

Updates on Permanent Magnets for the QD0

Kyoto University

Y. Iwashita, S. Ushijima, H. Tongu, H. Fujisawa

KEK

M. Masuda, T. Tauchi



Permanent Magnet Study Short History

2002~2005 First R&D program for FFQ

Permanent Magnet Quadrupole for Final Focus Lens
in a Linear Collider

2002 Fixed strength PMQ

2003 Adjustable PMQ (double ring)

2004 Measurement and fine tuning

2005 Higher gradient at small bore

2006~2009 Second R&D program

PMQ for Linear Collider and Neutron optics

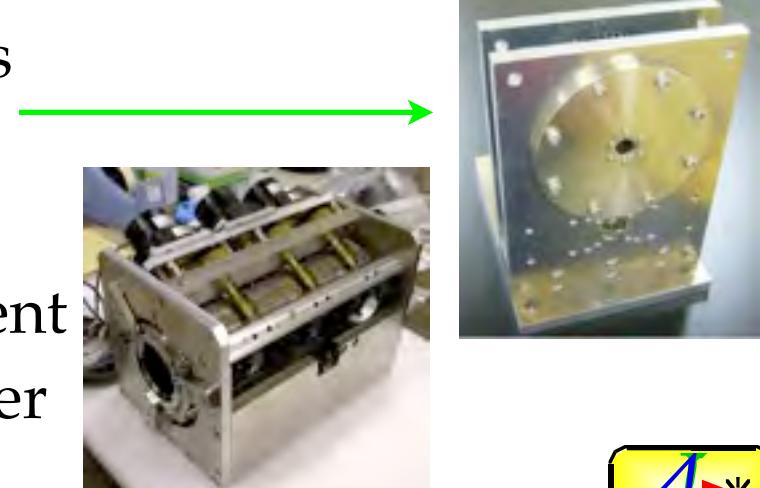
2006 Rapid Cycling Sextupole for neutron

2007 Adjustable PMQ (2nd model) started

2008 Assemble, Measurement and Adjustment

2009 Design and fabrication of Magnet mover

No project budget since then.



Permanent Magnet Study Short History

2002~2005 First R&D program for FFQ

Permanent Magnet Quadrupole for Final Focus Lens
in a Linear Collider

2002 Fixed strength PMQ



2003 Adjustable PMQ (double ring)

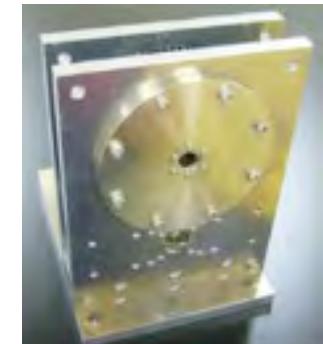
2004 Measurement and fine tuning

2005 Higher gradient at small bore

2006~2009 Second R&D program

PMQ for Linear Collider and Neutron optics

2006 Rapid Cycling Sextupole for neutron



2007 Adjustable PMQ (2nd model) started

2008 Assemble, Measurement and Adjustment



2009 Design and fabrication of Magnet mover

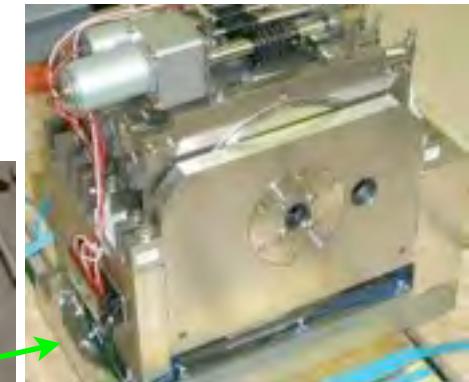
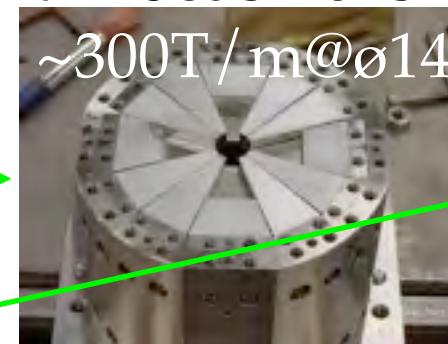
No project budget since then.

Permanent Magnet Study Short History

2002~2005 First R&D program for FFQ

Permanent Magnet Quadrupole for Final Focus Lens
in a Linear Collider

2002 Fixed strength PMQ



2003 Adjustable PMQ (double ring)

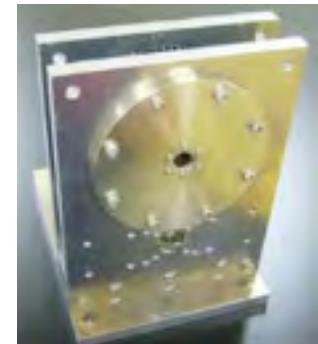
2004 Measurement and fine tuning

2005 Higher gradient at small bore

2006~2009 Second R&D program

PMQ for Linear Collider and Neutron optics

2006 Rapid Cycling Sextupole for neutron



2007 Adjustable PMQ (2nd model) started

2008 Assemble, Measurement and Adjustment



2009 Design and fabrication of Magnet mover

No project budget since then.

