

The Design of Magnetic Needles for EPU and Helical Undulator measurement

C.Y. Kuo, Y. L. Chu, C. S. Hwang, T. Y. Chung, F. Y. Lin, C. K. Yang, C. H. Chang, J. C. Jan

NSRRC

Aug 2017

25th International Conference on Magnet Technology Amsterdam, Netherlands

MT25 Tue-Mo-O10-03



國家同步輻射研究中心
National Synchrotron Radiation Research Center

Outline

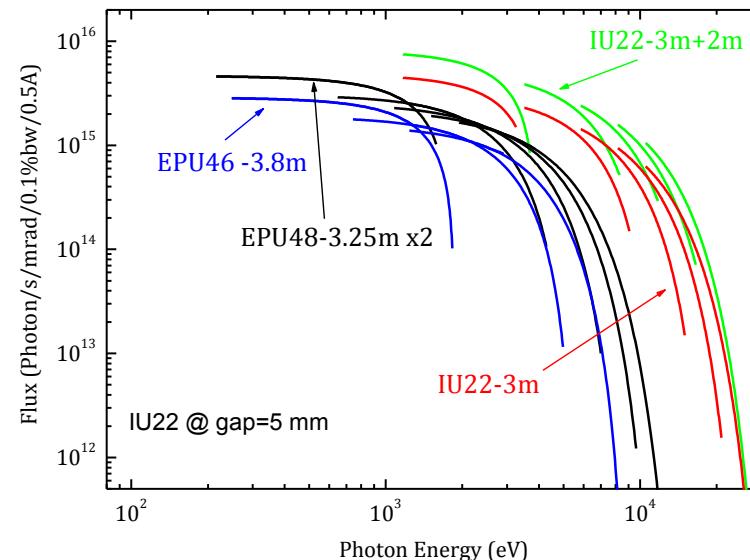
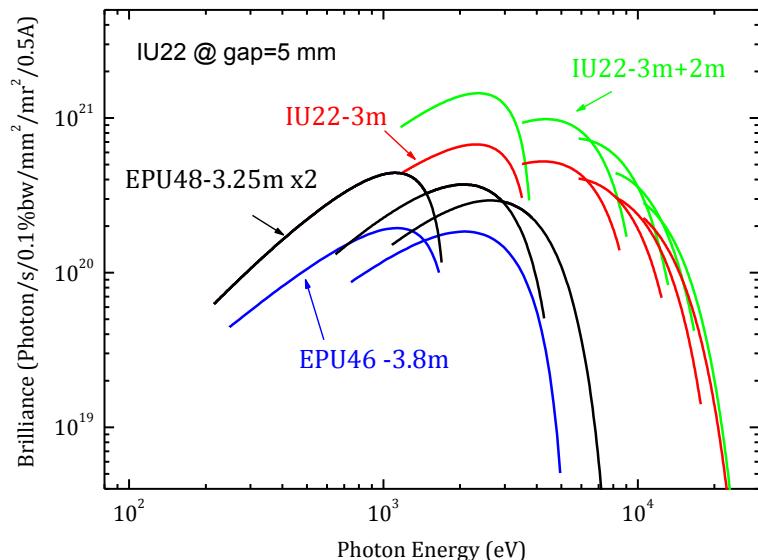
- Current status of TPS & TLS
- TPS ID plan in phase-I and –II
 - In-vacuum undulator, Cryogenic undulator, Elliptically polarized undulator
- Helical Permanent Magnet Undulator
- Magnetic Needles for Magnetic Field Measurement System
- Summary

Aerial view of NSRRC campus



ID Specification in phase-I & II

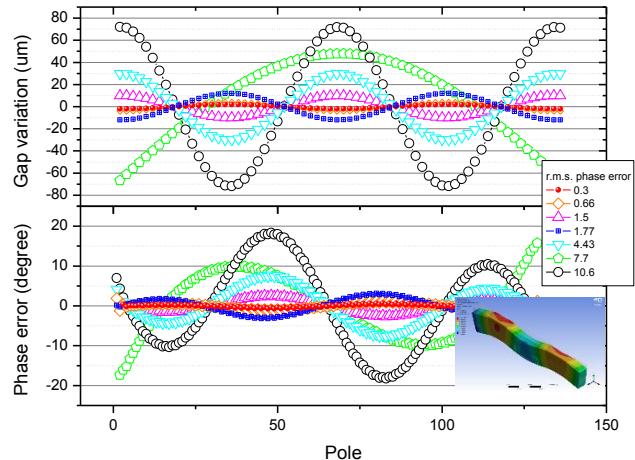
Phase I/II		EPU48	IUT22	IU22	EPU46	IU24	CU15	QEPU200	EPU66
Photon energy, keV	HP	0.23-1.5	5 - 20	5 - 20	0.35-1.5 (0.25-1.5)	4 - 23	8-34	0.01-0.65	0.09 -2
	VP	0.42-1.5			0.65-1.5 (0.45-1.5)			0.06-0.65	0.15 - 2
λ , mm		48	22	22	46	24	15	200	66
N_{period}		67	140	140	82	168	133	18	66
B_y/B_x , T		0.85/0.59	0.72	0.72(1.01)	0.73/0.43 (0.835/0.49)	0.86	1.01(1.31)	0.53/0.53	0.87/0.64
L, m		3.436	3.57	3.57	3.89	4.032	2.490	4.36	4.36
Gap, mm		13	7-5	7(5)	15 (14)	6.8	5(4)	29	16



