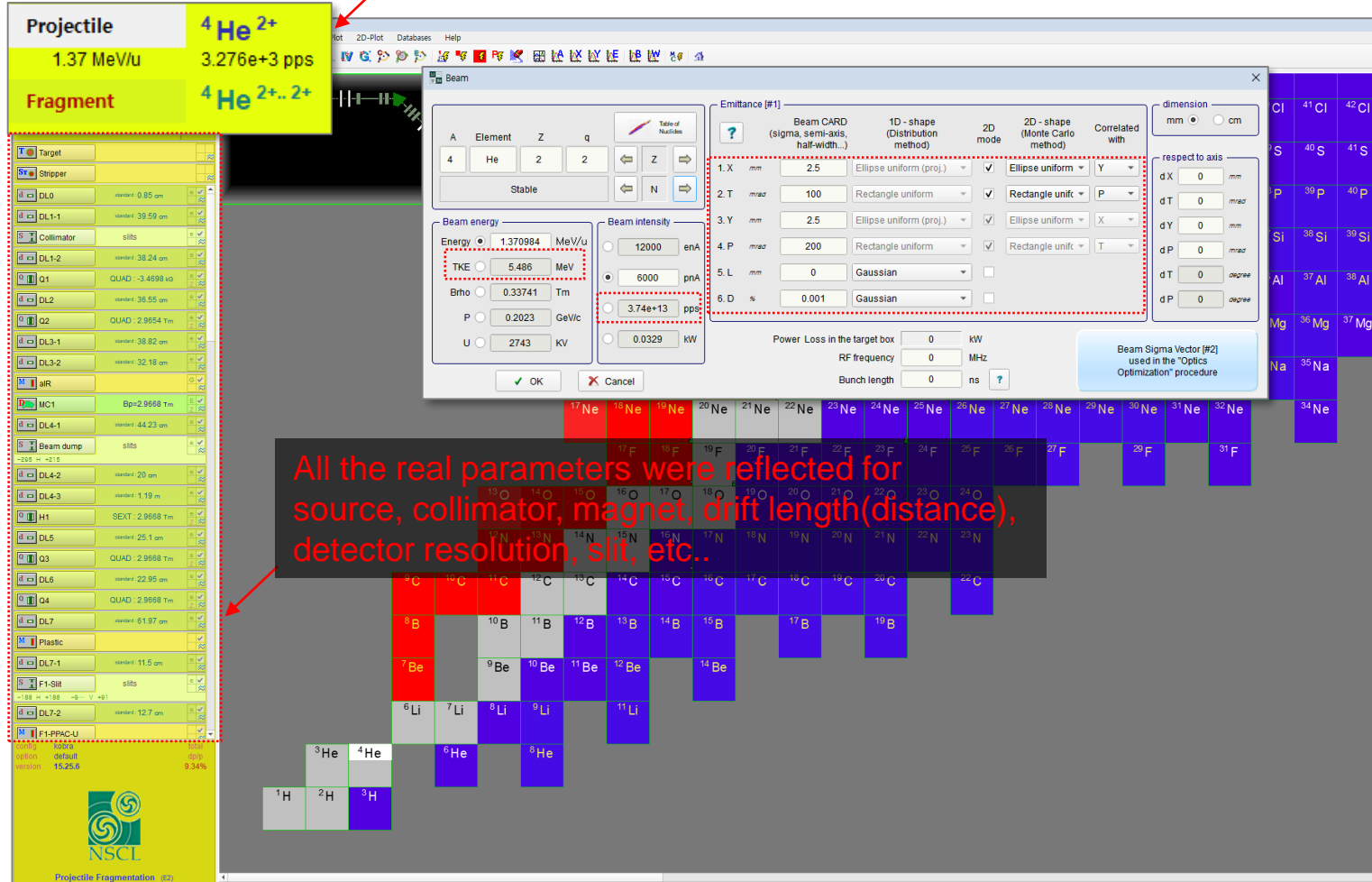
Electric current of Magnet Power Supply (A) Manual

	Q15	Q14	Q13	WF	Q12	Q11	Q10	Q9	Q8	Q7	D2	H2	Q6	Q5	Q4	Q3	H1	D1	Q2	Q1	SW2	SW1
Present values	0.0000	0.0000	-0.0400		-0.0300	-0.0400	-0.0400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0100	0.0000	0.0000	-0.0100	0.0000
Setting values	3.1682	3.1682	3.1682		3.1679	3.1682	3.1679	3.1874	6.6882	15.1445	173.0628	6.3628	161.2310	151.0888	108.6264	83.4044	20.5941	103.2169	136.2811	3.5237	18.0542	10.2039