Permanent Magnet Study Short History

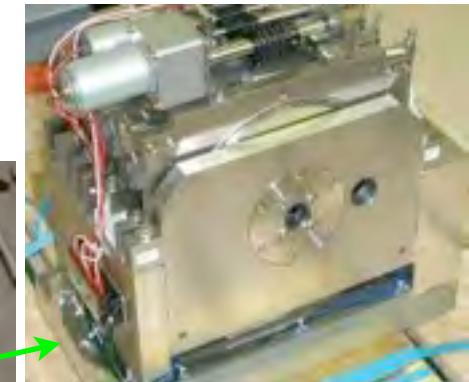
2002~2005 First R&D program for FFQ

Permanent Magnet Quadrupole for Final Focus Lens
in a Linear Collider

2002 Fixed strength PMQ



$\sim 300\text{T/m} @ \varnothing 14$



2003 Adjustable PMQ (double ring)



2004 Measurement and fine tuning



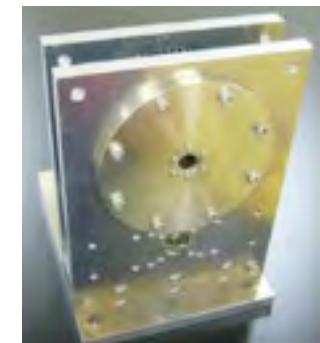
2005 Higher gradient at small bore



2006~2009 Second R&D program

PMQ for Linear Collider and Neutron optics

2006 Rapid Cycling Sextupole for neutron



2007 Adjustable PMQ (2nd model) started

2008 Assemble, Measurement and Adjustment

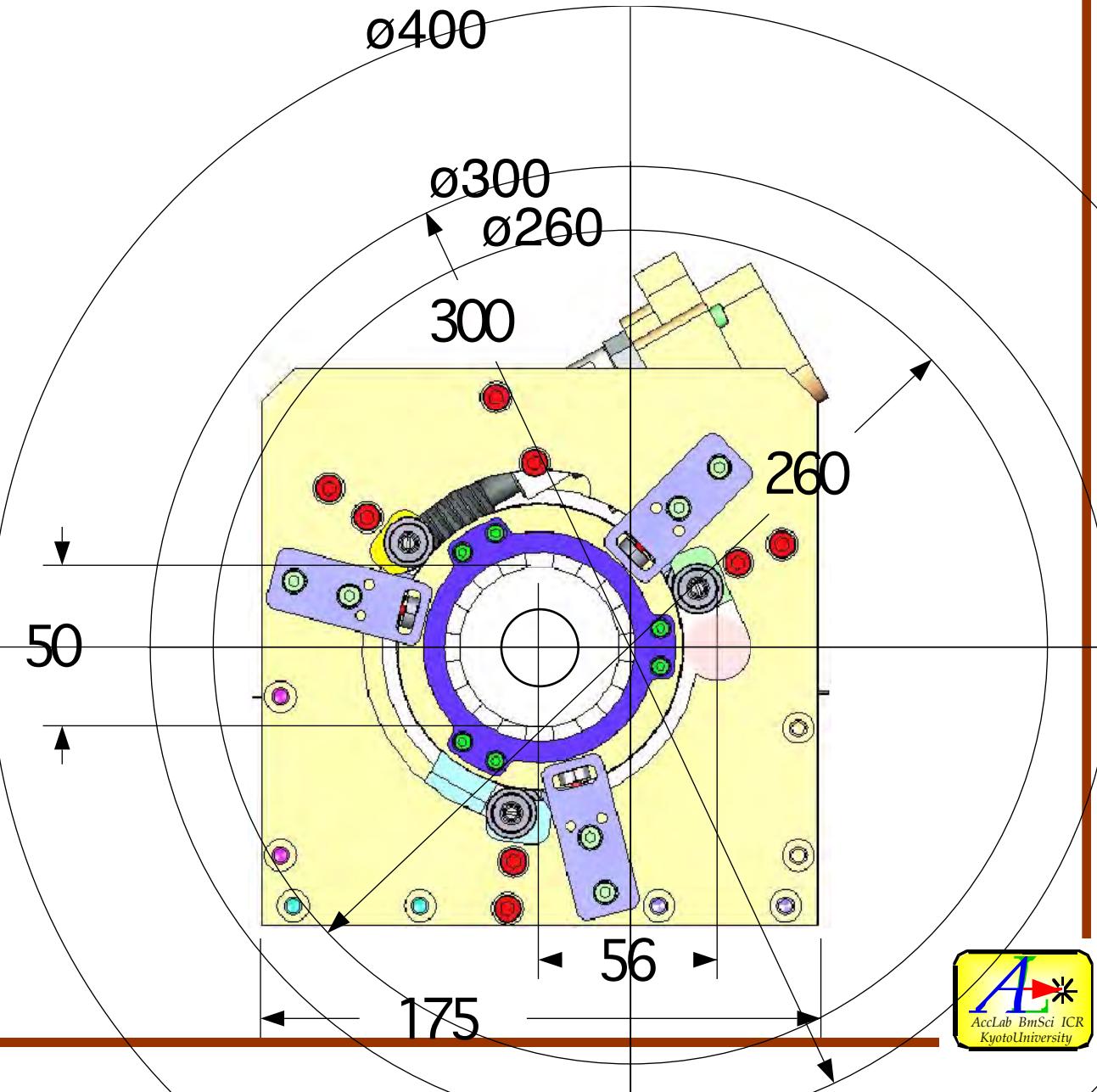
2009 Design and fabrication of Magnet mover

No project budget since then.

Cross Section

— ATF2 version in a support tube —

- Separation:
 - $14\text{mr} \times 4.0 = 56\text{mm}$
 - $14\text{mr} \times 4.5 = 64\text{mm}$
 - $14\text{mr} \times 5.0 = 70\text{mm}$
- Corners may be cut.
- No magnetic mat'l.
- Supersonic Motor.
- Mover to be installed

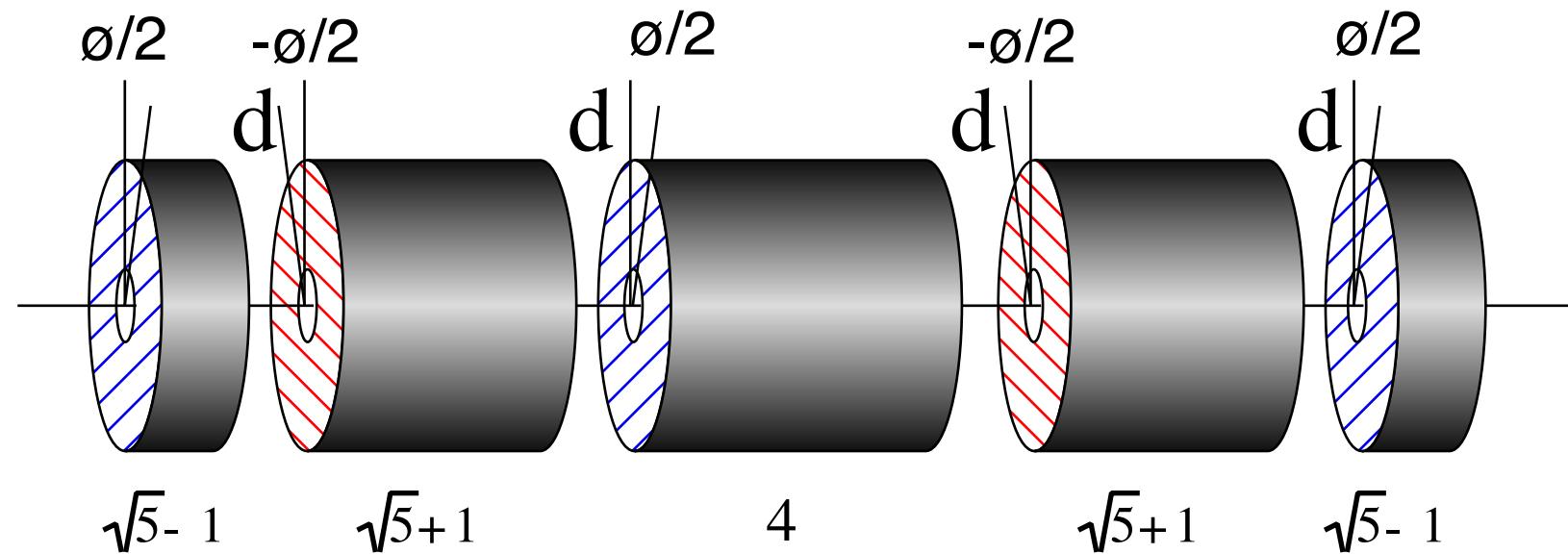


Target

- Evaluate feasibility of PM FFQ.
- Less vibration (rigid enough).
- Reserve space for outgoing beam.
- Less high order multipoles.
- Less magnetic center excursion.
- Good stability (durability).
- Down to 20% adjustability.

Gluckstern's adjustable PMQ

Gluckstern's skewless variable PMQ



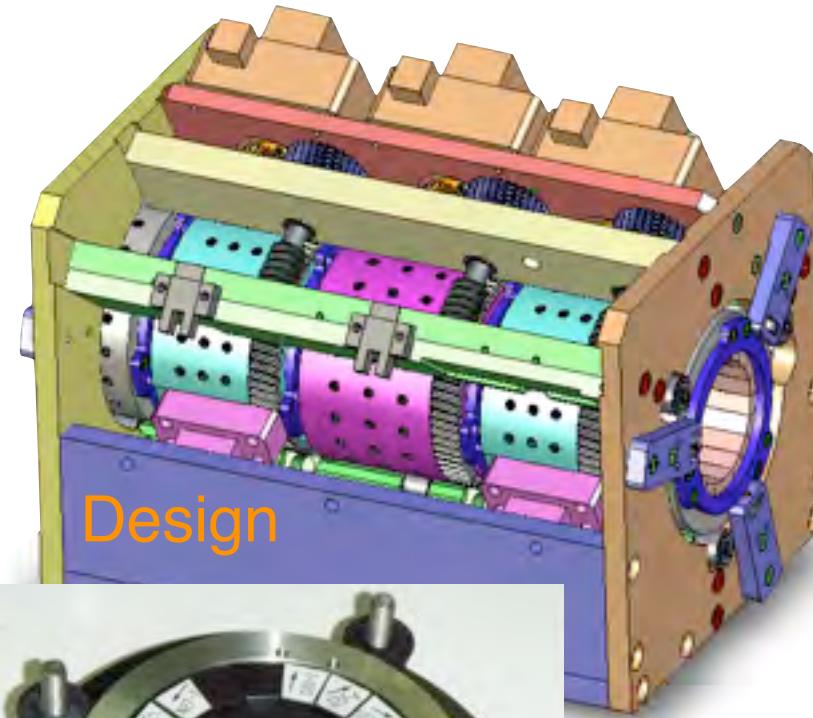
$$M = R \cdot M_2 \cdot R^{-2} \cdot M_1 \cdot R^2 \cdot M_0 \cdot R^{-2} \cdot M_1 \cdot R^2 \cdot M_2 \cdot R^{-1}$$