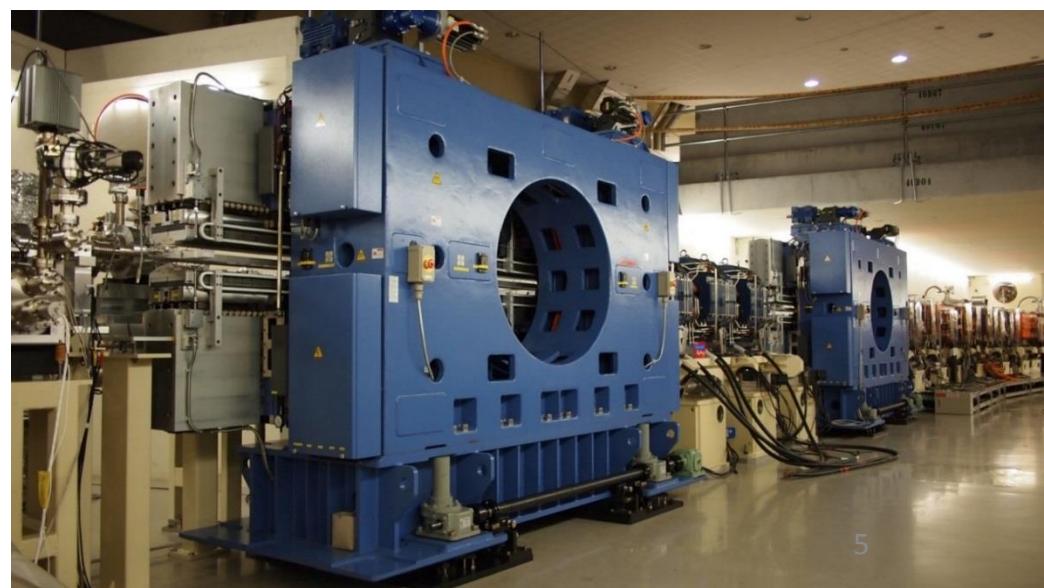
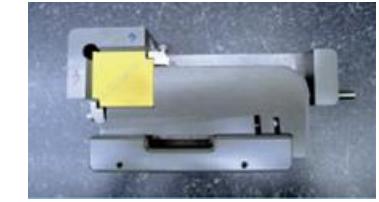
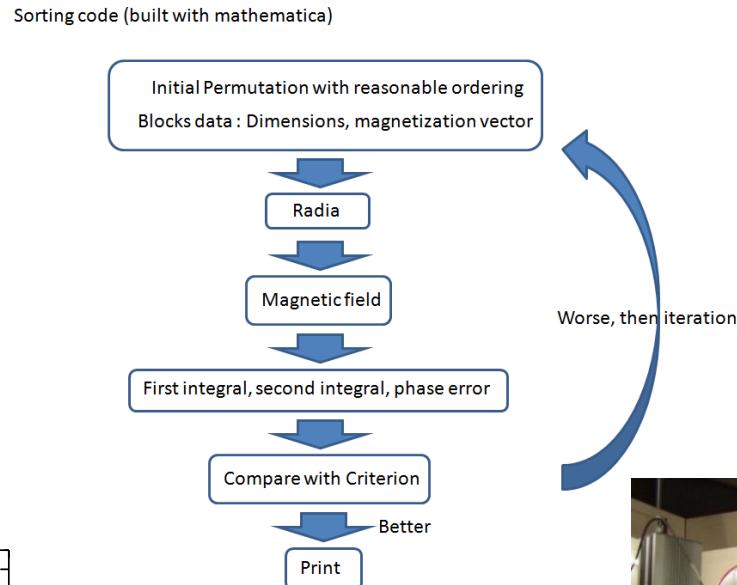
Elliptically Polarized Undulator

- Design, construction and field optimization at NSRRC.

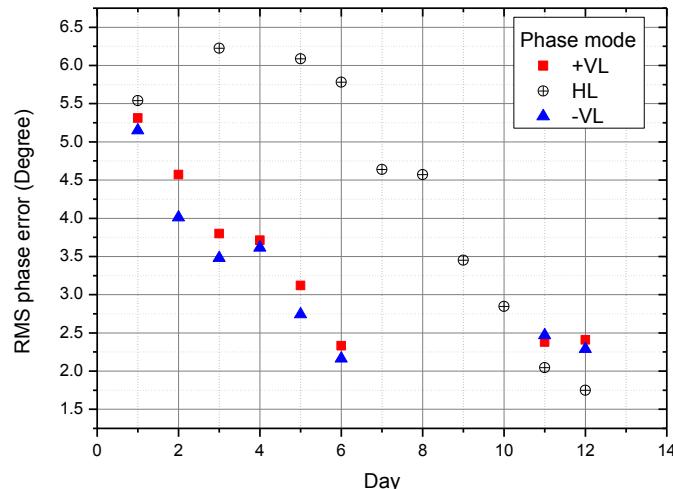
Reducing gap variation in design phase



Magnet measurement and sorting

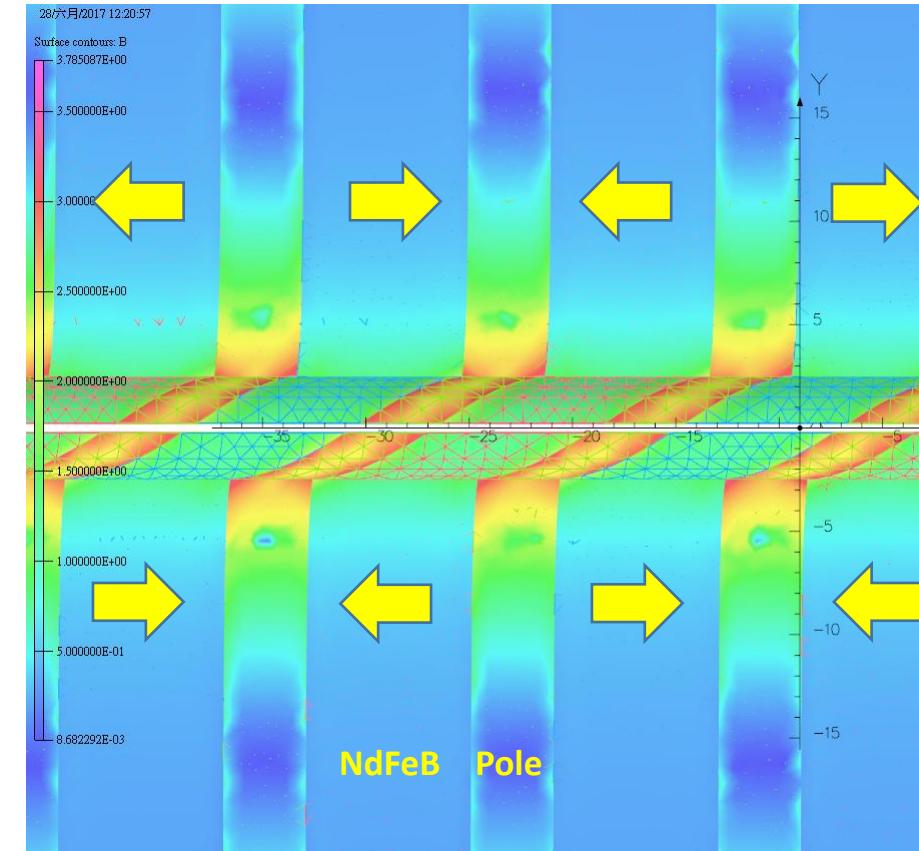
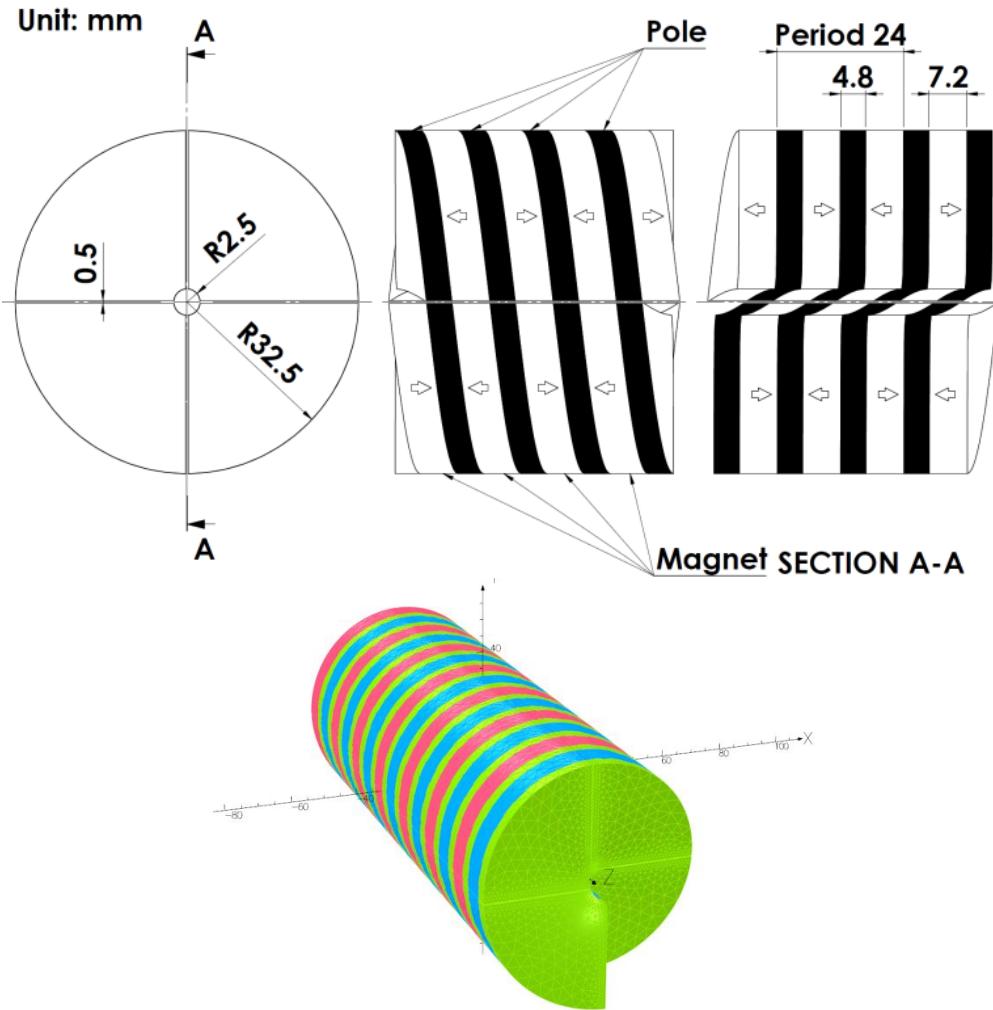


