KoBRA Magnet Control for Beam Tuning with Ion Optics

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Low Energy Experimental System Team

Hanyang University, Ph. D Candidate

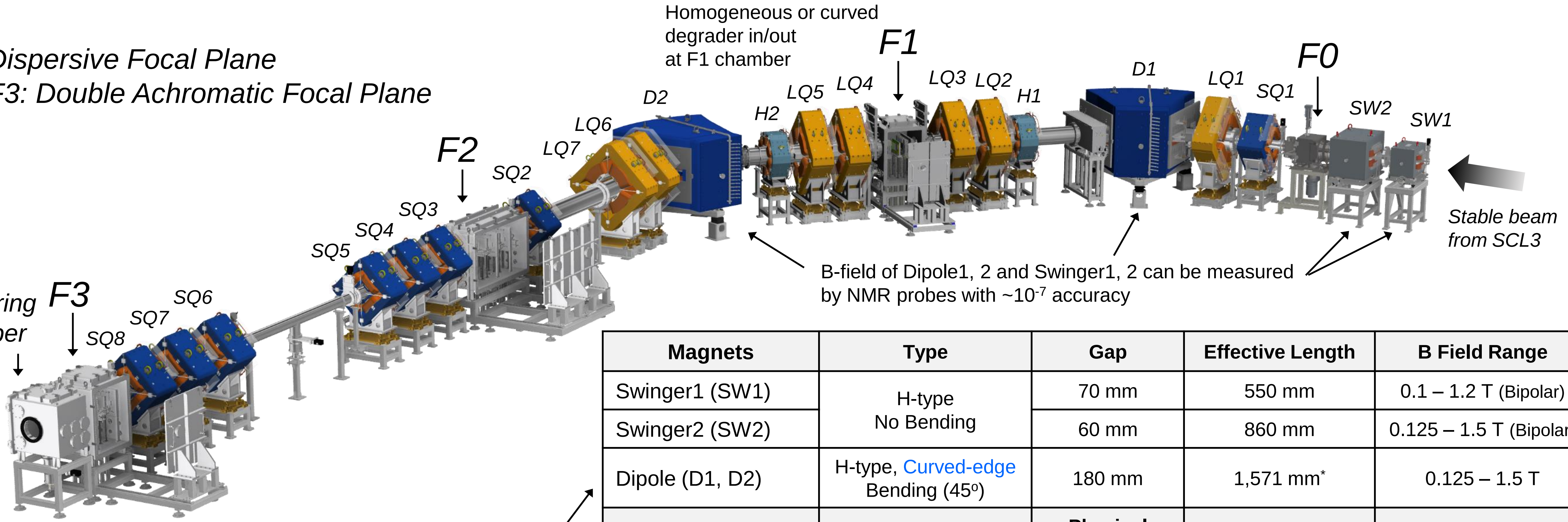
Dong Geon Kim

2022 1st Low Energy Rare Isotope Workshop, 20-21 July

Contents

KoBRA Stage1

F1: Dispersive Focal Plane
F2, F3: Double Achromatic Focal Plane



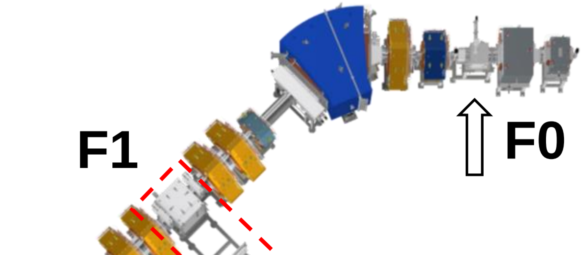
For large acceptance and minimization of high order aberrations

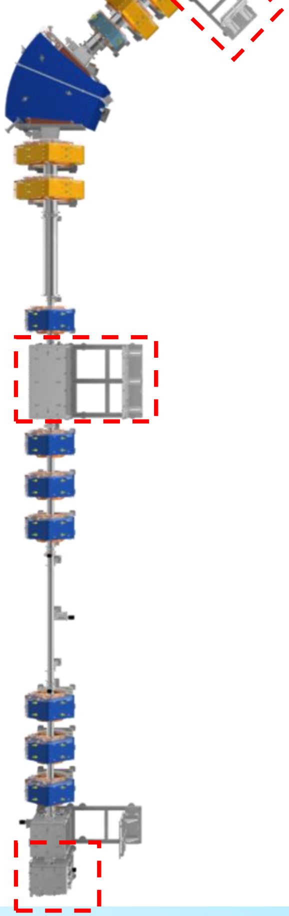
- ✓ Angular acceptance = 80 mrad (H), 200 mrad (V)
- ✓ Momentum acceptance = 8%
- ✓ Magnetic rigidity (Bρ) = 0.25 – 3.0 Tm
- ✓ High order correction = up to 5^{th} order

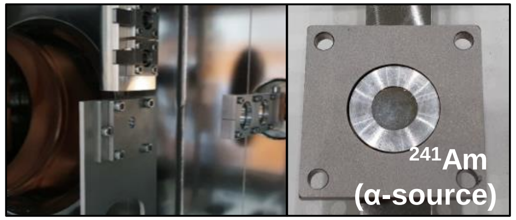
Magnets	Type	Gap	Effective Length	B Field Range
Swinger1 (SW1)	H-type No Bending	70 mm	550 mm	0.1 – 1.2 T (Bipolar)
Swinger2 (SW2)		60 mm	860 mm	0.125 – 1.5 T (Bipolar)
Dipole (D1, D2)	H-type, Curved-edge Bending (45°)	180 mm	1,571 mm*	0.125 – 1.5 T
Magnets	**Aperture diameter**	**Physical Length**	**Effective 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

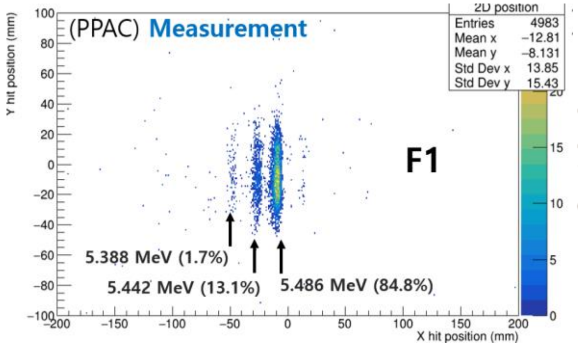
*Effective length of dipole magnet is considered in optics tuning depending on B-field

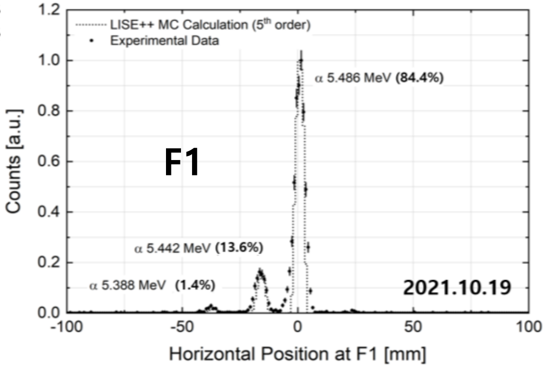
(First) Alpha Beam Commissioning at 2021.10.