4x4 matrix: $M = \begin{pmatrix} M_{xx} & O^5 \\ O^5 & M_{yy} \end{pmatrix}$ when $d=0$.

R.L. Gluckstern and R.F. Holsinger: Adjustable Strength REC Quadrupoles,
IEEE Trans. Nucl. Sci., Vol. NS-30, NO. 4, August 1983,
http://epaper.kek.jp/p83/PDF/PAC1983_3326.PDF

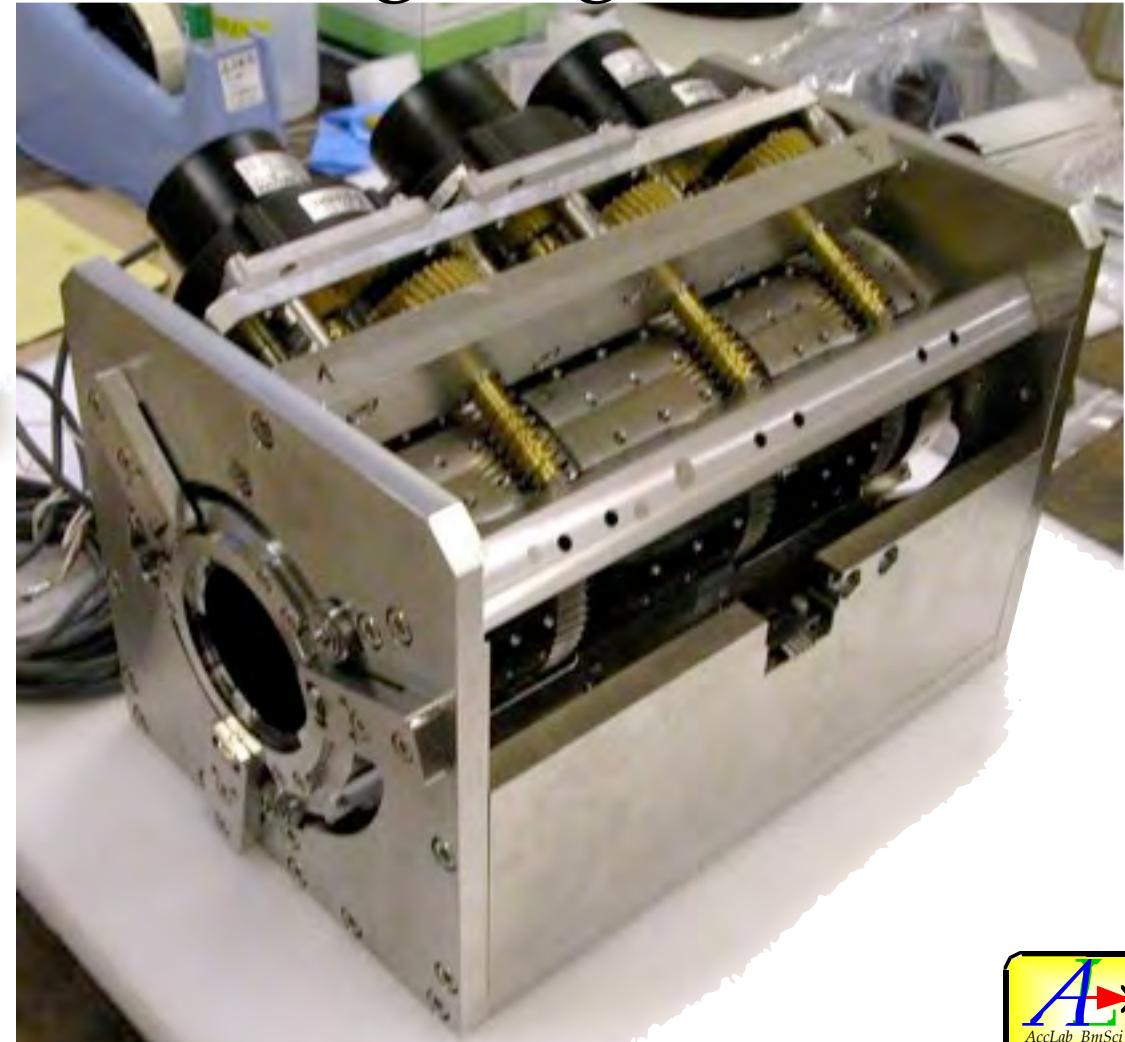
Gluckstern's 5-ring PMQ Singlet(2):

“Continuously Adjustable” PMQ fabricated



Disc(20mm)

The 5-ring singlet PM-FFQ



Test at ATF2 – replace QD0

Req'd spec for QD0: L=45cm, \varnothing 50mm, G=13T / m

OD: \varnothing 72 ($=2 \times (56-20)$)

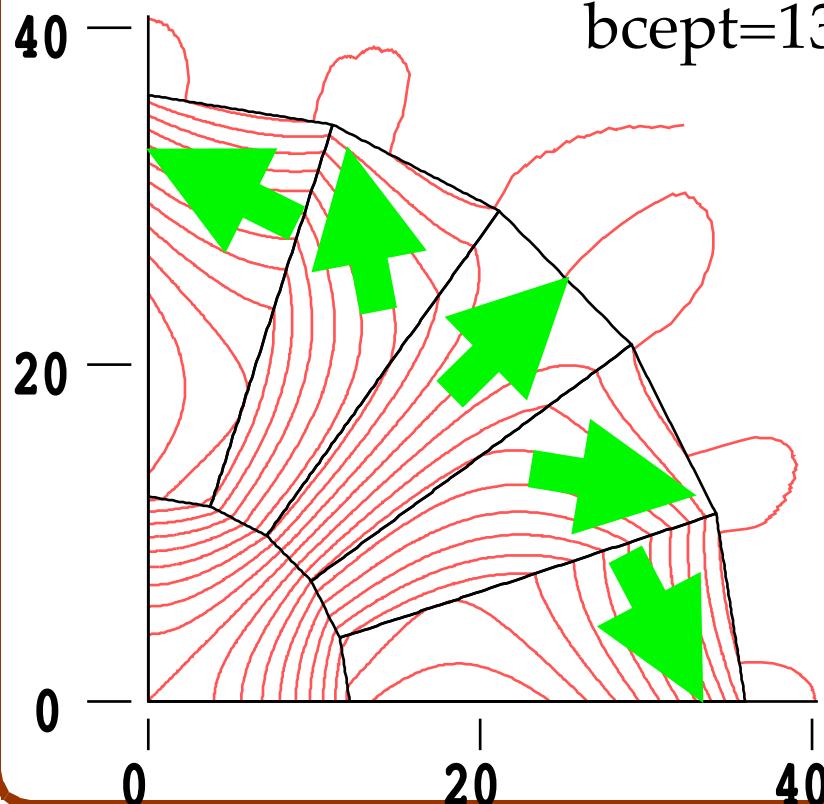
GL=5.85 T

140T / m

@ \varnothing 24

48H

hcept=-12890,
bcept=13600.