Magnetic field shimming



Helical Permanent Magnet Undulator

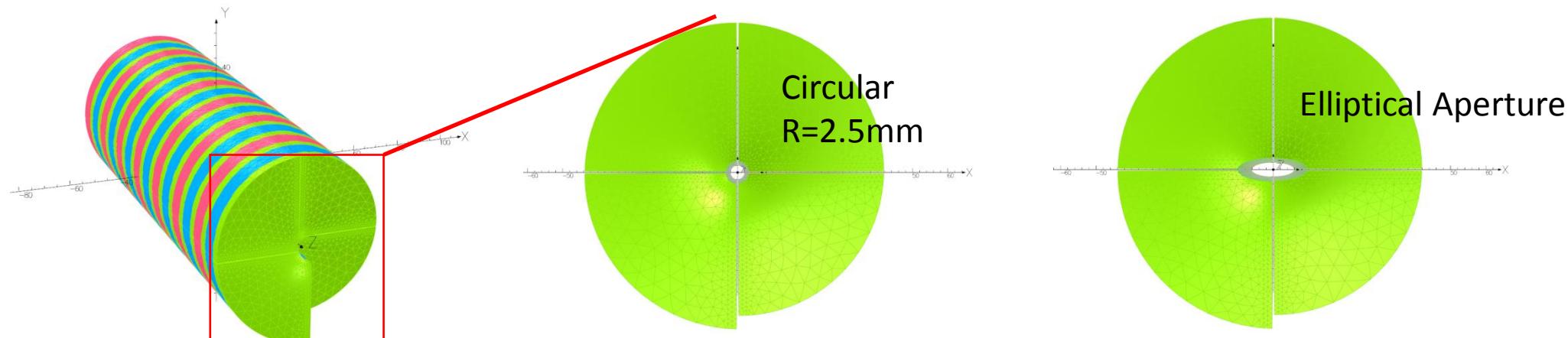
Hybrid Structure



NdFeB: VACODYM 863 ($B_r=1.29$ T, $H_{cb}=950$ kA/m)
Pole: Vanadium Permendur

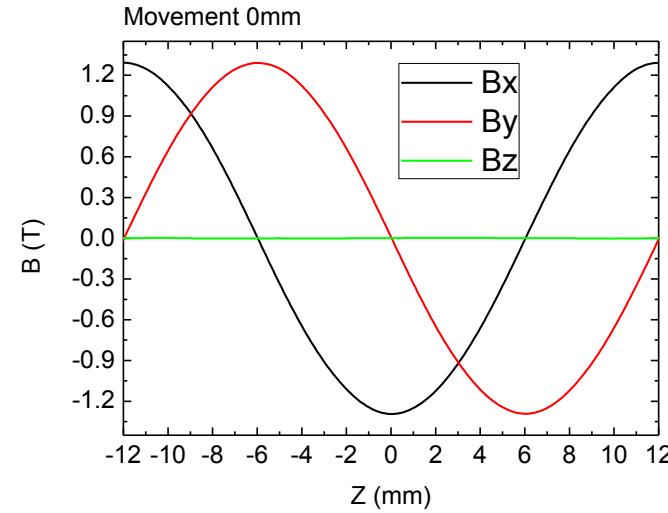
HU24 Circular & Elliptical Aperture

	Unit	Circular r=2.5mm	Pure r=2.5mm	Circular R=5mm	Elliptical Ra=7.5mm Rb=2.5mm
L(NdFeB)/L(pole)		1.5	-	3 / 1	1
Helical (Bx=By)	T	1.292	1.033	0.632 / 0.516	0.772
Vertical (By)	T	0.895	0.913	0.549 / 0.399	0.867
Horizontal (Bx)	T	0.895	1.236	0.549 / 0.399	0.550
$\Delta B_y(x) \& \Delta B_x(y)$ G.F.R @ $\pm 1\text{mm}$	%	0.2	2.5	0.3 / 1.3	1.5
$\Delta B_y(y) \& \Delta B_x(x)$ G.F.R @ $\pm 1\text{mm}$	%	2.7	0.9	3.1 / 2.0	3.9