Door

KoBRA LISE++ MC Calculation

For ^{241}Am alpha beam commissioning



Projectile
1.37 MeV/u
3.276e+3 pps
Fragment
4 He $^{2+}$
4 He $^{2+..2+}$

Beam

Emittance [#1]

1D - shape (Distribution method)	2D mode	2D - shape (Monte Carlo method)	Correlated with
1. X mm 2.5 Ellipse uniform (proj.)	<input checked="" type="checkbox"/>	Ellipse uniform	Y
2. T mmad 100 Rectangle uniform	<input checked="" type="checkbox"/>	Rectangle unif.	P
3. Y mm 2.5 Ellipse uniform (proj.)	<input checked="" type="checkbox"/>	Ellipse uniform	X
4. P mmad 200 Rectangle uniform	<input checked="" type="checkbox"/>	Rectangle unif.	T
5. L mm 0 Gaussian	<input type="checkbox"/>		
6. D % 0.001 Gaussian	<input type="checkbox"/>		

Beam energy
Energy 1.370984 MeV/u
TKE 5.486 MeV
Emho 0.33741 Tm
P 0.2023 GeV/c
U 2743 KV

Beam intensity
12000 enA
6000 pps
3.74e+13 pps
0.0329 kW

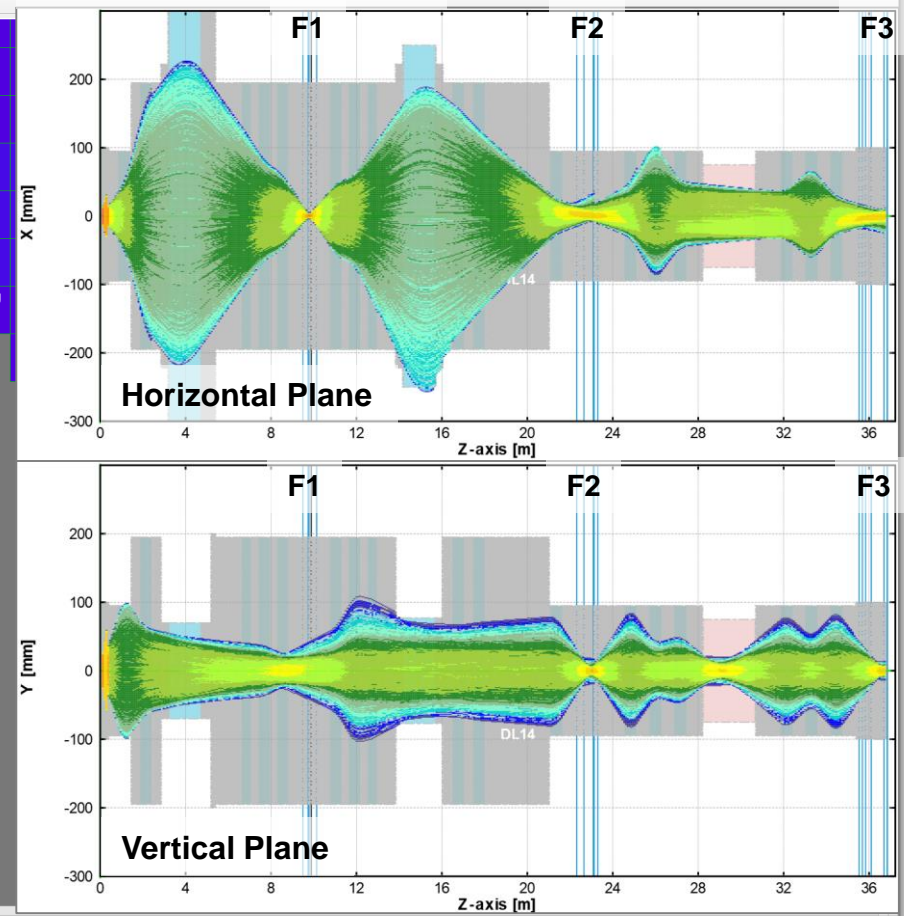
Power Loss in the target box
0 kW
RF frequency 0 MHz
Bunch length 0 ns

Beam Sigma Vector [#2] used in the "Optics Optimization" procedure

All the real parameters were reflected for source, collimator, magnet, drift length(distance), detector resolution, slit, etc..