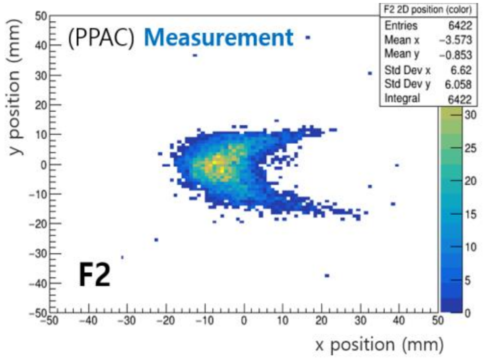


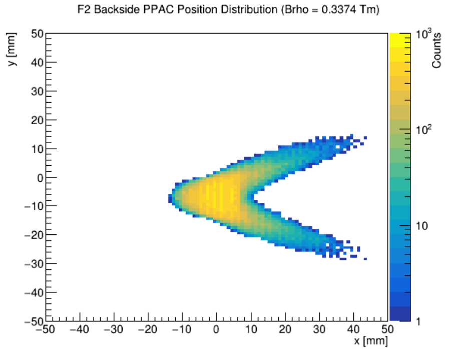




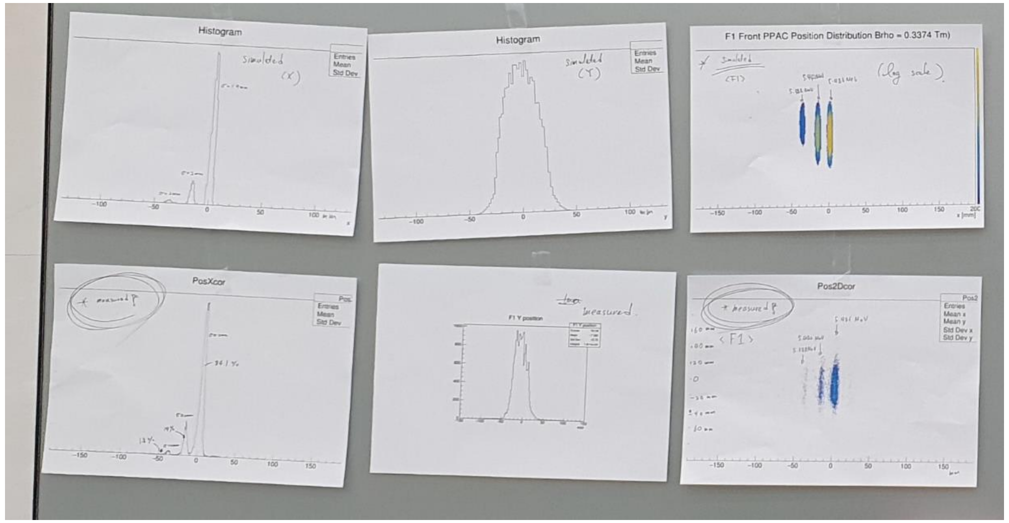


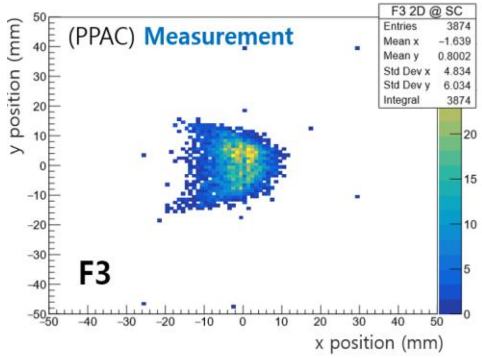


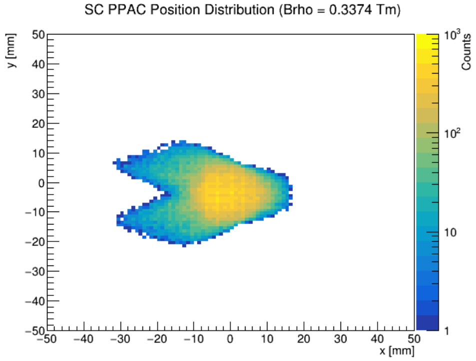




F1

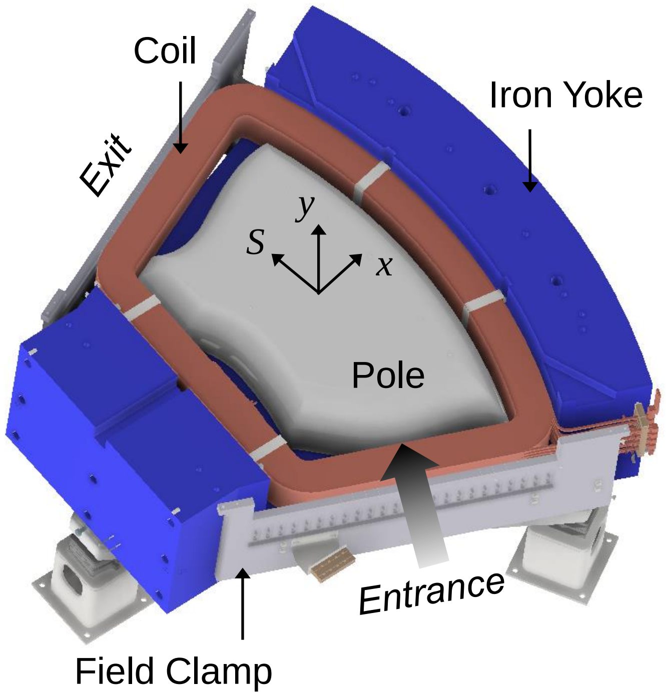




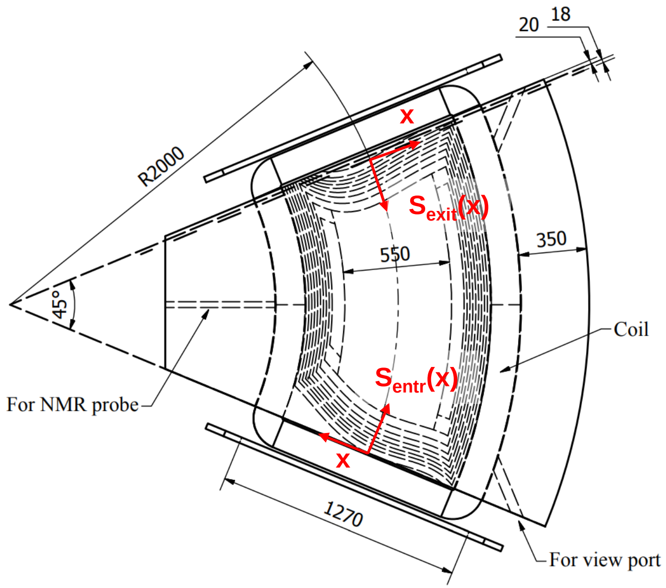


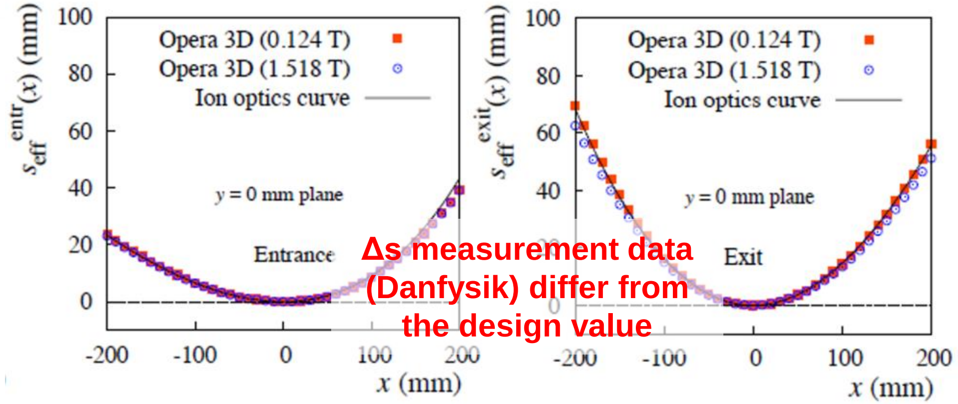
- ✓ The results of the position distributions were consistent with each other