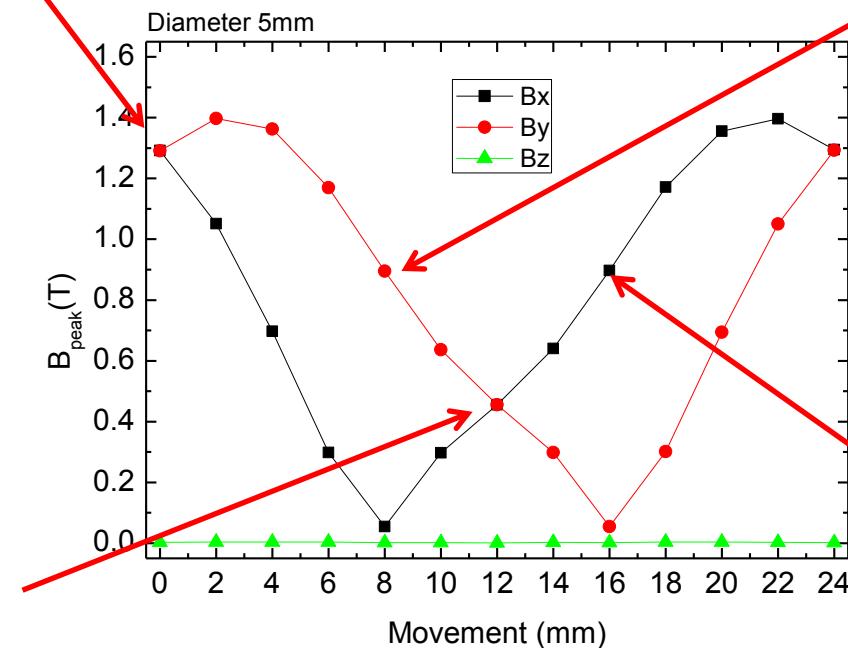
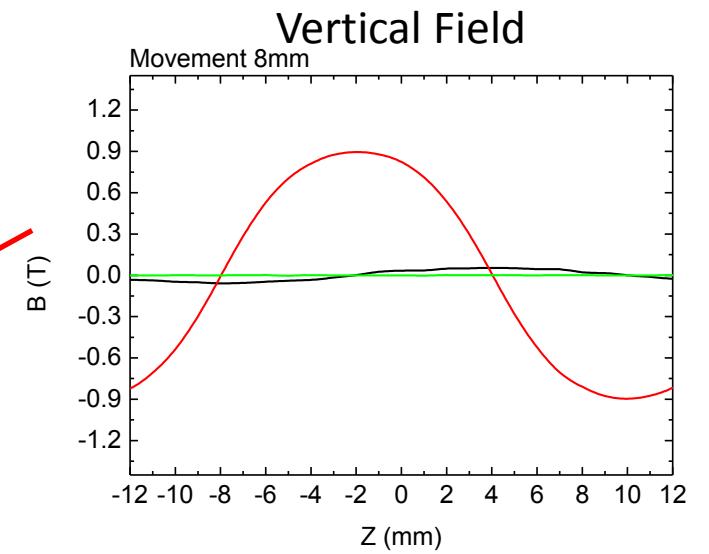


HU24 Magnetic field properties

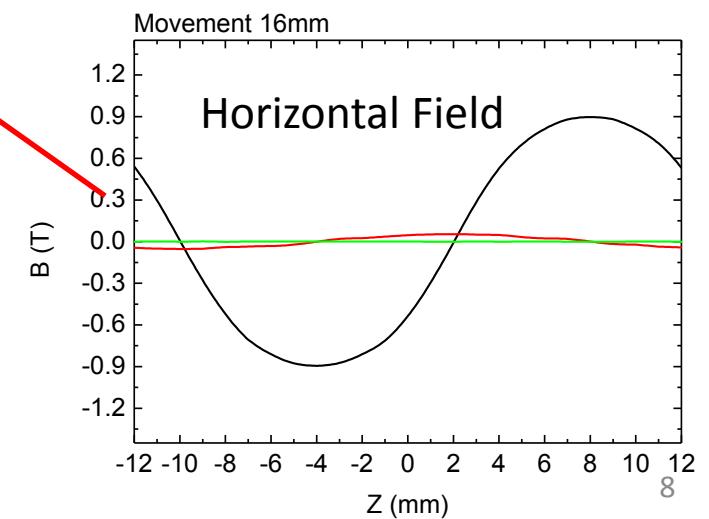
Bx,y,z in helical mode



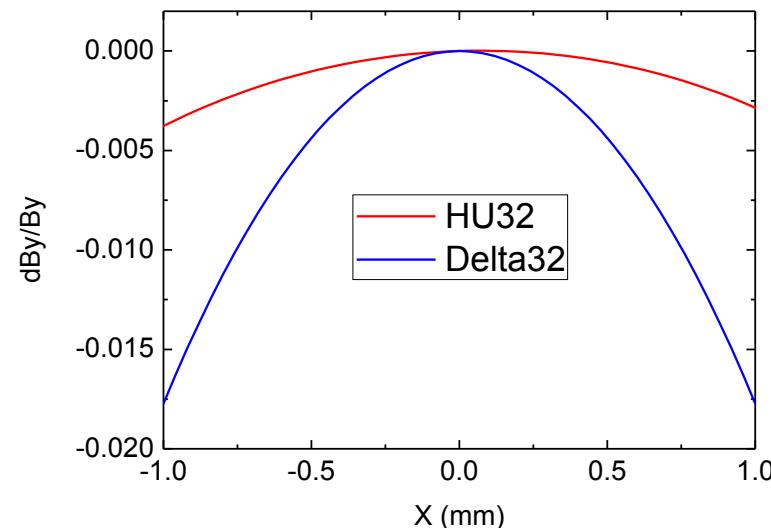
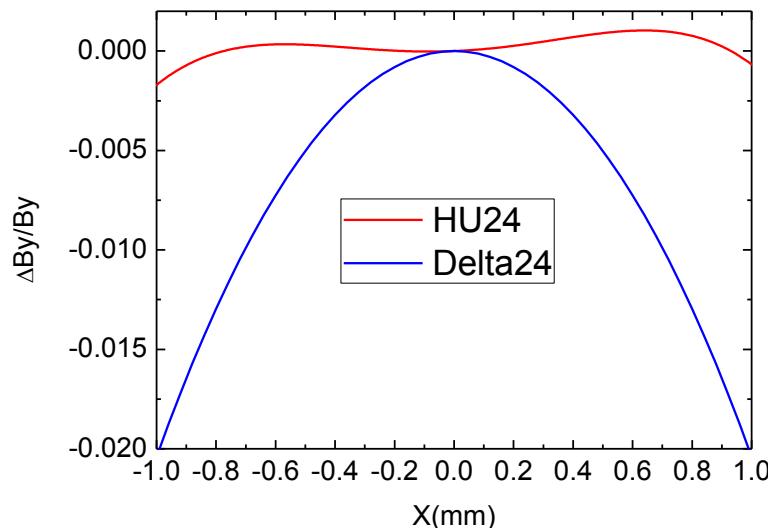
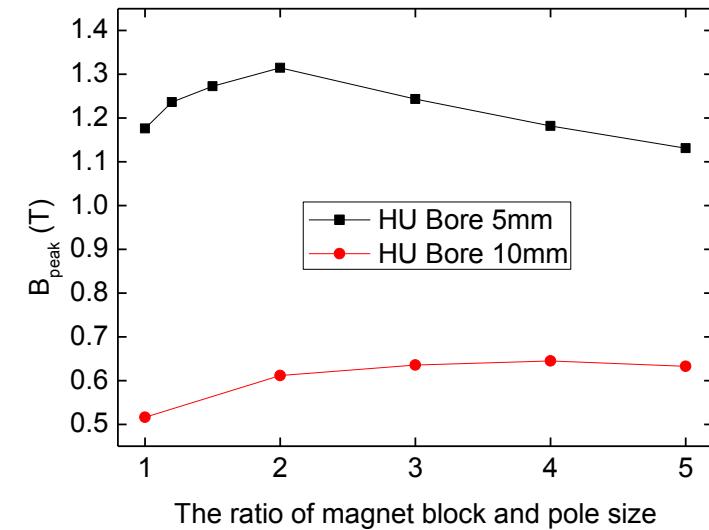
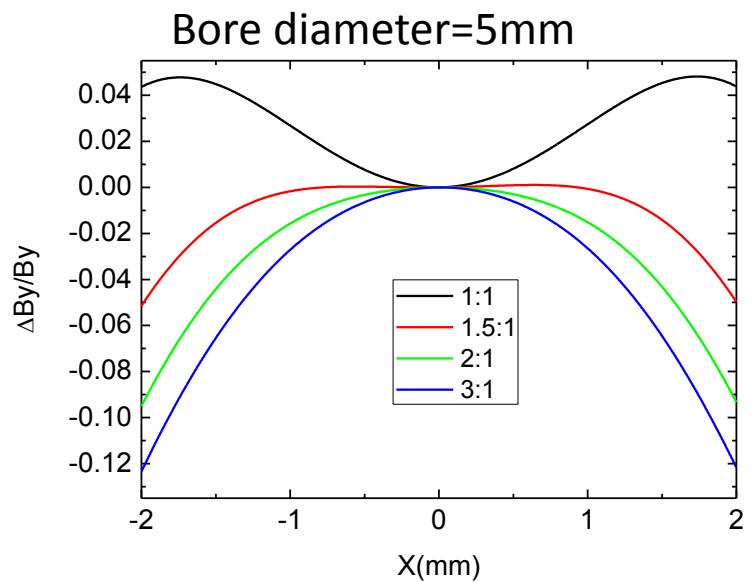
Bx,y,z in planar mode