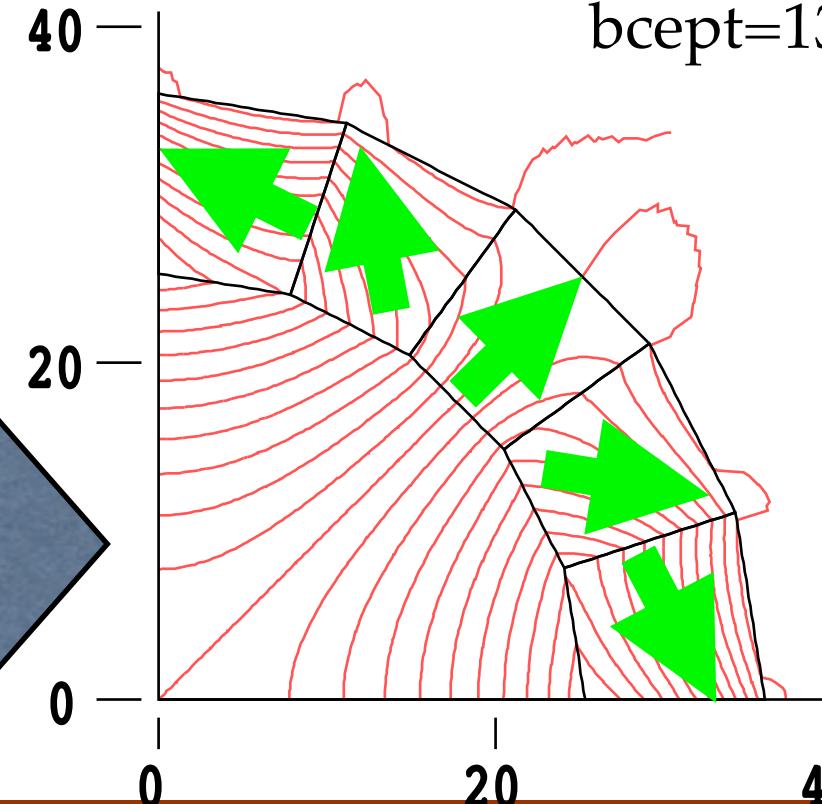


30T / m

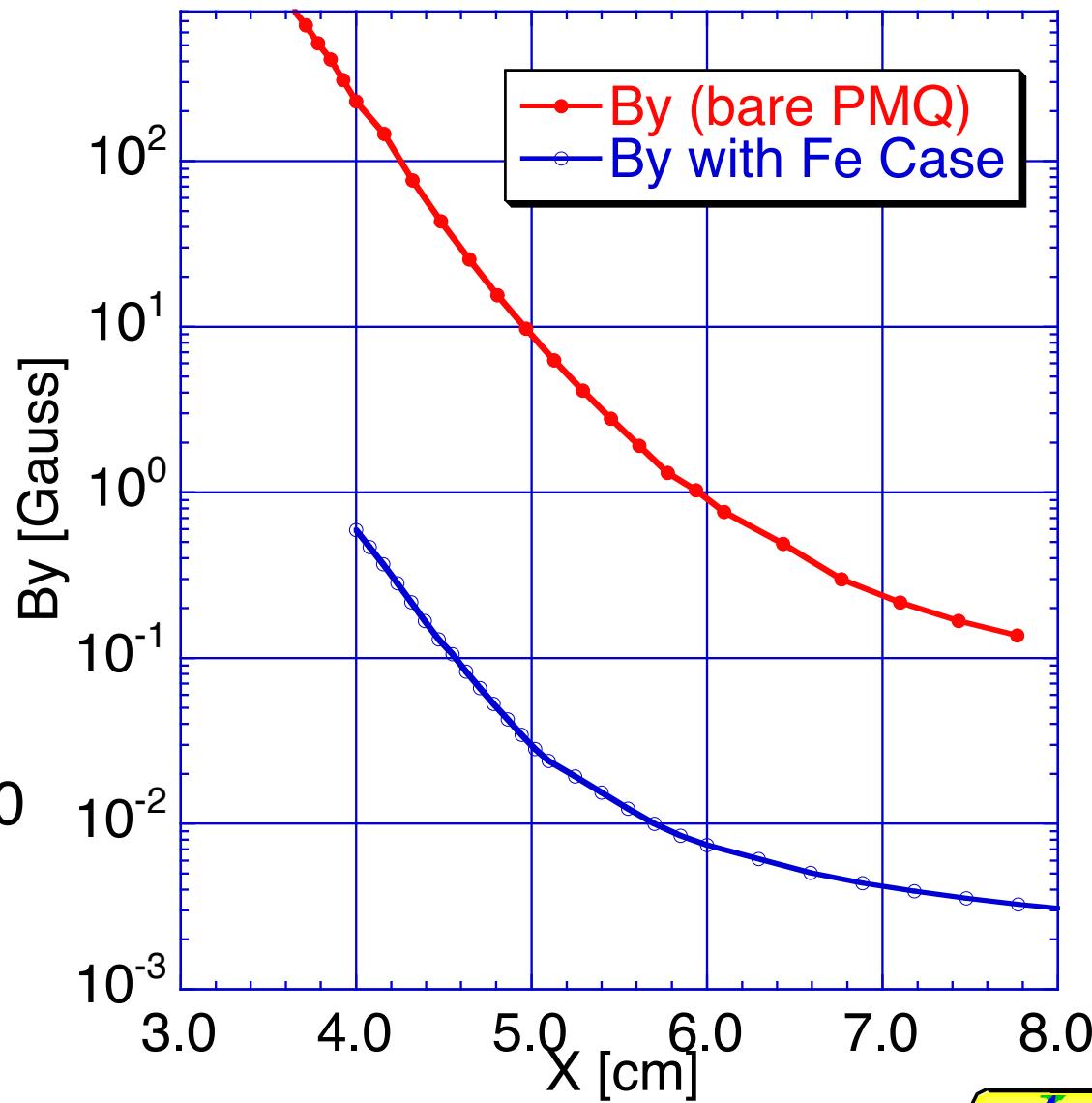
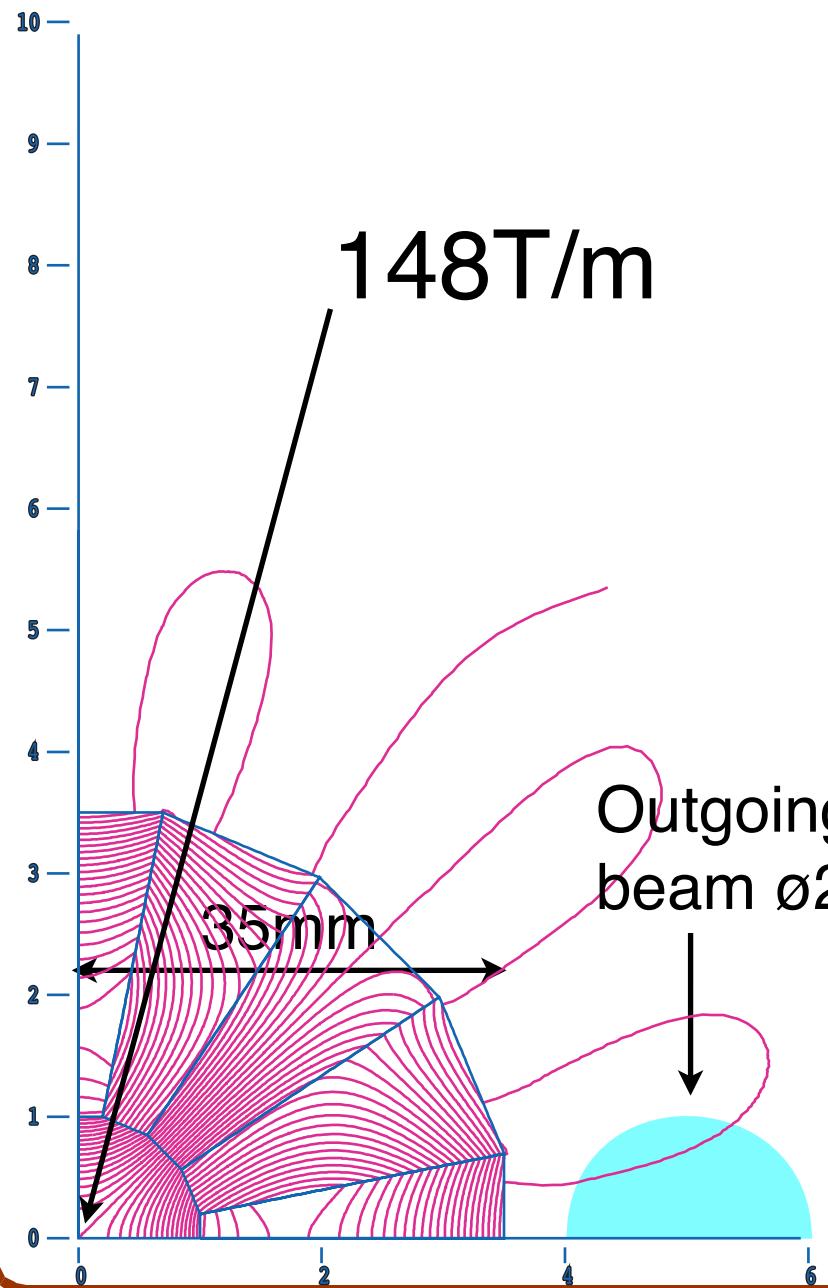
@ \varnothing 50