KoBRA Ion Optics Calculation



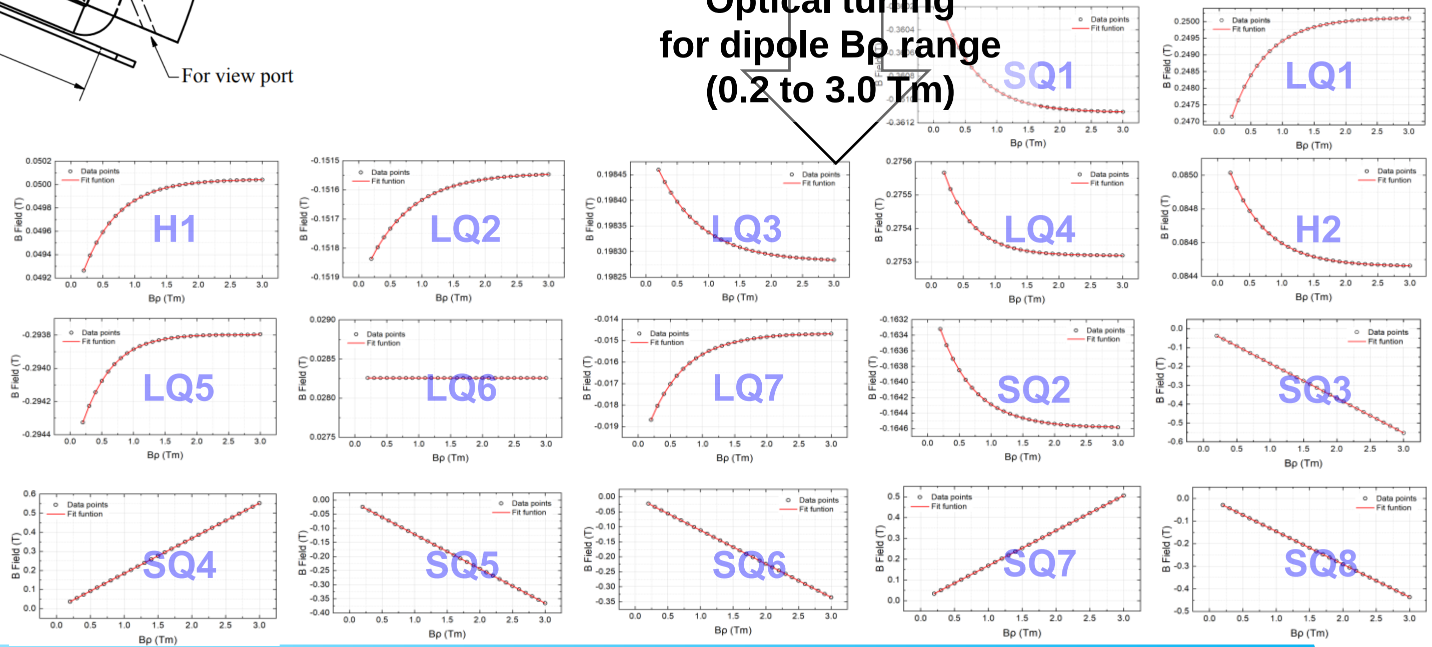
Curved Boundary Bending Magnet





Effective field boundary curves at entrance and exit

Optical tuning for dipole Bρ 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)

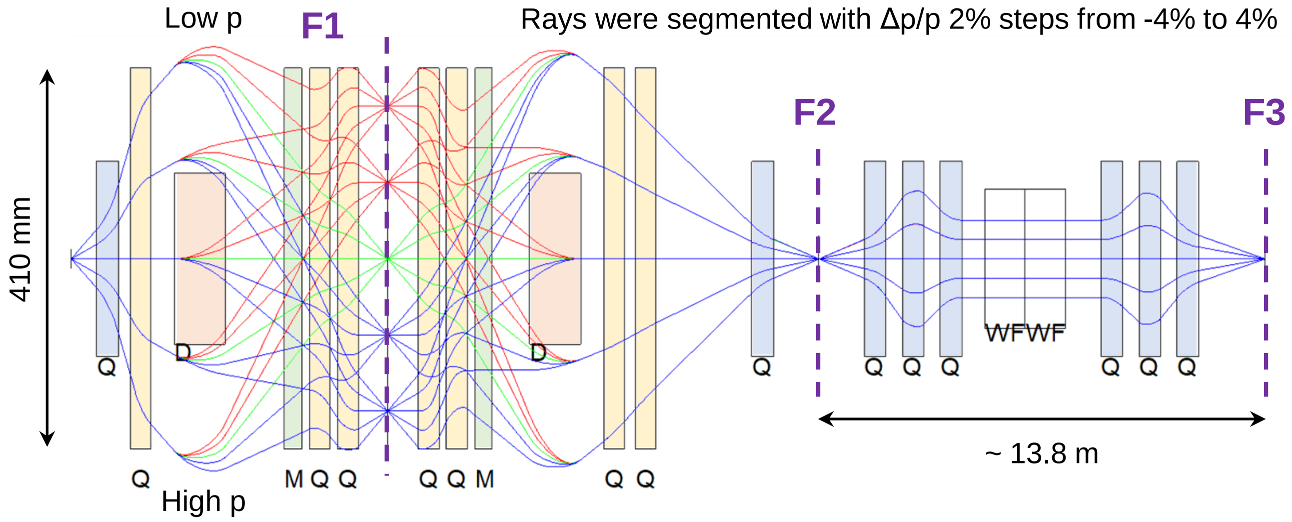
- ✓ B Field Optical Tuning of SQ, LQ, SX for dipole Bρ range (0.2 to 3.0 Tm)
- ✓ Optical tuning observes KoBRA optics design parameters
  - F1: Dispersive Focal Plane (Momentum dispersion at F1 = 4.1 cm/%)
  - F2, F3: Double Achromatic Focal Plane (Angle & momentum dispersion = 0)

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

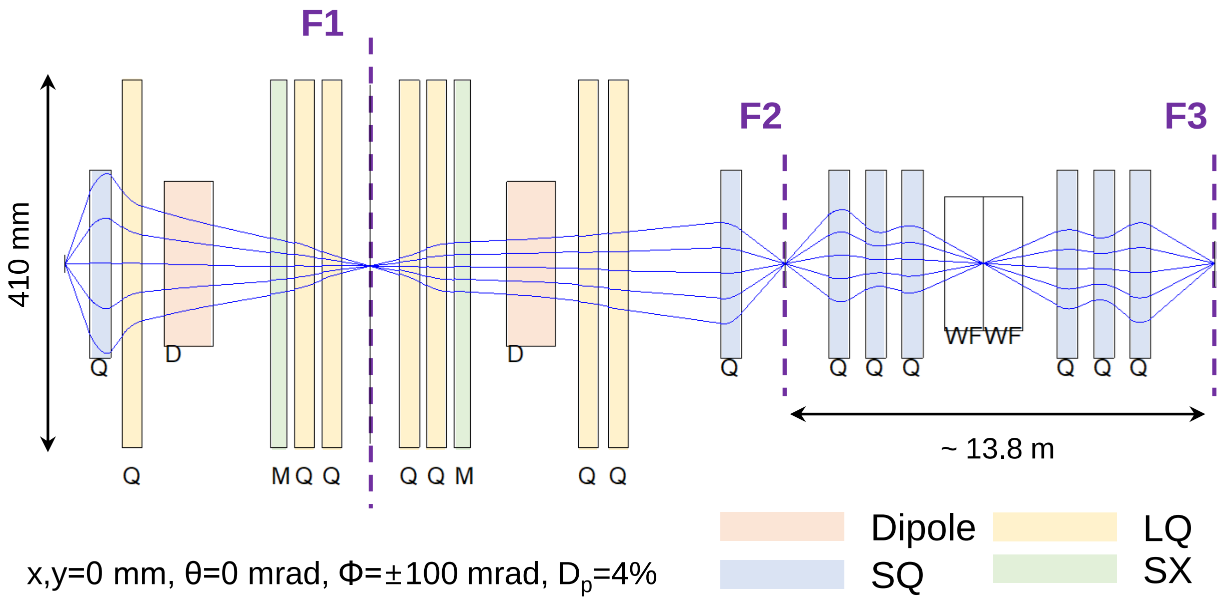
※ Degrader not use

Horizontal Ray Plot



x,y=0 mm, θ=±40 mrad, Φ=0 mrad, D_p=4%

Vertical Ray Plot



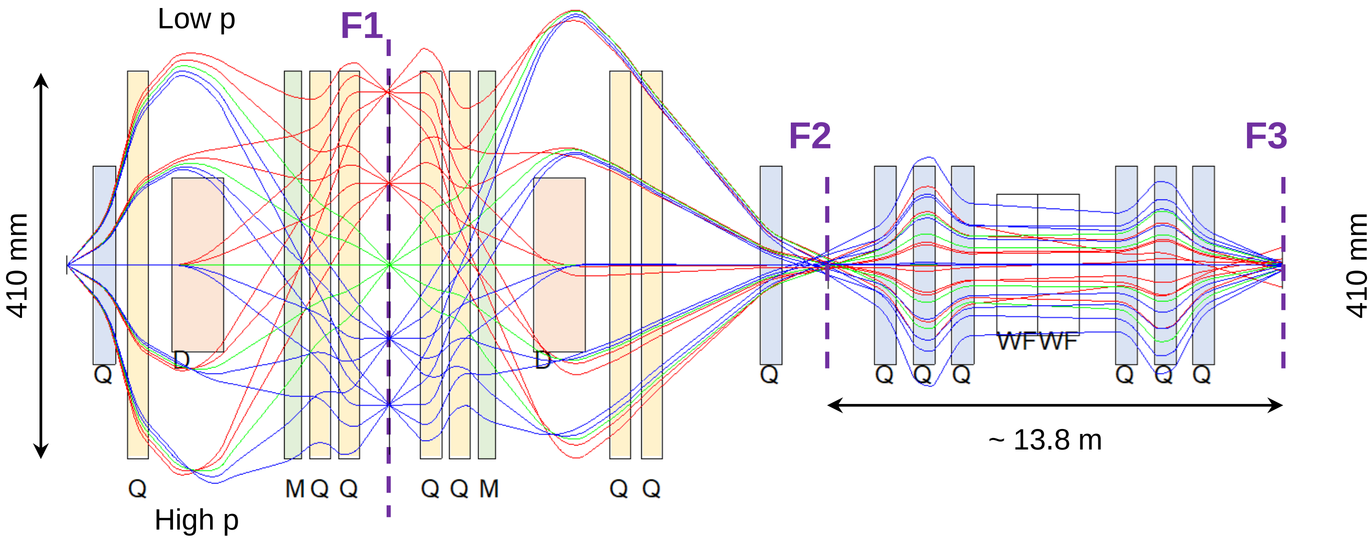
x,y=0 mm, θ=0 mrad, Φ=±100 mrad, D_p=4%

KoBRA Ion Optics Calculation (5th order)