Moving the diagonal arrays.

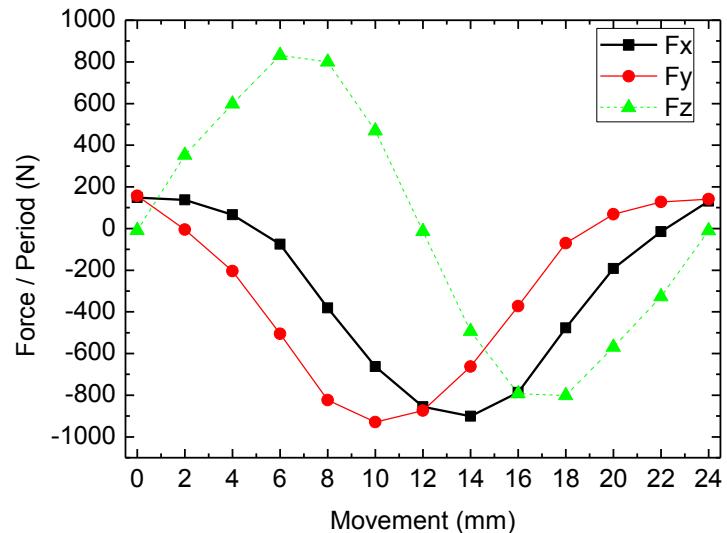


HU24 & HU32 Field Homogeneity



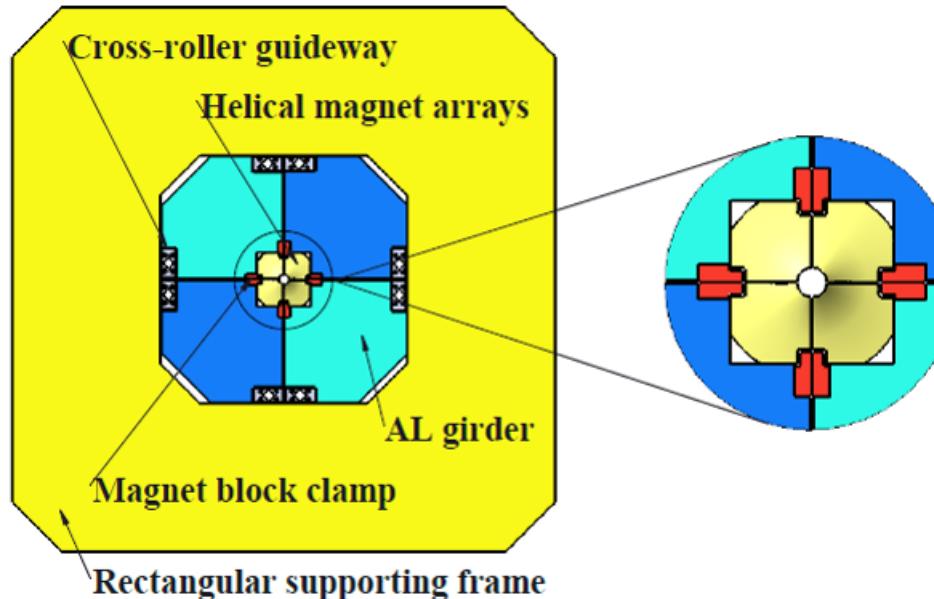
$$\text{ratio} = \frac{L_{NdFeB}}{L_{pole}}$$

HU24 Mechanical Design



Force distributions when the phase position of a magnet array is changed in the HPMU.