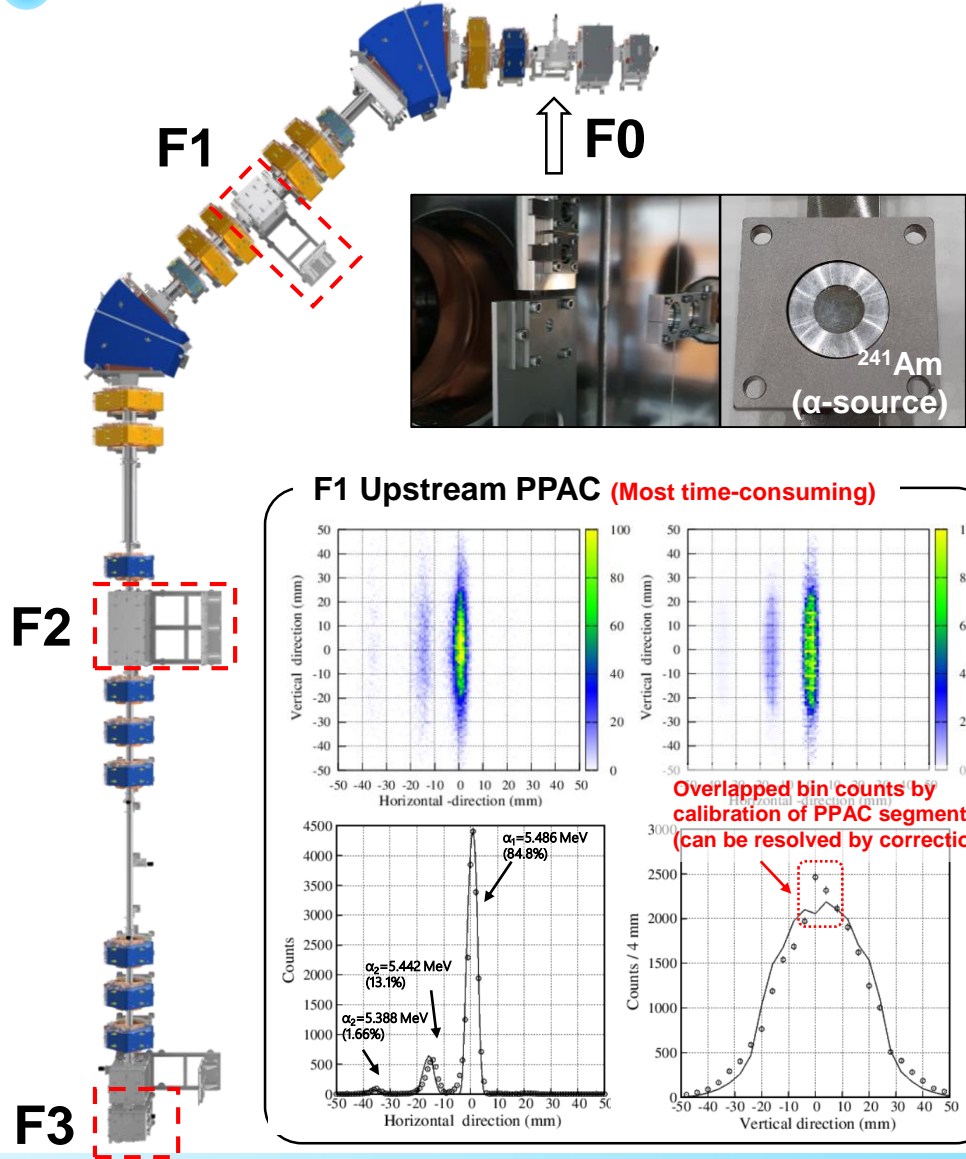
Optical matrix(up to 5th order) were reflected from COSY INFINITY

Beam Envelope (5th order)