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

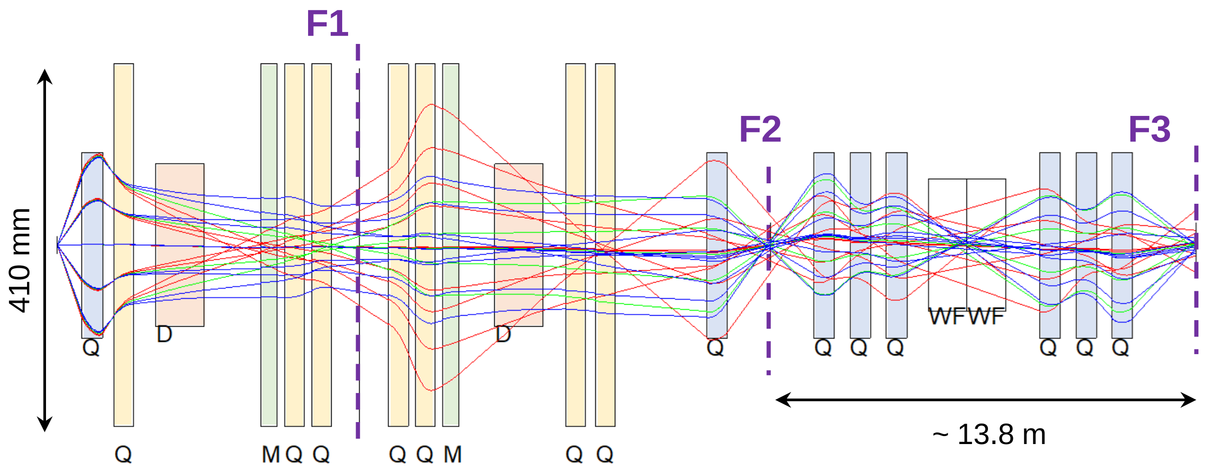
Horizontal Ray Plot

Rays were segmented with Δp/p 2% steps from -4% to 4%



x,y=0 mm, θ=±40 mrad, Φ=0 mrad, D_p=4%

Vertical Ray Plot



x,y=0 mm, θ=0 mrad, Φ=±100 mrad, D_p=4%

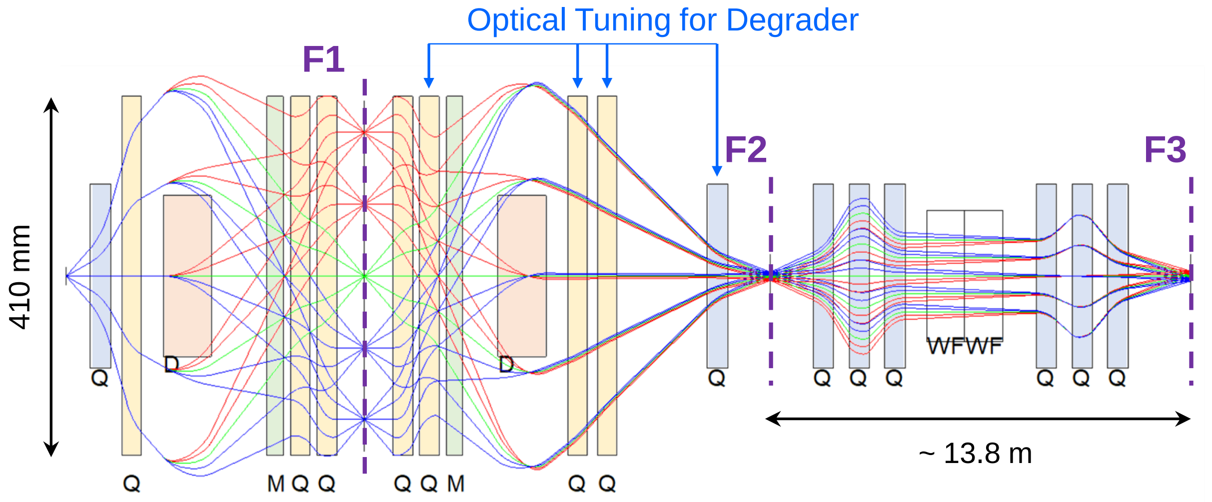
Dipole
SQ
LQ
SX

KoBRA Ion Optics Calculation – Degrader

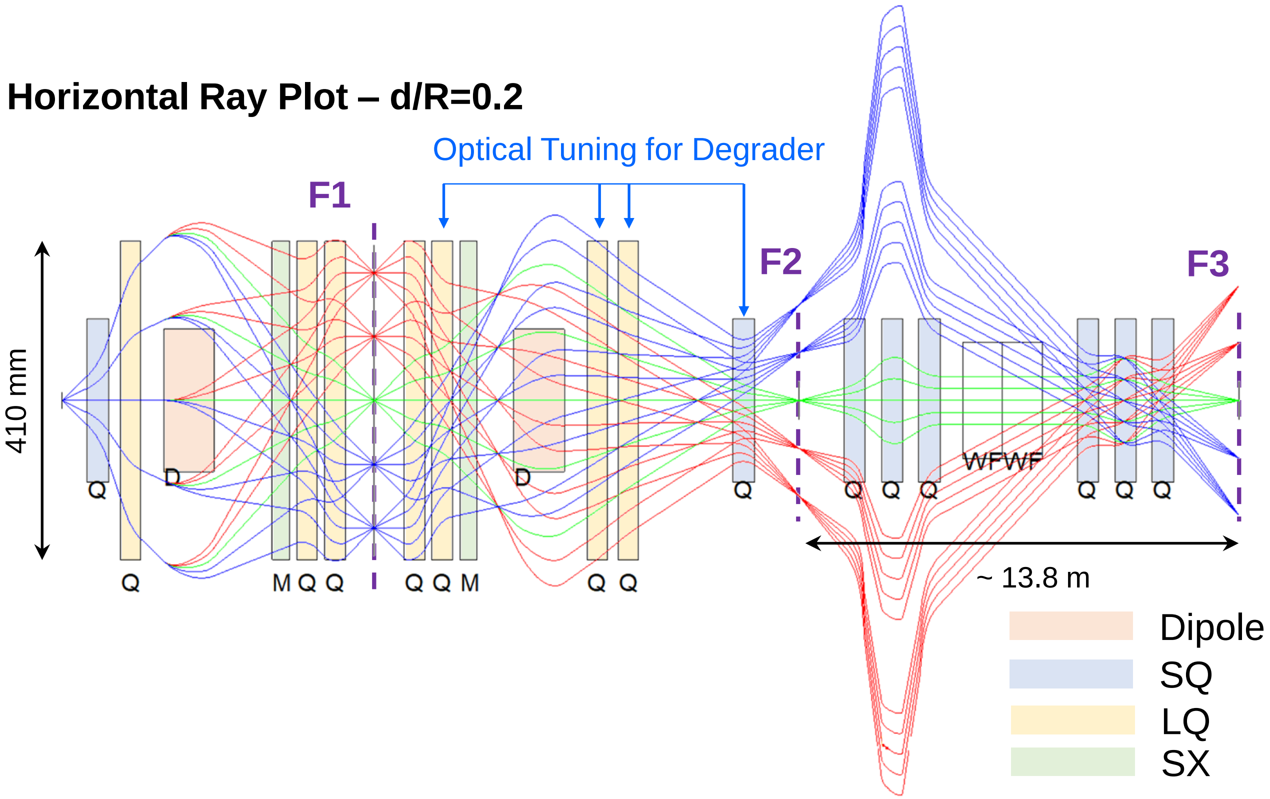
- ✓ Homogeneous(flat) or curved degrader can be installed in F1 chamber
- ✓ Quadrupole (LQ6-8, SQ2) B Field Optical Tuning for dipole Bρ range (0.2 to 3.0 Tm) and d/R range (0.01 to 0.2)