Diameter	Fx MAX. (N)	Fy MAX. (N)	Fz Max. (N)
5mm	930	930	830
10mm	630	630	760

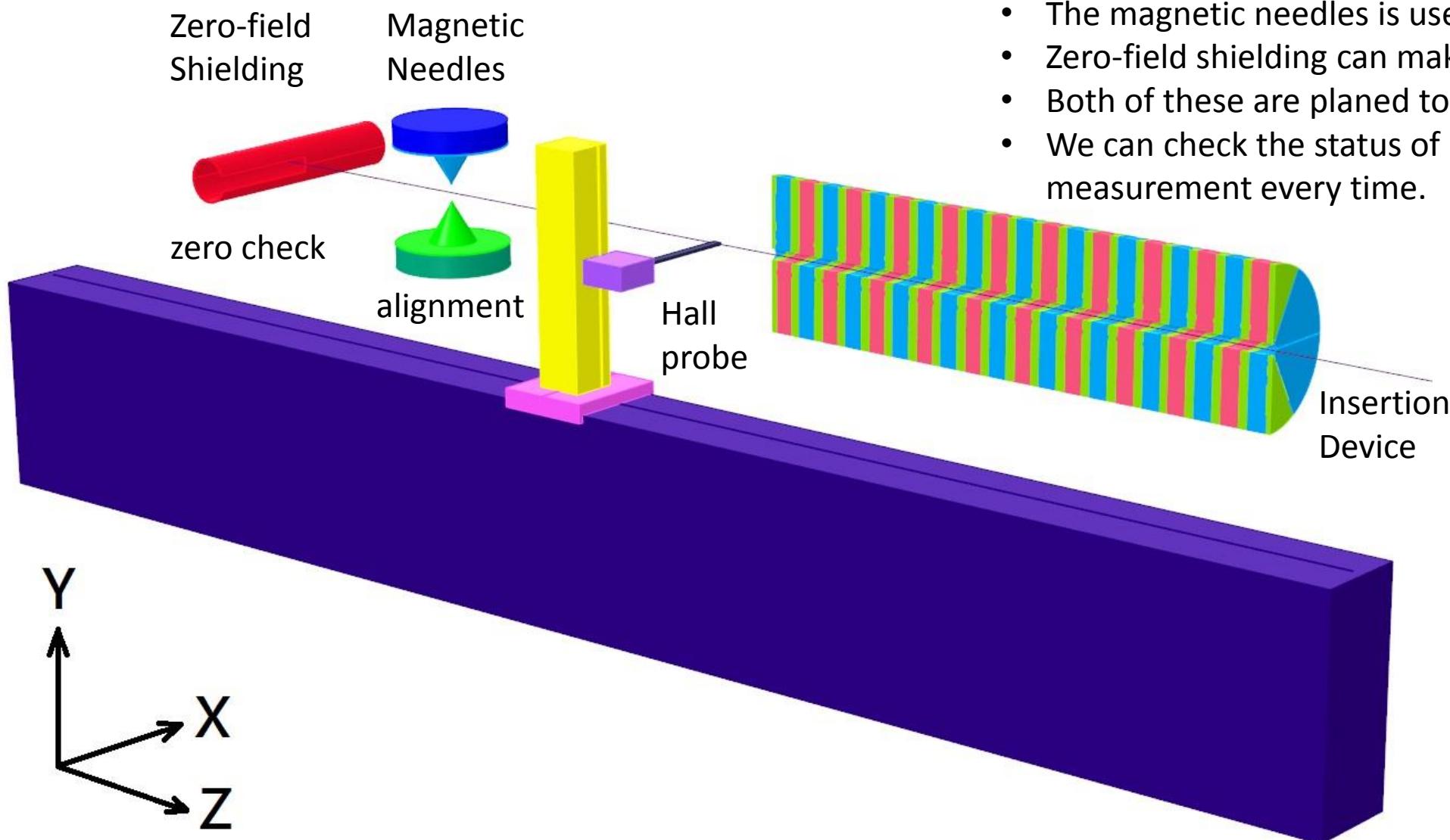


- A 500mm × 500mm box-like frame
- The magnetic blocks are 7.2 mm thick with a cross section of 32 mm × 28 mm and with $5 \times 5\text{mm}^2$ cuts.
- Blocks are needed to clamp the blocks onto the aluminum girder.
- Four 0.5mm gaps exist between adjacent magnet arrays.
- Helical array girders are assembled in a rectangular frame with a cross-roller guideway

Helical Permanent Magnet Undulator

- ◆ The helical permanent magnet undulator has a simple magnet configuration to generate helical and linear fields by shifting magnet arrays.
- ◆ This aggressive design has been designed with the aim to reach higher helical magnetic peak fields and increased field homogeneity.
- ◆ The peak field is 1.292T in helical mode for a 24 mm period length within a bore diameter of 5 mm.
- ◆ The end pole configuration is optimized to minimize the helical first and second field integrals as well as the fringe fields over the operating range of phase movement.
- ◆ A 24 cm long prototype with 24 mm period and 5 mm round bore is under construction in 2017.

Improvement of Hall probe system



Why do we choose N-N type magnetic needles instead of N-S type

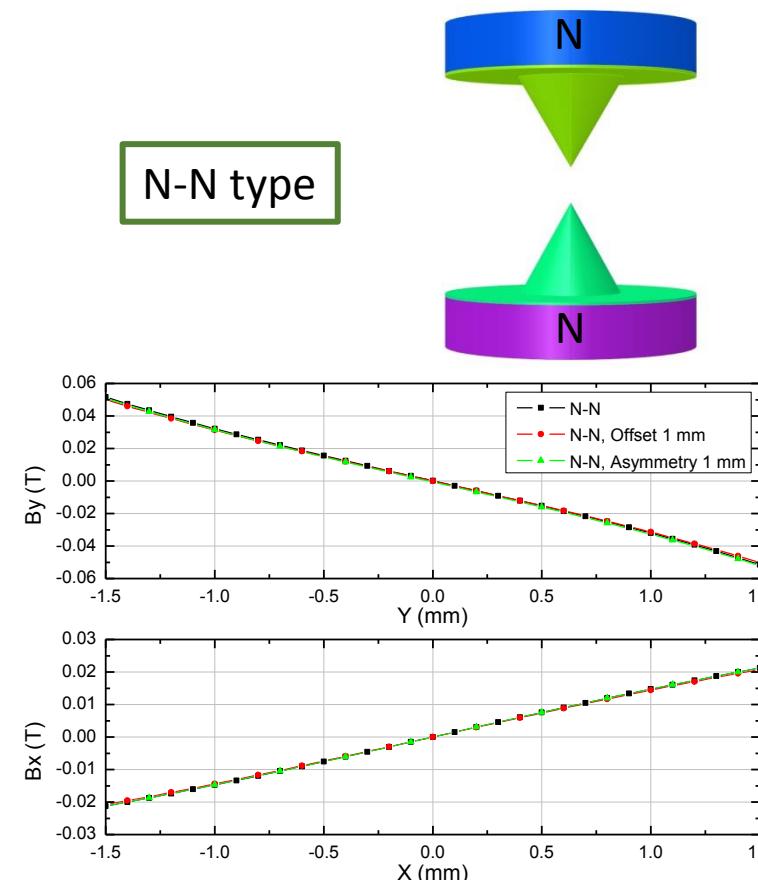
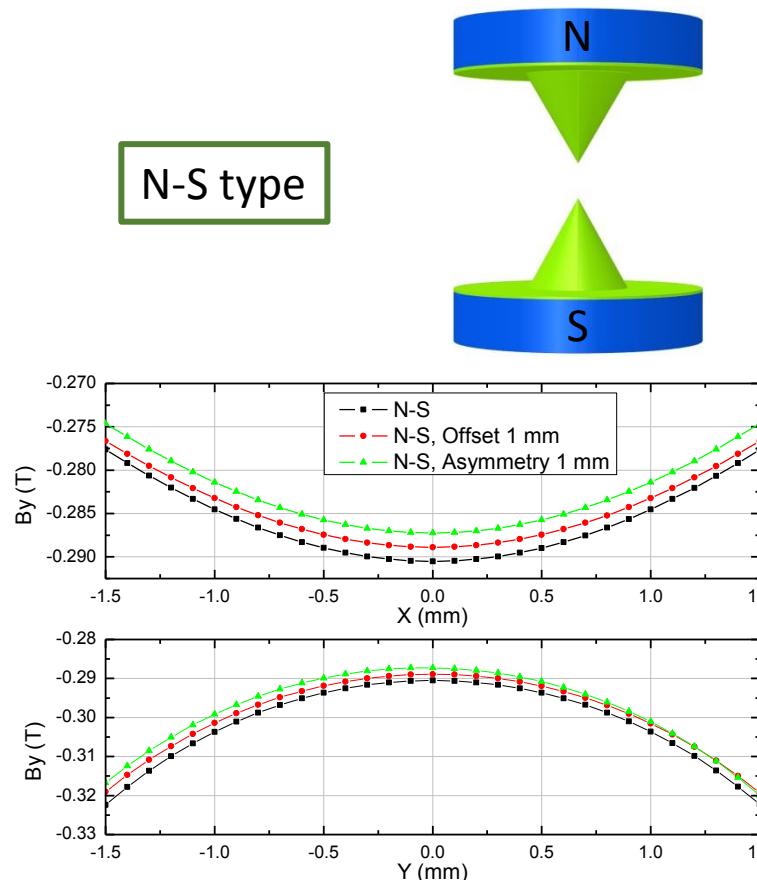
➤ **Offset :**