48H

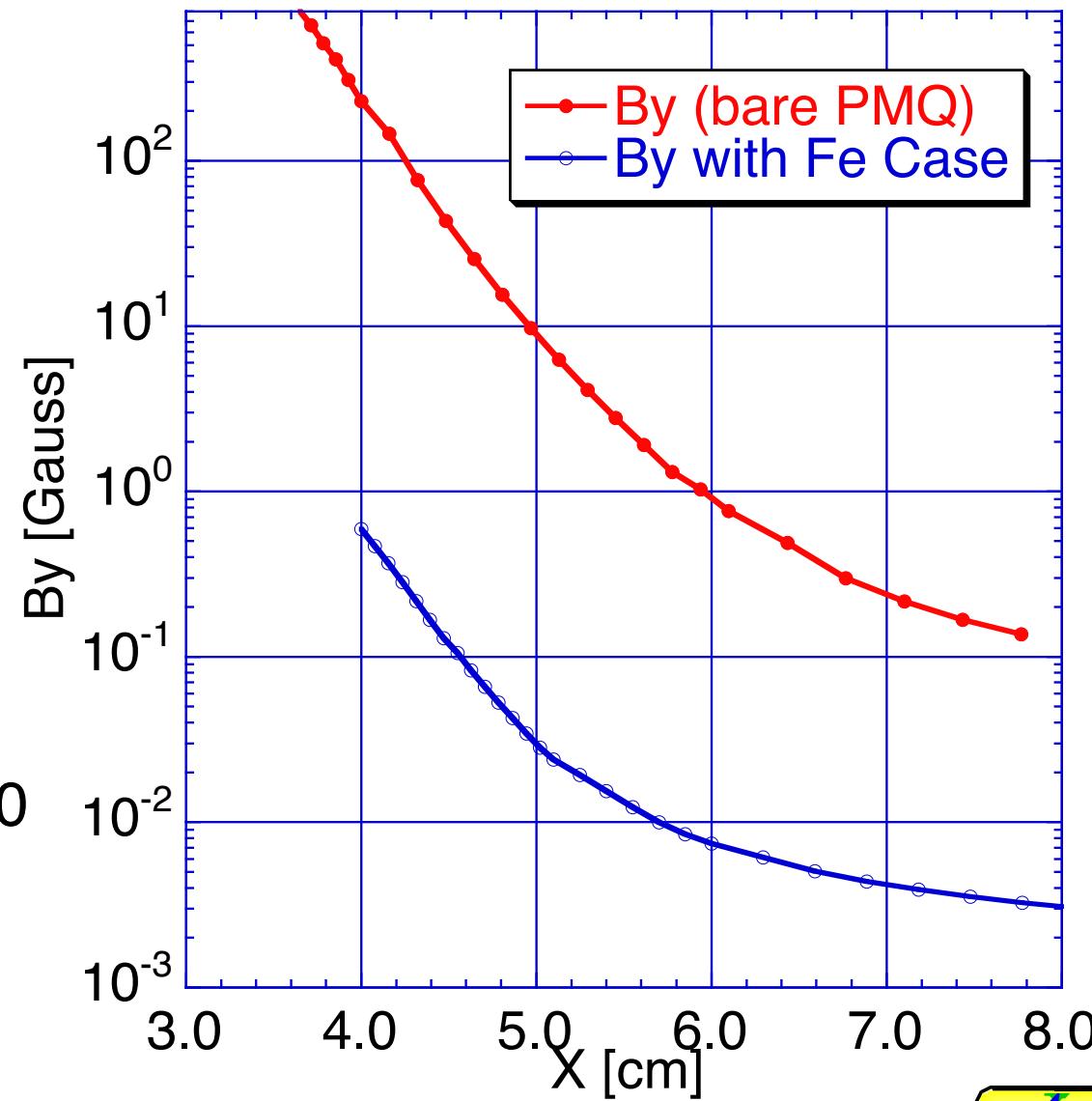
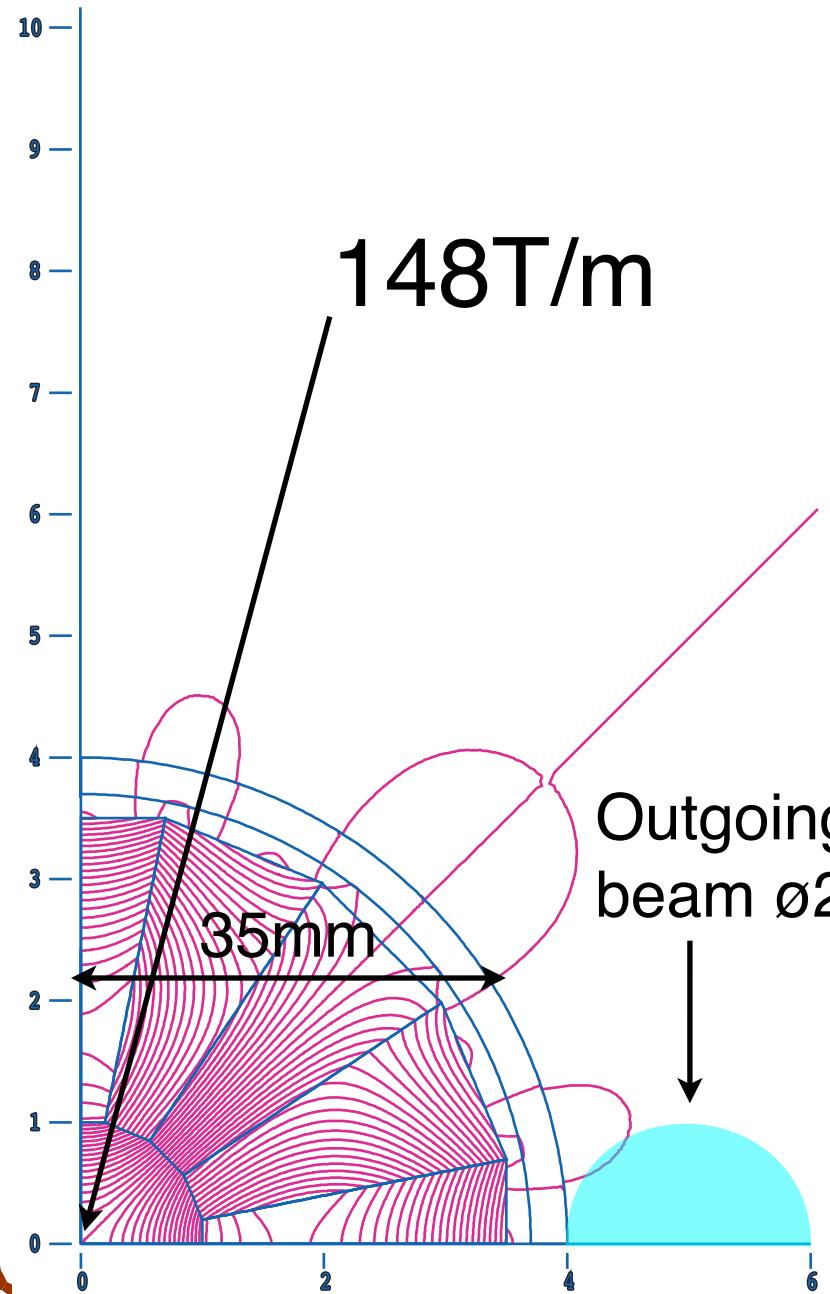
hcept=-12890,
bcept=13600.