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

Horizontal Ray Plot – d/R=0.01



Horizontal Ray Plot – d/R=0.2



Rays were segmented with Δp/p 2% steps from -4% to 4%

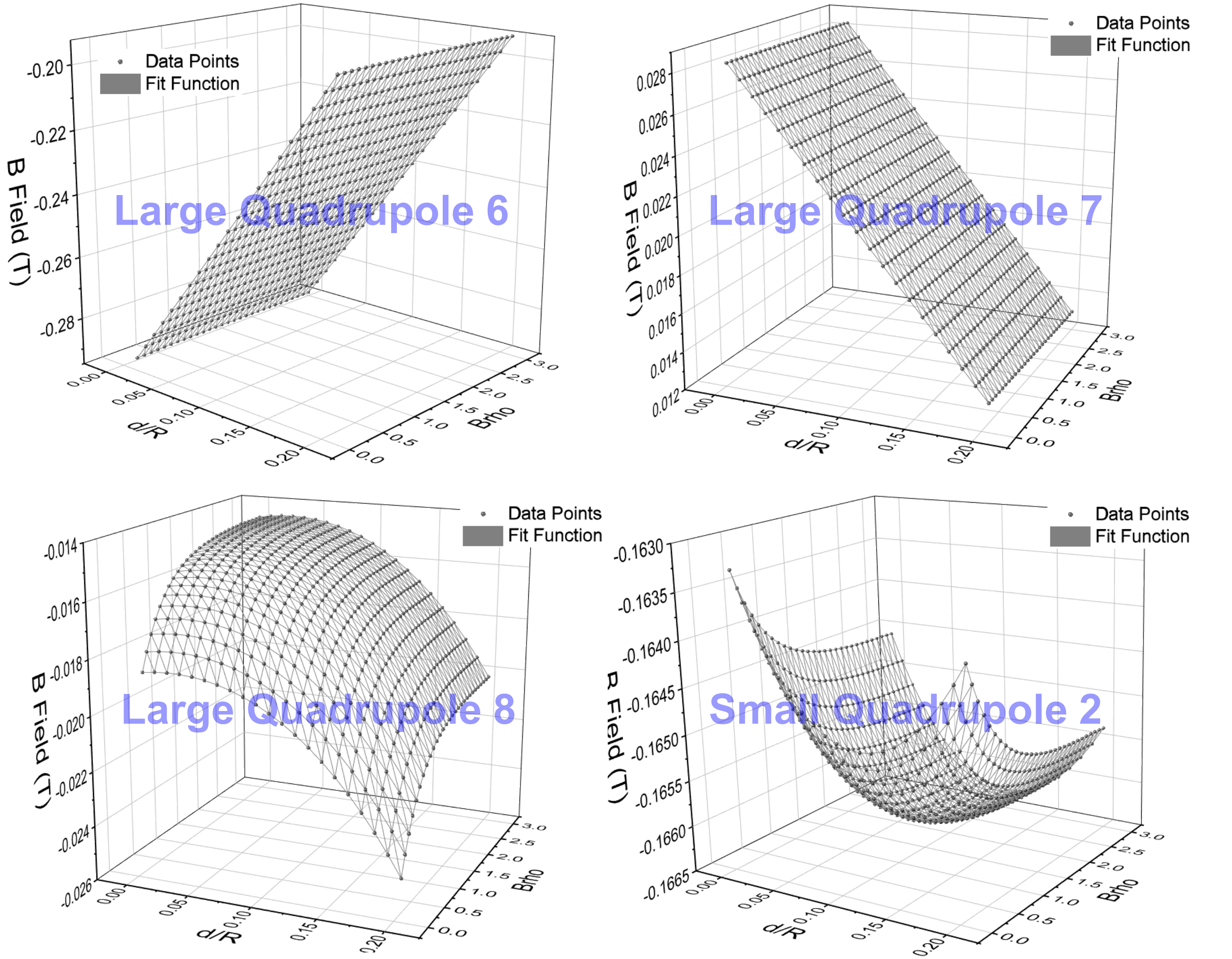
x,y=0 mm, θ=±40 mrad, Φ=±100 mrad, D_p=4%

KoBRA Ion Optics Calculation – Degrader (Cont.)

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

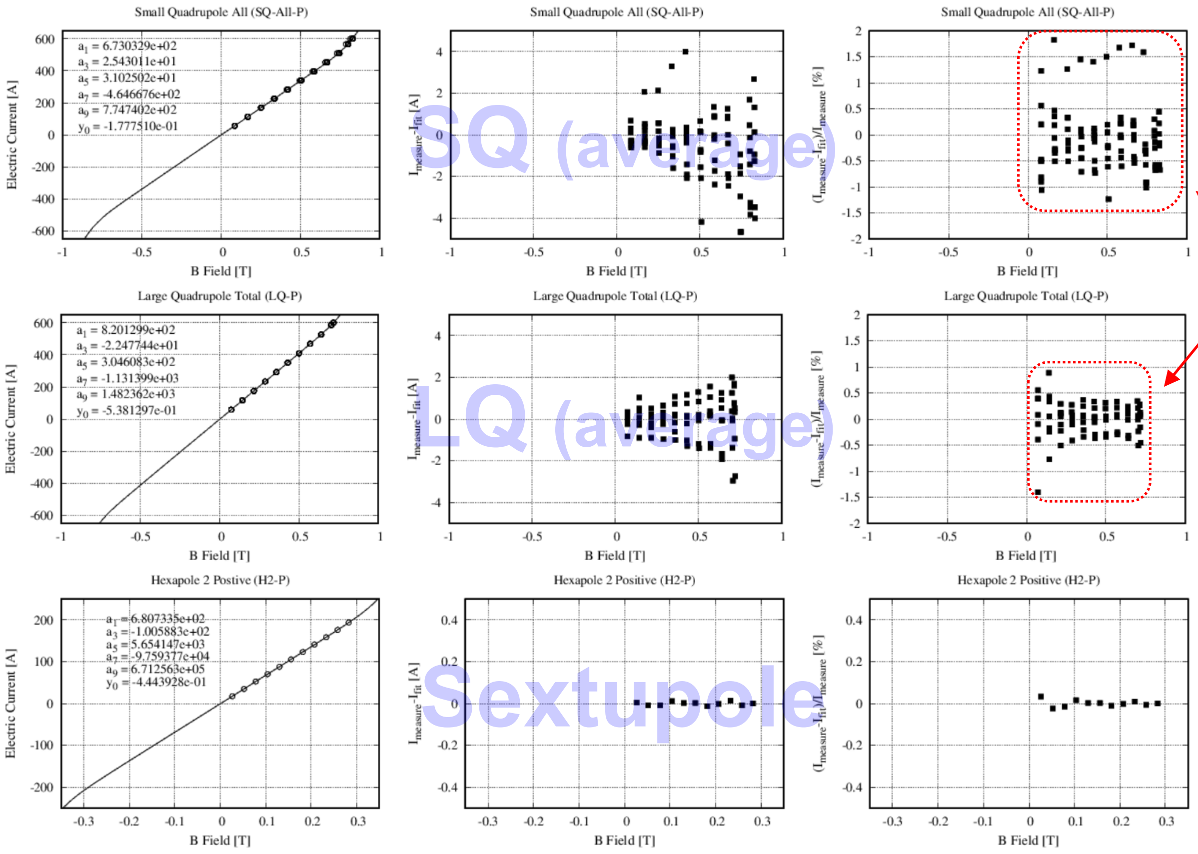
KoBRA Ion Optics Parameters (Degrader Use)