KoBRA_F3+SNACK_2022_05.lpp

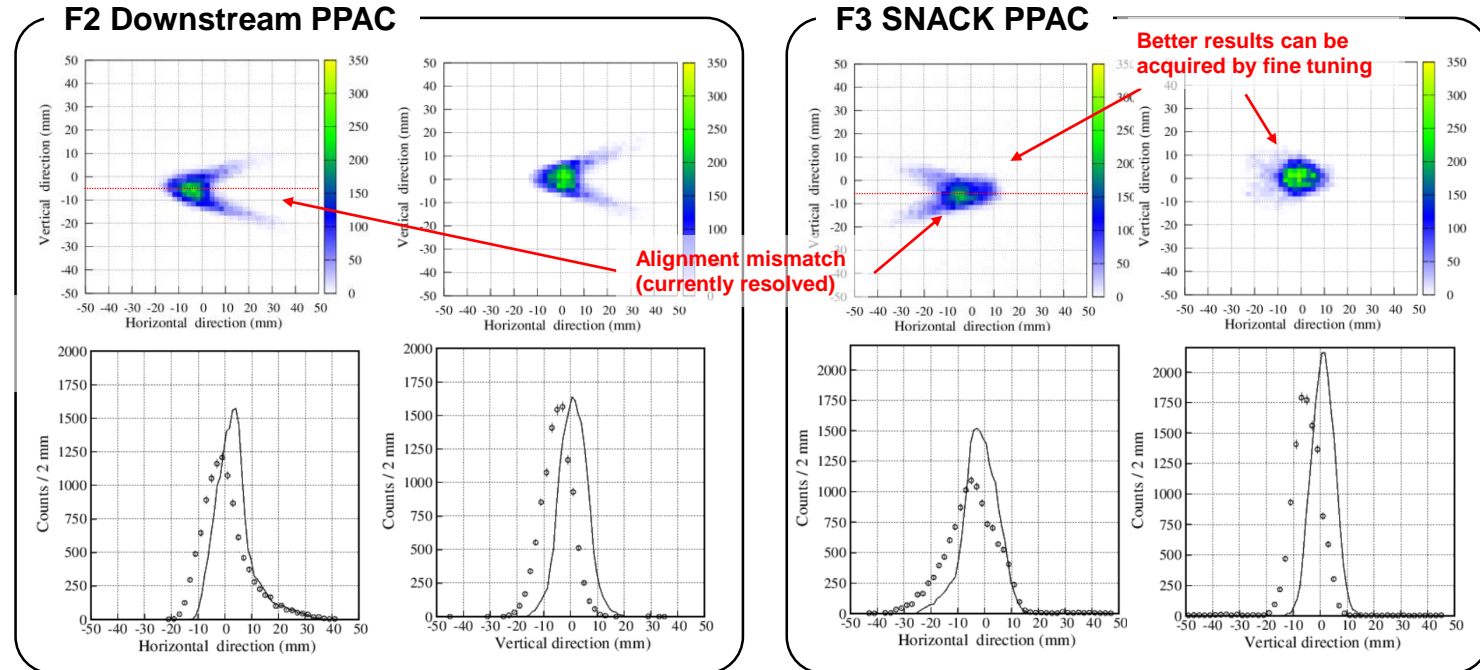
(Second) Beam Commissioning at 2022.04.



- ✓ The experimental results were more consistent to MC calculation with consistent correction of magnet B-field

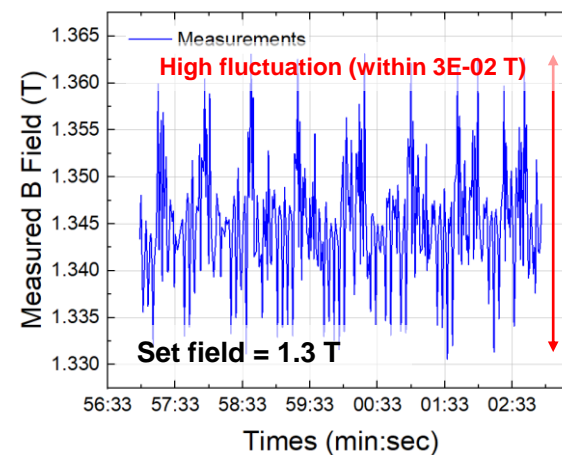
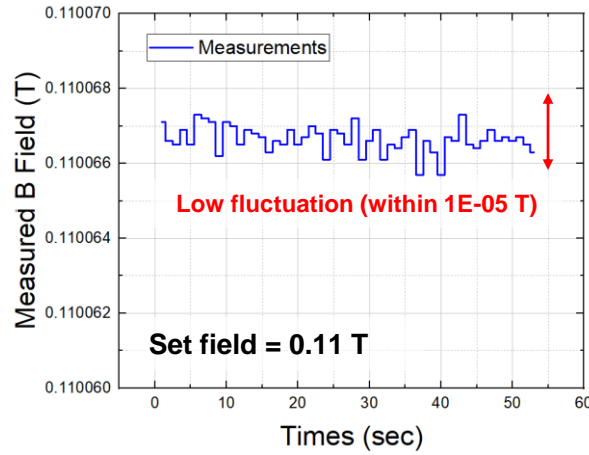
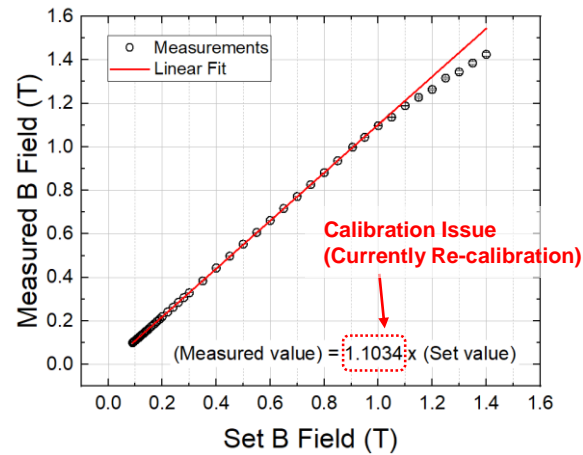
B-Field Difference between Ion Optics Calculation and Experiment