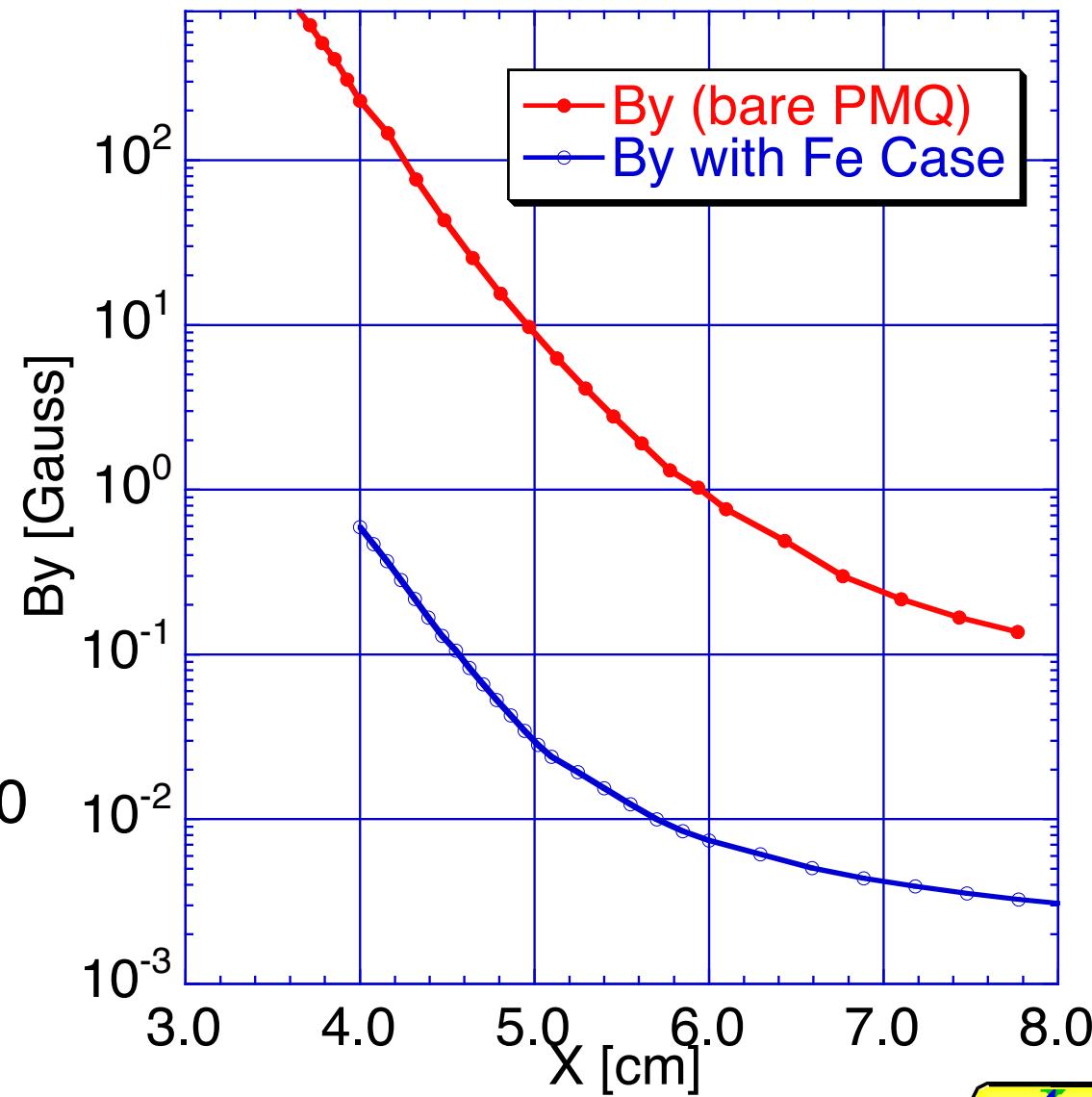
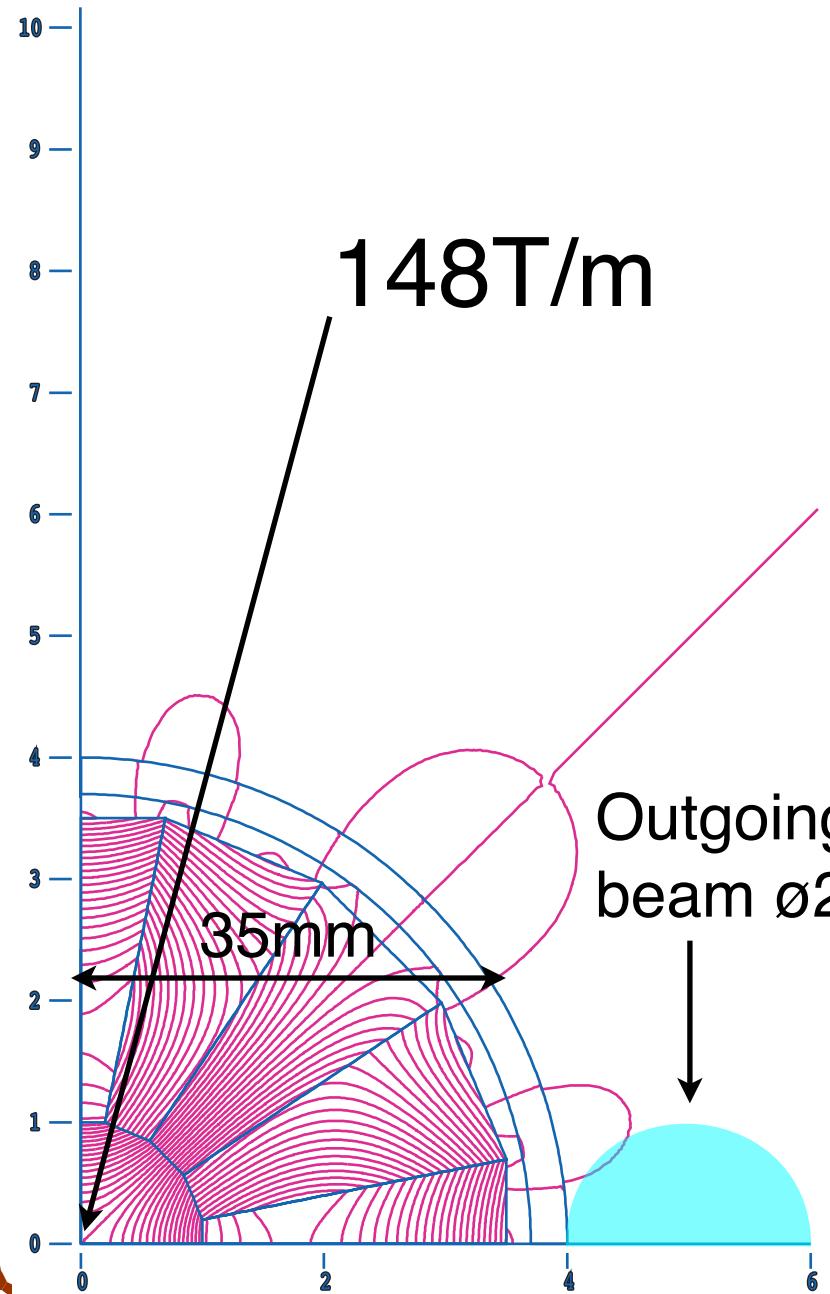
External Stray Field