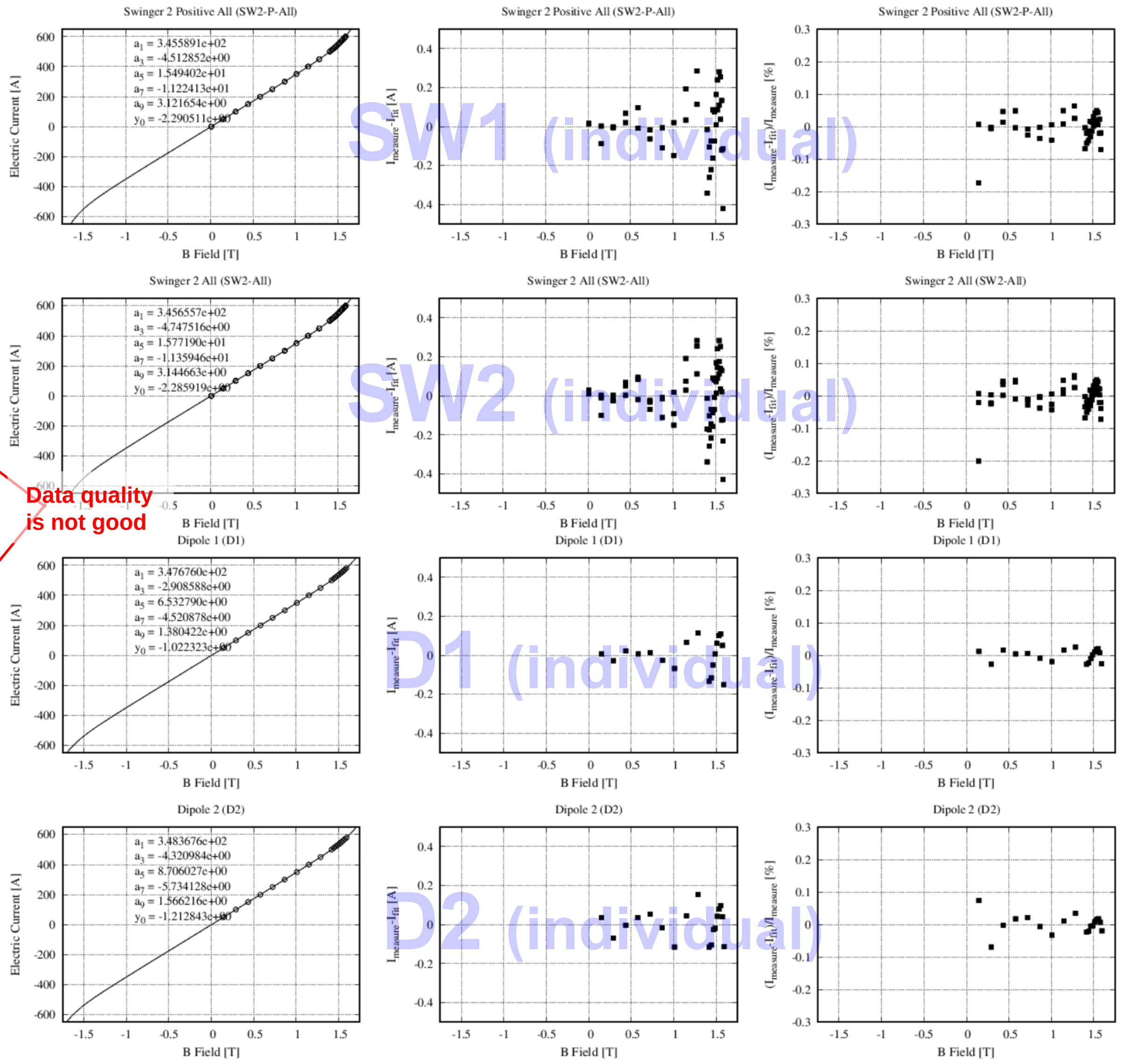
	F1	F2	F3
(x|x)	0.96	2.7 ~ 3.6	3.2 ~ 4.3
(x|θ)	0	0	0
(y|y)	10.7	1.8 ~ 3.0	2.3 ~ 3.9
(y|Φ)	0	0	0
(x|δ)	4.1	0	0
(θ|δ)	0	0	0



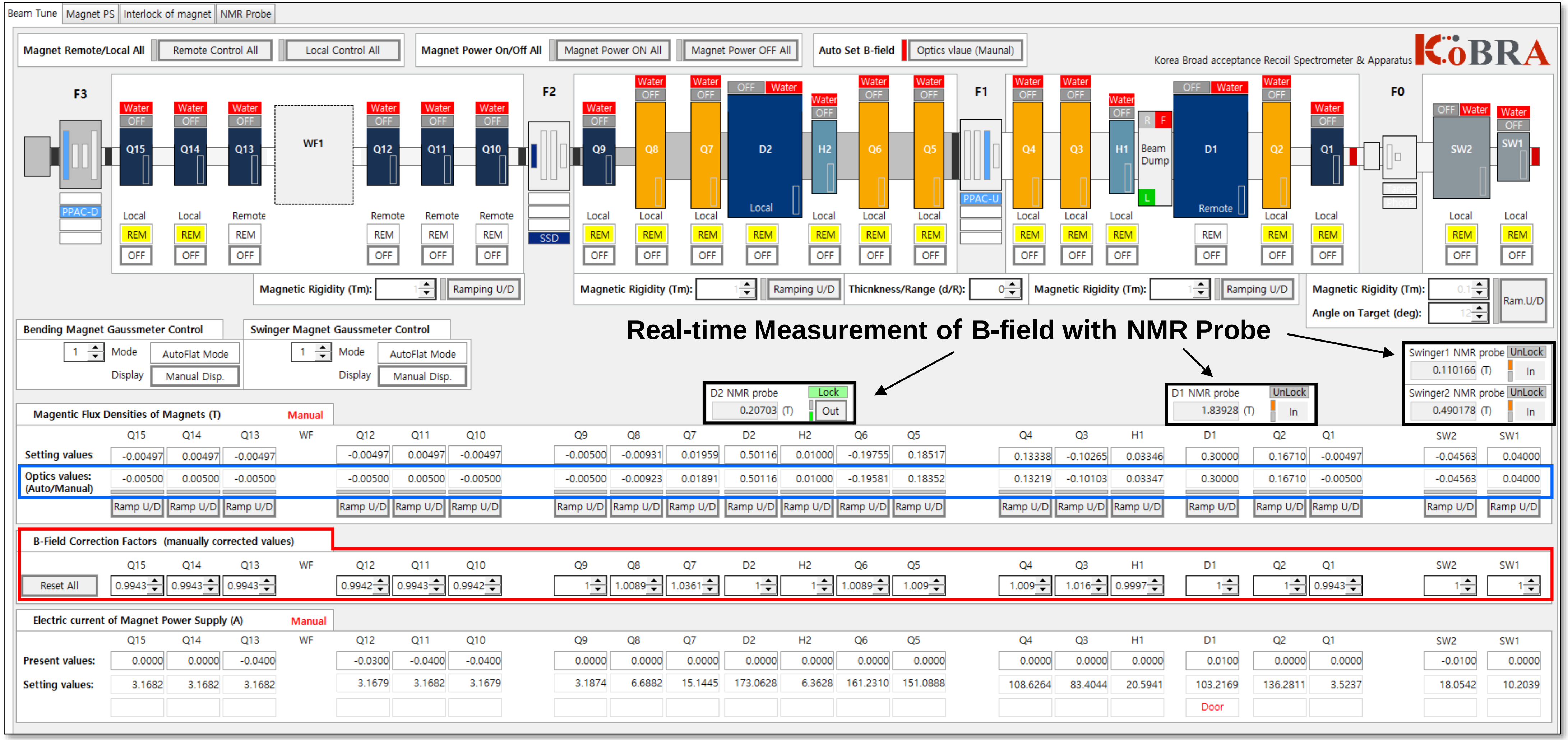
KoBRA Magnet BH Curve

- ✓ Fit functions were acquired from BH curve measurement data and reflected in control software
- ✓ Fit function: $I(B) = a_1B + a_3B^3 + a_5B^5 + a_7B^7 + a_9B^9 + y_0$