➤ **Asymmetry :**

➤ **Fitting Error :**

linear fitting V.S. parabolic fitting

Magnetic Needles	N-S type	N-N type
Downside Pole Offset 1 mm	$\Delta x = 0.28 \mu\text{m}$	$\Delta x = 0.03 \mu\text{m}$
	$\Delta y = 3.71 \mu\text{m}$	$\Delta y = 4.80 \mu\text{m}$
Downside Pole Shrink 1 mm	$\Delta x = 0.38 \mu\text{m}$	$\Delta x = 0.54 \mu\text{m}$
	$\Delta y = 37.6 \mu\text{m}$	$\Delta y = 23.4 \mu\text{m}$



Material Selection

- **B_r** : remanence
- **H_{cb}** : coercivity
- **Temperature** :

	NdFeB					Sm ₂ Co ₁₇
B _r (T)	1.12	1.24	1.28	1.30	1.36	1.04
H _{cb} (kA/m)	859	923	962	970	1018	732
∂B _x / ∂x (T/m)	11.18	12.02	12.39	12.50	12.97	10.05
∂B _y / ∂y (T/m)	22.42	24.09	24.82	25.05	25.97	20.18
ΔBr / ΔT	0.1%					0.03%



20 T/m is good enough.

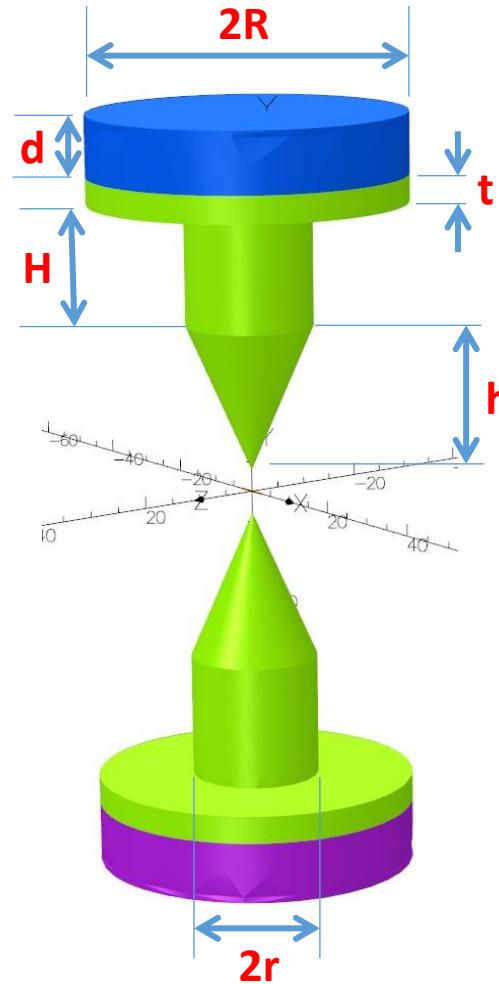
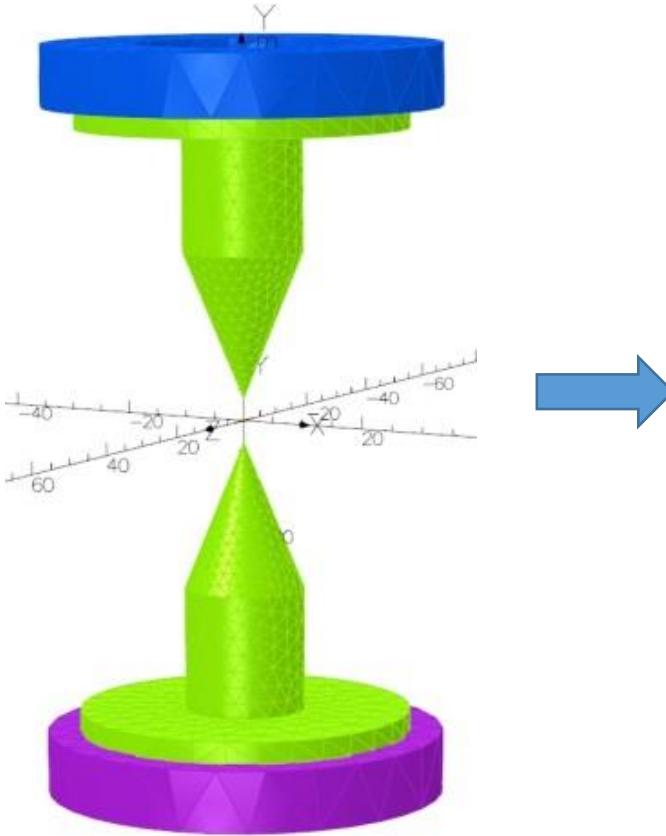
For example,

If we would like resolution of position is 1 μm,
The gradient have to be larger than 10 T/m
because the resolution of Hall probe system is better than 0.1 gauss.

$$\frac{\partial B_x}{\partial x} = 10 \text{ (T / m)} = 100 \text{ (gauss / mm)} = 0.1 \text{ (gauss / } 1 \mu\text{m)}$$

$$\frac{\partial B_y}{\partial y} = 20 \text{ (T / m)} = 200 \text{ (gauss / mm)} = 0.1 \text{ (gauss / } 0.5 \mu\text{m)}$$

Optimized Process



Y.L. Chu, NSRRC

Some parameters in geometry.