External Stray Field

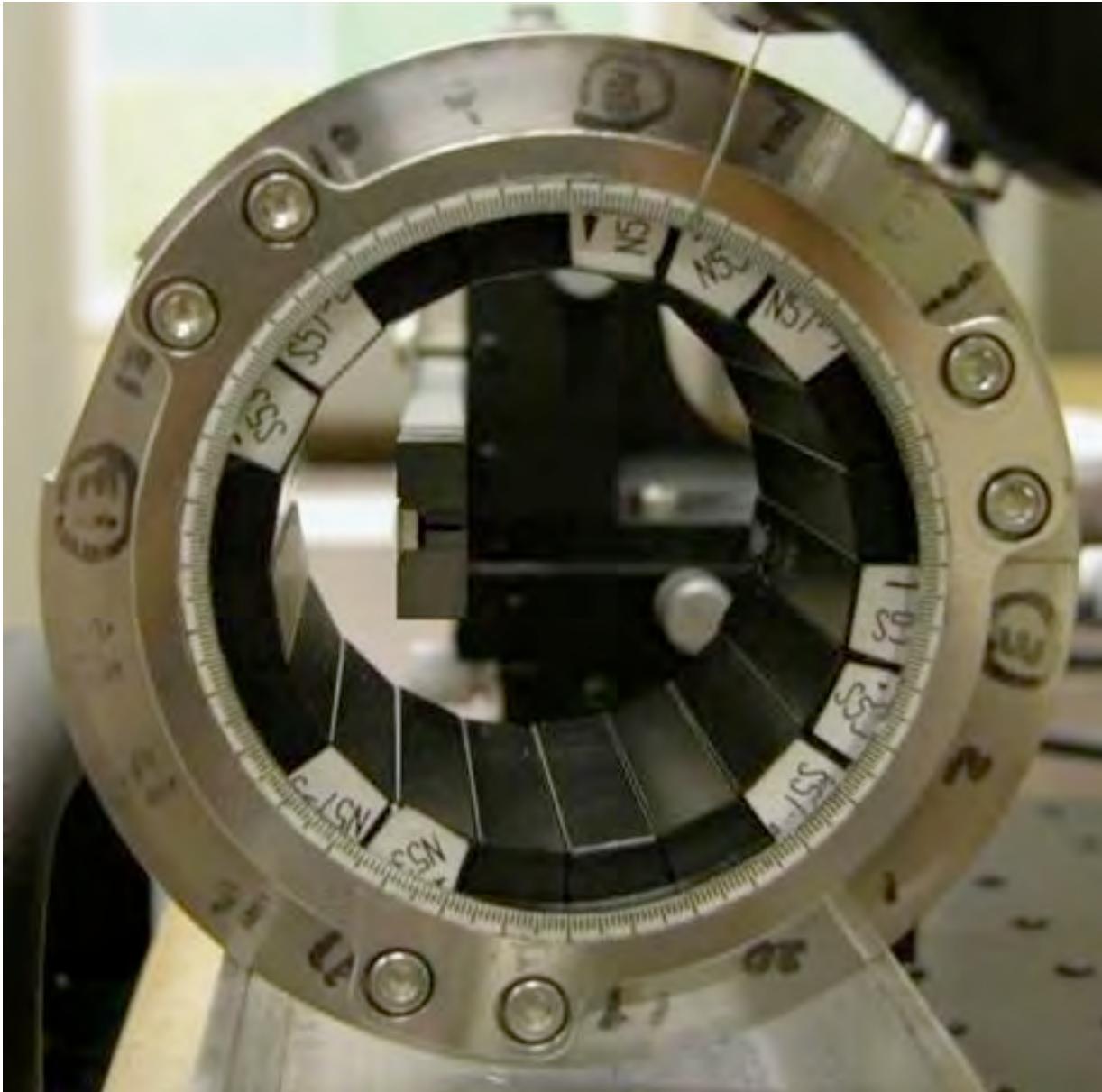


External Stray Field

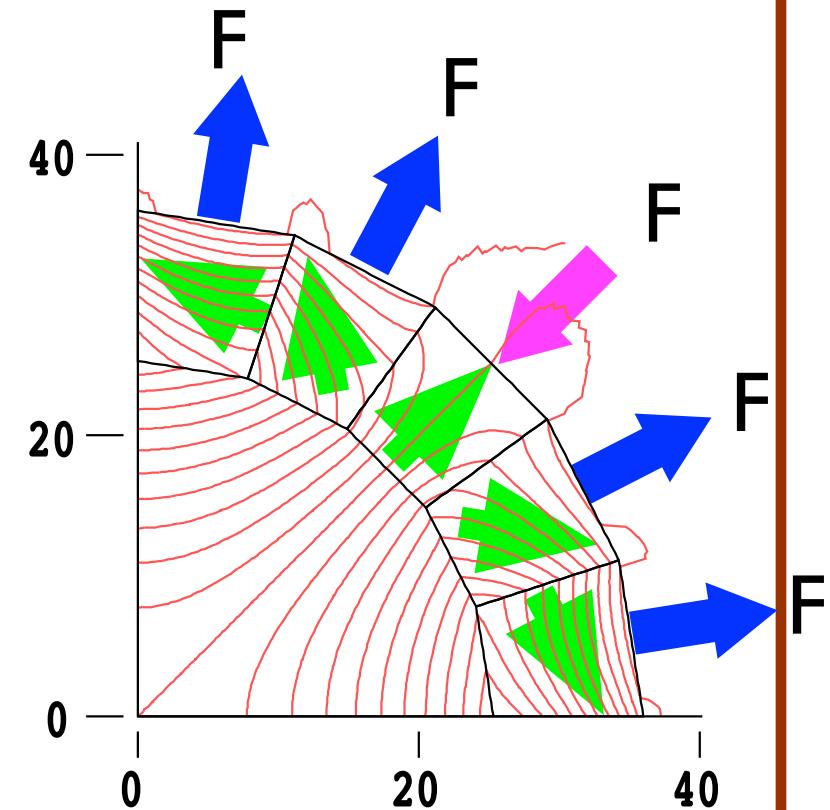


Adjustment

Magnet Bore



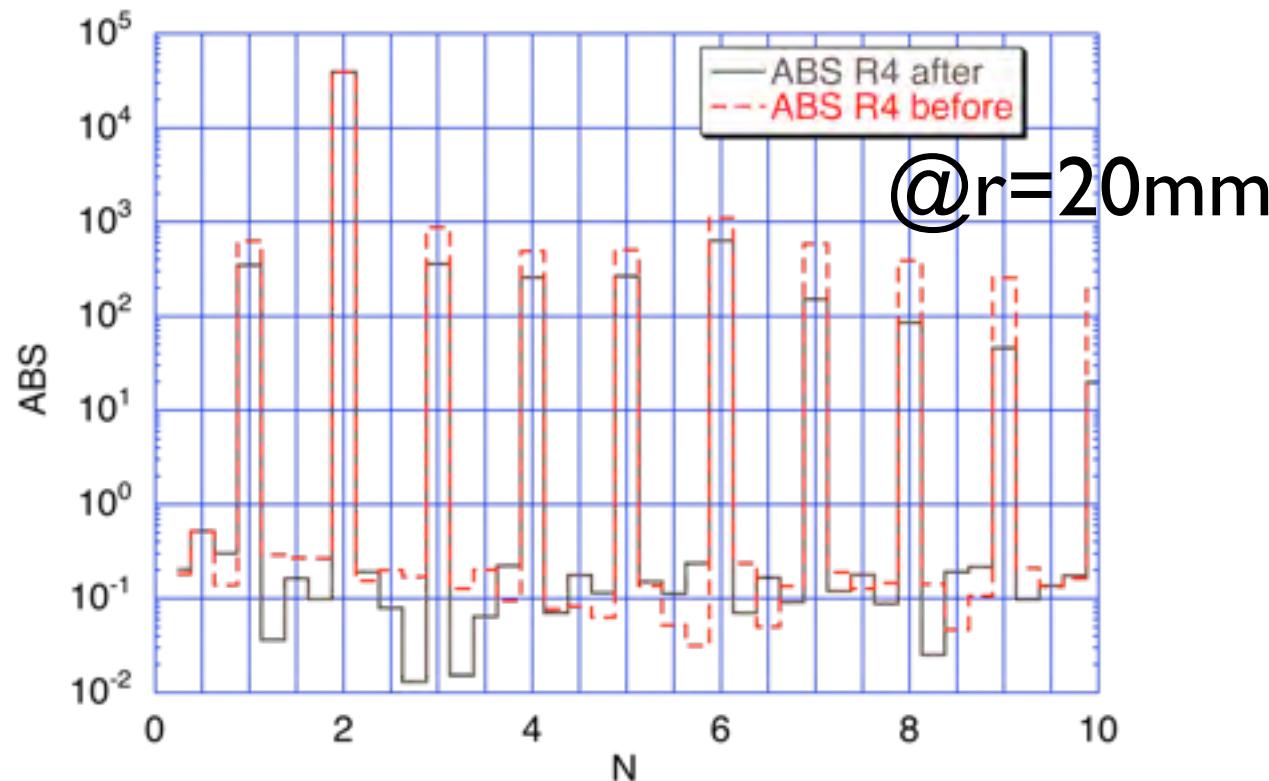
Pole magnets are attracted.



Others are
repulsive.