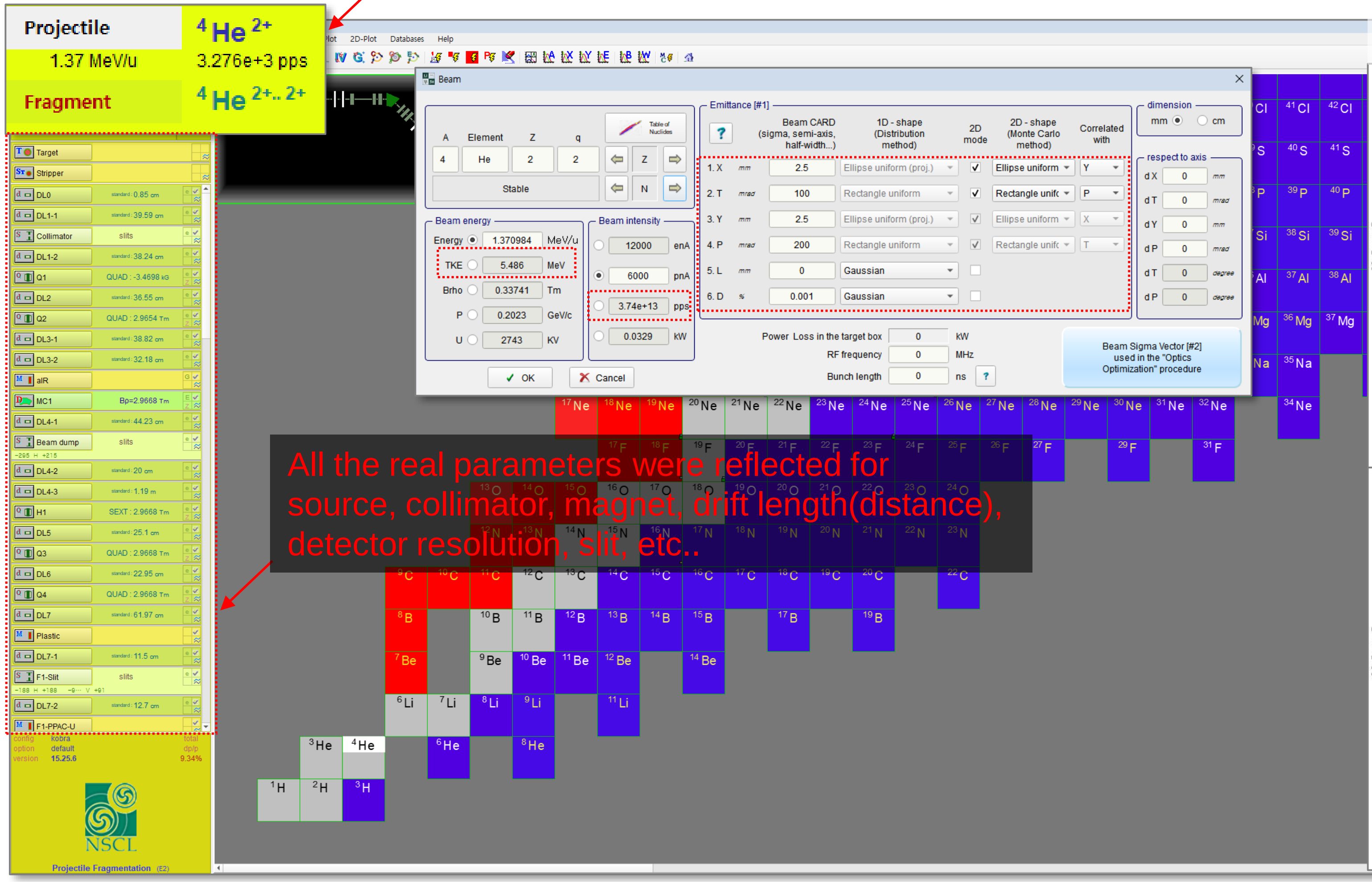
Remote Magnet Control with CSS



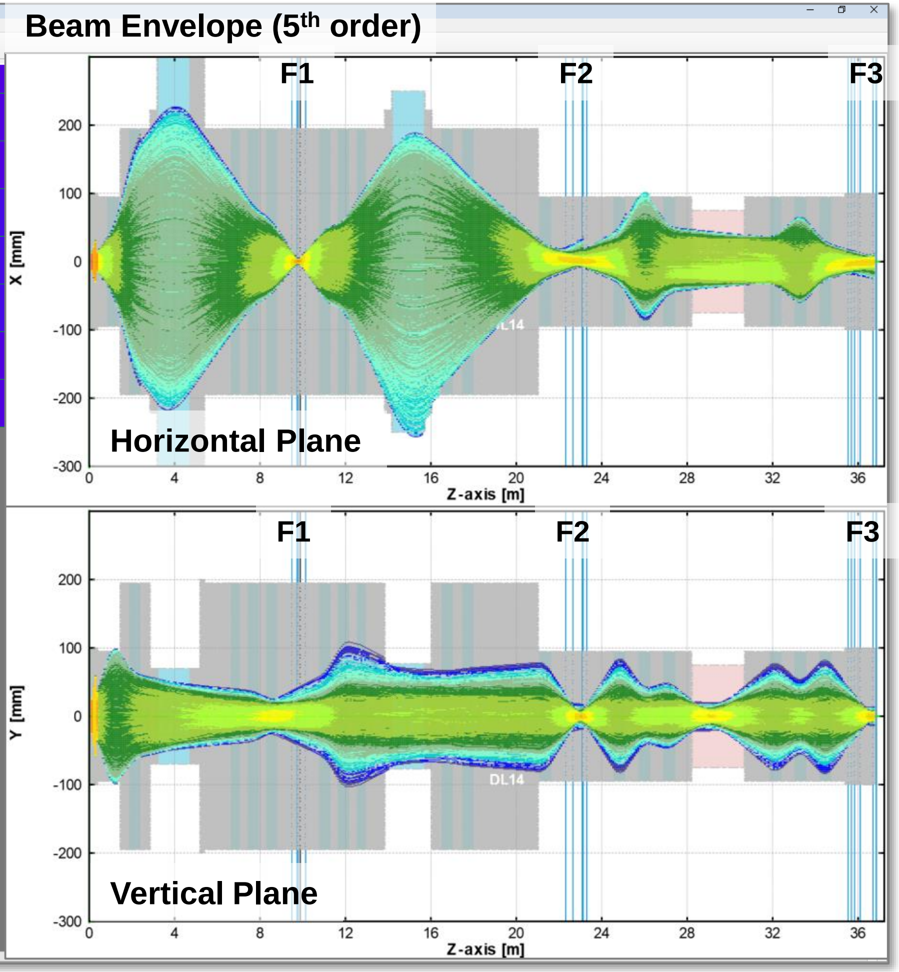
KoBRA LISE++ MC Calculation

For ^{241}Am alpha beam commissioning

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

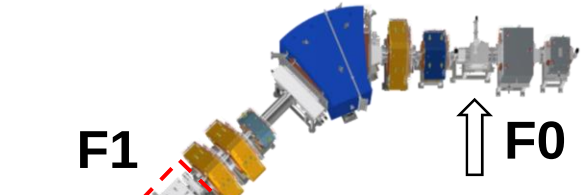
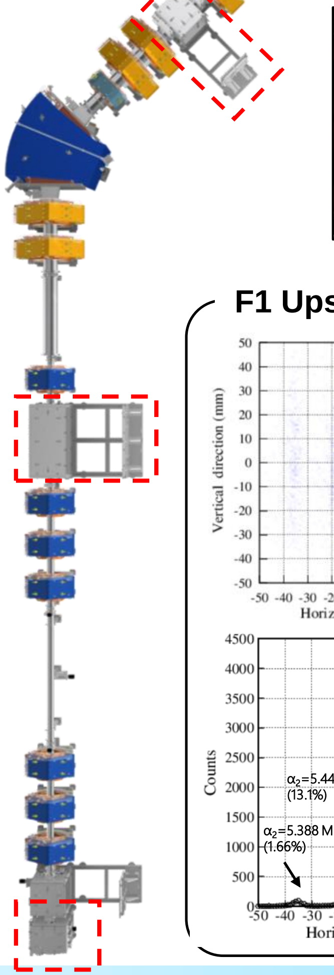


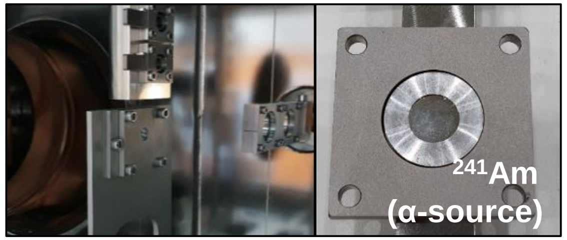
All the real parameters were reflected for source, collimator, magnet, drift length(distance), detector resolution, slit, etc..



KoBRA_F3+SNACK_2022_05.lpp

(Second) Beam Commissioning at 2022.04.