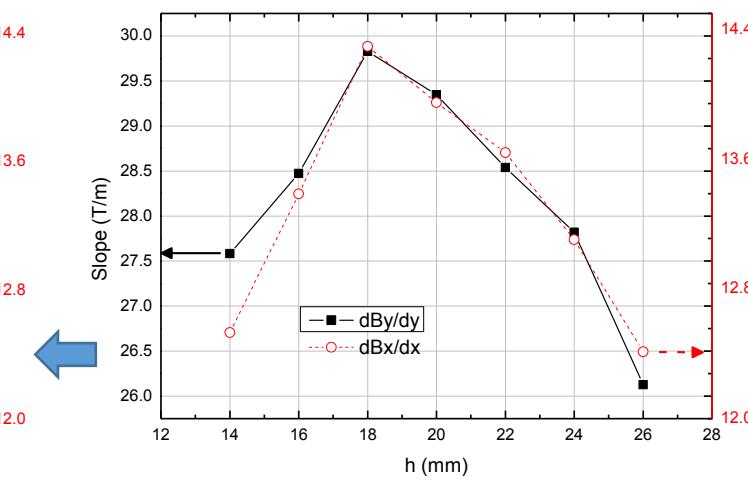
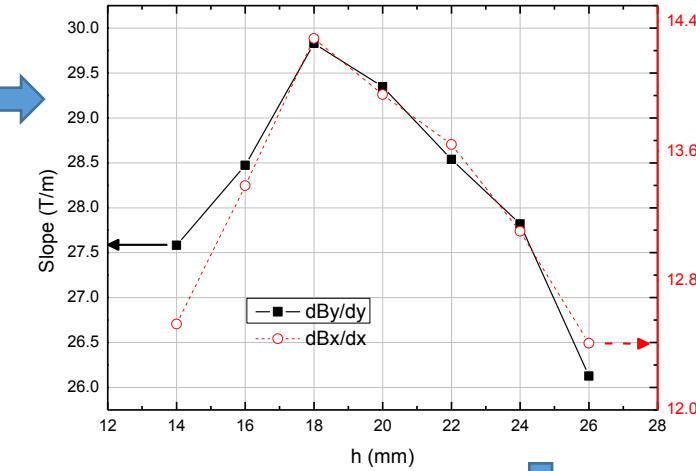
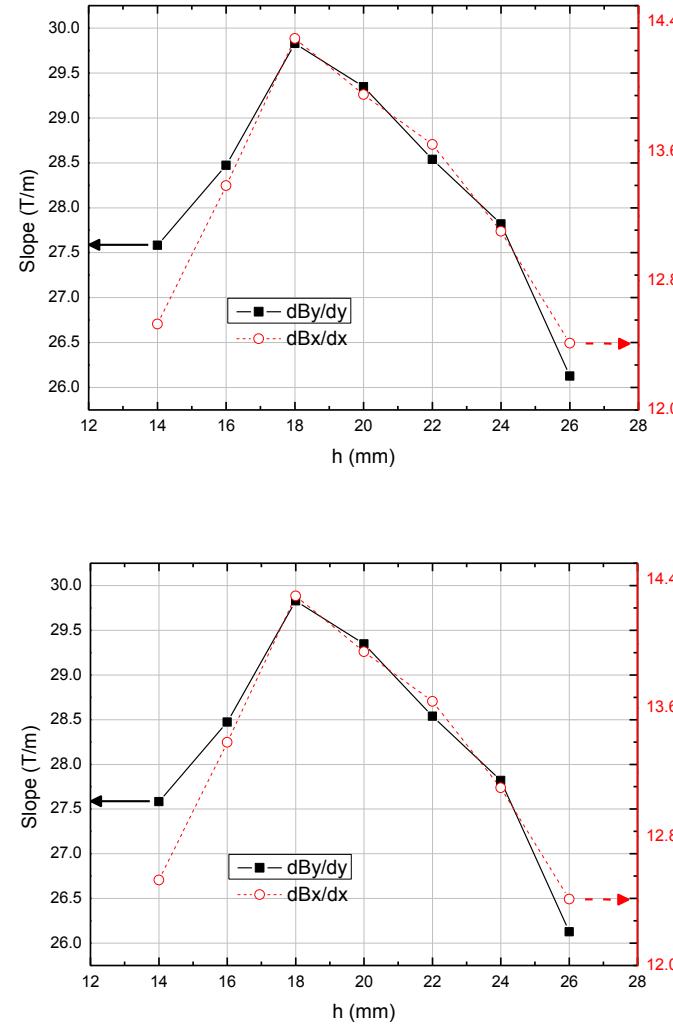
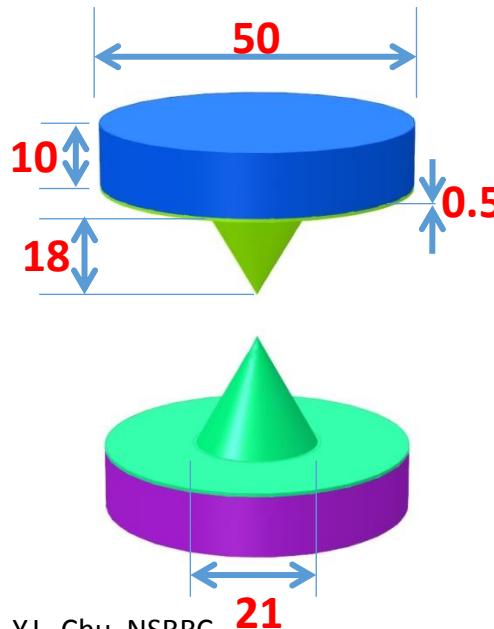
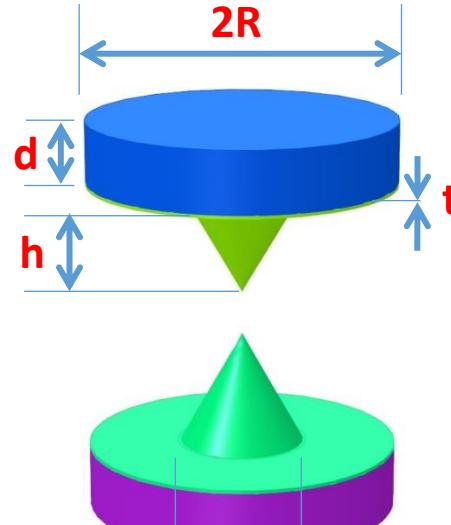
Gap = 7 mm

$2R$ = 50 mm

d = 10 mm

In sequence,
we adjusted t , H , h , r .

Optimized Process ($t \rightarrow H \rightarrow h \rightarrow r$)

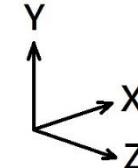
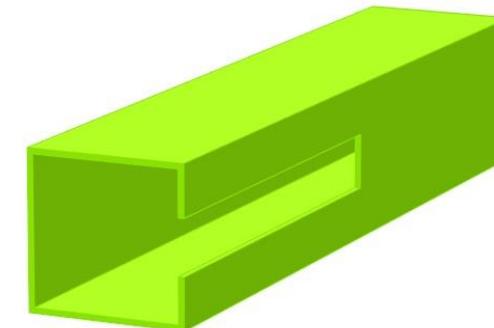
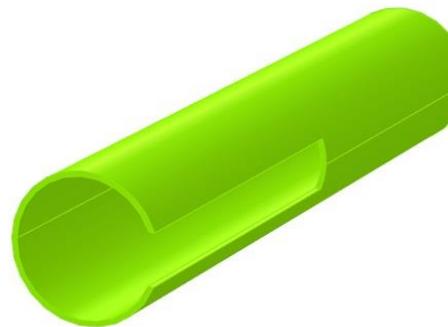


$$\frac{\partial B_x}{\partial x} = 15.38 \text{ (T/m)}$$

$$\frac{\partial B_y}{\partial y} = 30.56 \text{ (T/m)}$$

Zero-field Shielding

In the uniform external
magnetic field
0.3 gauss



Cylinder	thickness (mm)	B _x (gauss)	B _y (gauss)	B _z (gauss)
Natic S3-6	0.76	0.1	0.05	0.05
CoNaticAA	0.76	0.00040	0.00011	0.00011

CoNaticAA	thickness (mm)	B _x (gauss)	B _y (gauss)	B _z (gauss)
Cylinder	0.76	0.00040	0.00011	0.00011
	0.51	0.00054	0.00015	0.00015
	0.36	0.00075	0.00021	0.00021
Cubic	0.76	0.00025	0.00015	0.00014
	0.51	0.00034	0.00019	0.00019
	0.36	0.00048	0.00027	0.00027

Zero-field shielding is a closed container, and the material selection is crucial.
we prefer cylinder with 0.7mm CoNaticAA.

Summary

- Magnetic needles and zero-field shielding are used to align center and check zero field.
- N-N type is suited to magnetic needles because of fitting error.
- After optimization, the magnetic needles we design can provide magnetic field gradient 30.5 T/m so that the resolution of position will be 0.065 μm .
- Zero-field shielding is made of μ -metal (CoNatic AA) 0.7 mm thickness as a cylinder shape. The material selection is crucial.

Thank you for your attention.