Dipoles	Large Quadrupoles	Small Quadrupoles	Sextupoles
< 0.01% with NMR probe	0.9%	0.57%	0.03%



Current Issues for Magnet Control

Dipole B-Field Mismatch & Unstable Measurement of NMR Probe



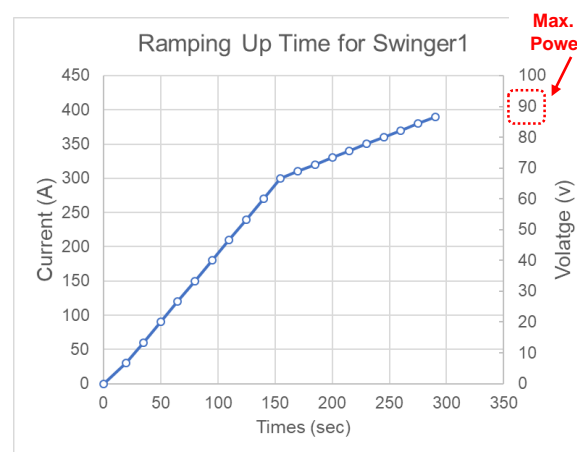
Interlock Issues of Power Supply

Dipole magnet Power Supply

D1	D2
PS:IDoor	PS:IDoor
PS:IACinOCP	PS:IACinOCP
PS:IPhaseError	PS:IPhaseError
PS:ITransformerOverTemp	PS:ITransformerOverTemp
PS:IRectifierOverTemp	PS:IRectifierOverTemp
PS:IChokeOverTemp	PS:IChokeOverTemp
PS:ITransistorOverTemp	PS:ITransistorOverTemp
PS:IWaterFlow	PS:IWaterFlow

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Ramping-Up Time of Power Supply



$$V = RI_0 + \frac{2}{I_0 \Delta t} \times \frac{B^2}{2\mu_0} \left(V_{gap} + \frac{V_{coil}}{3} + \frac{1}{\mu} V_{yoke} \right)$$

Induced Voltages by Stored Energy

Δt = Ramping up time
 R = Total Resistance ($R_{cable} + R_{coil}$)
 μ = Permeability of yoke
 μ_0 = Permeability of vacuum
 V_{gap} = Volume of magnet gap
 V_{coil} = Volume of magnet coil
 V_{yoke} = Volume of magnet yoke

Power Supply Maintenance

- LQ2(Q3) & Sextupole1
- Swinger2

(Summary)

- ✓ Effective length of the bending magnet is changed as a function of magnetic rigidity (0.2 to 3.0 Tm) of ion beam
- ✓ The variation of the effective length was reflected in the ion optics calculation
- ✓ If we use the homogeneous degrader at F1, additional optical tuning is required due to the change of the dispersion at F1
- ✓ Since the additional optical tuning depends on the d/R , we obtained all of the B-field values in the range of d/R (0.01 to 0.2)
- ✓ We obtained the B-fields as a function of the current for all magnets, from the measurement of the BH curve
- ✓ Such effects were reflected in the control software thereby giving an automatic optical tuning
- ✓ We improved the optics tuning program by reflecting the above effects, and confirmed that the position distribution of alpha particle is consistent with that of the Monte Carlo calculation

(Future plan)

- ✓ Several issues such as B-field measurement are still remained, which will be addressed in the near future
- ✓ We have a plan to perform third alpha beam commissioning at Oct. 2022 for debugging all the devices

Thank you