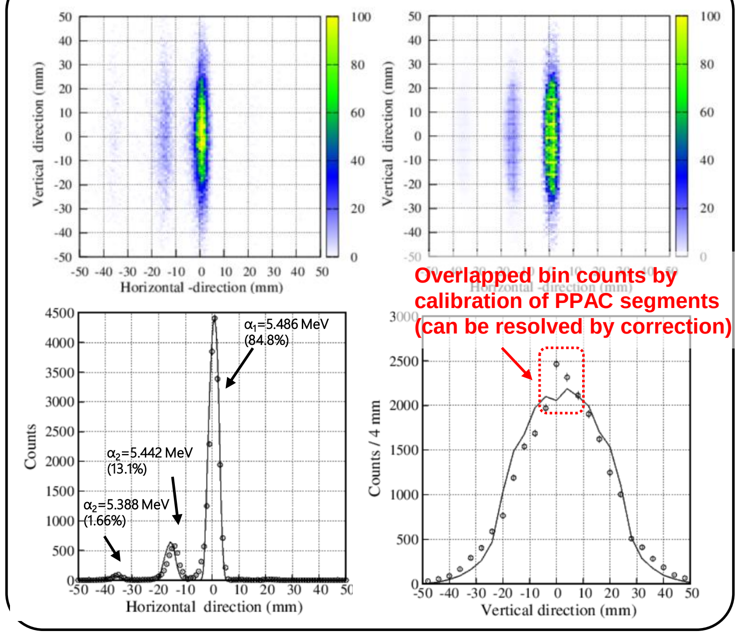


- ✓ The experimental results were more consistent to MC calculation with consistent correction of magnet B-field

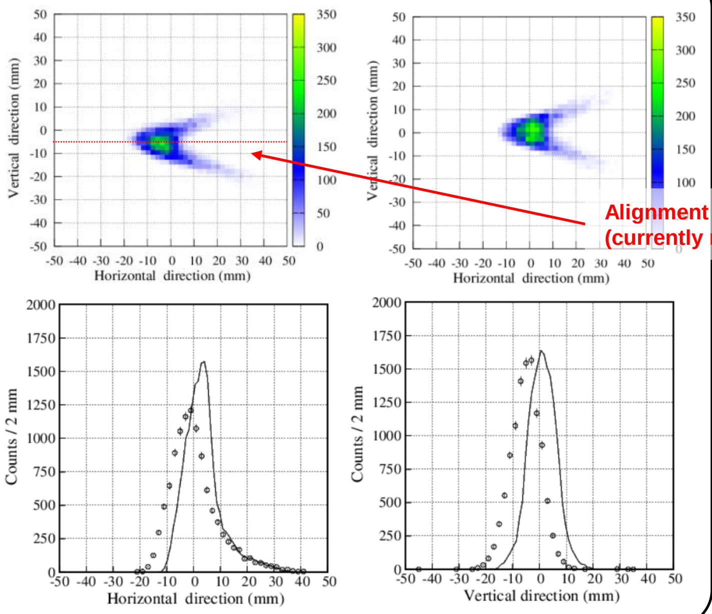
B-Field Difference between Ion Optics Calculation and Experiment

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

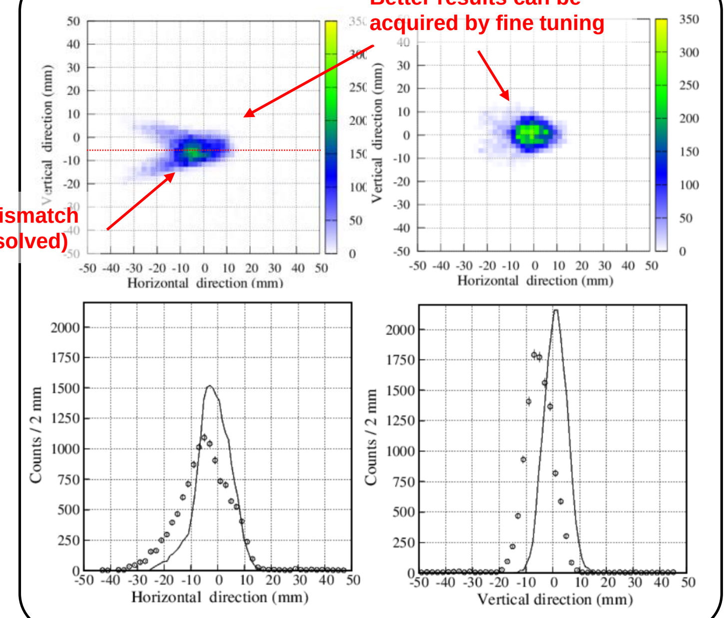
F1 Upstream PPAC (Most time-consuming)



F2 Downstream PPAC

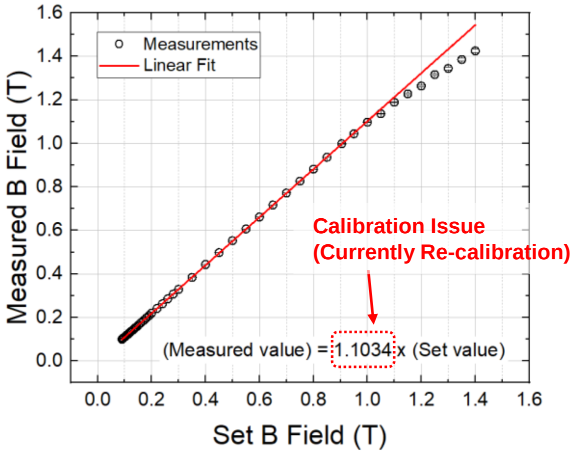


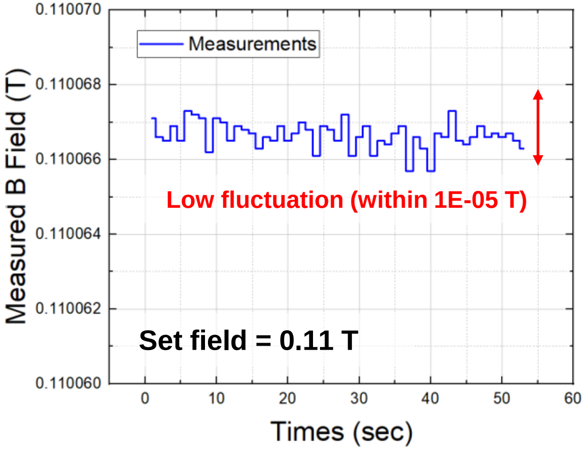
F3 SNACK PPAC

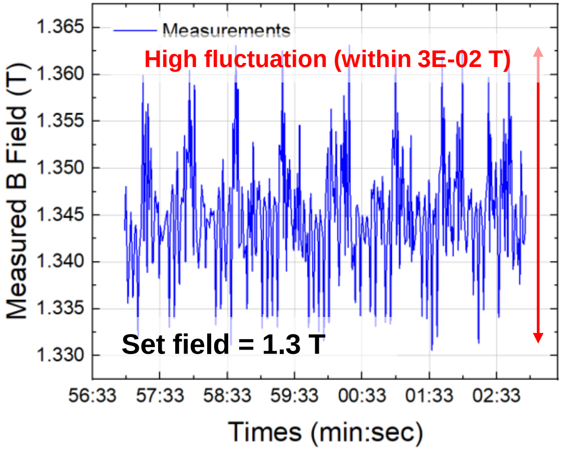


Current Issues for Magnet Control

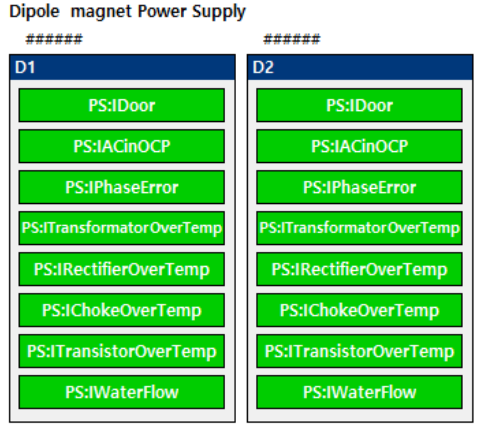
Dipole B-Field Mismatch & Unstable Measurement of NMR Probe







Interlock Issues of Power Supply



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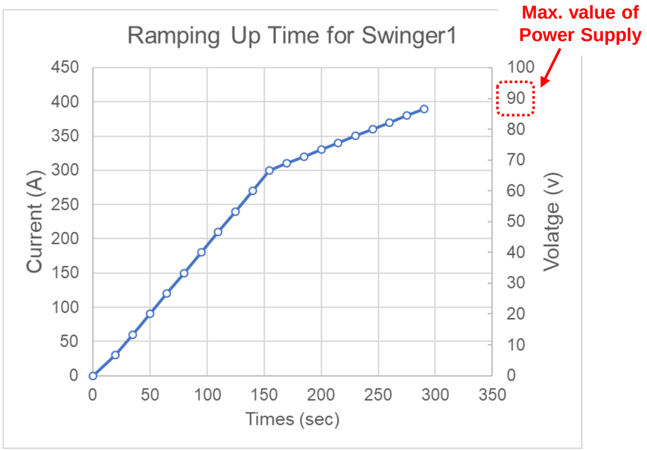
Ramping-Up Time of Power Supply



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

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 & Future Plan

(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