Measurement on each PMQ

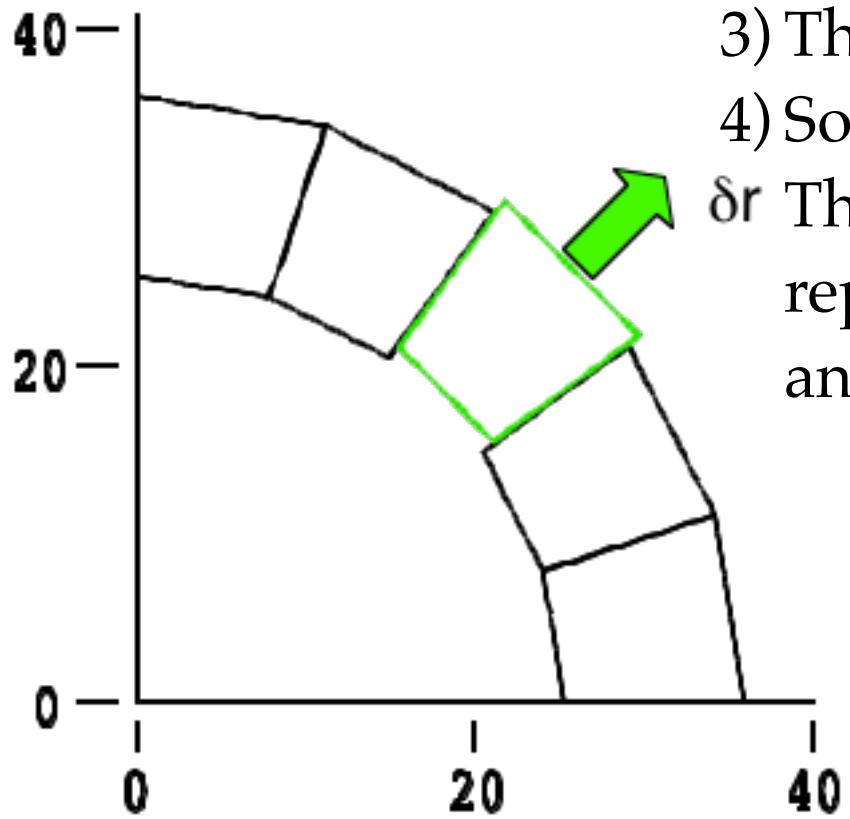
Just before and after a wrong
magnet piece replacement



- Reduced errors (still large - to be adjusted).
- noise level $< 10^{-5}$

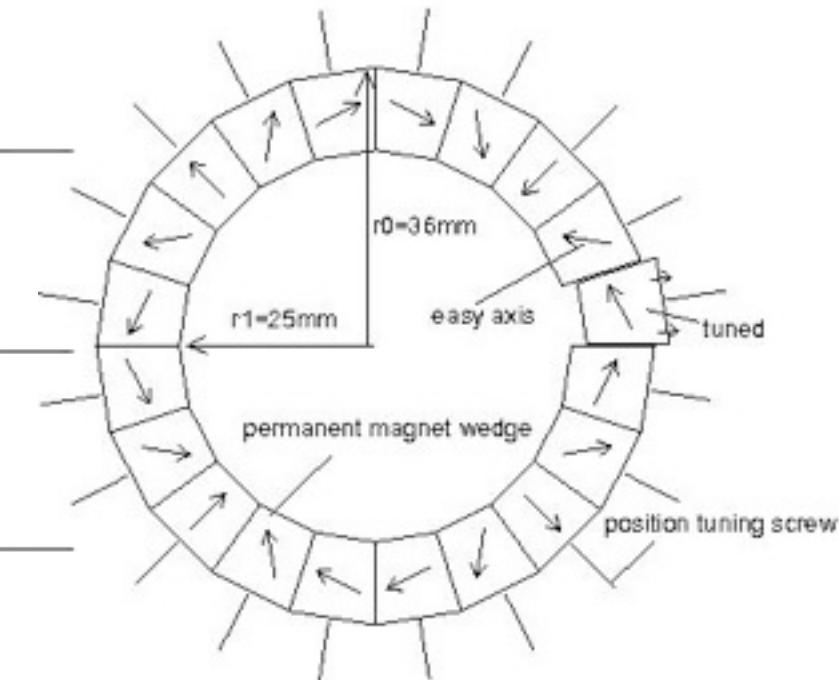
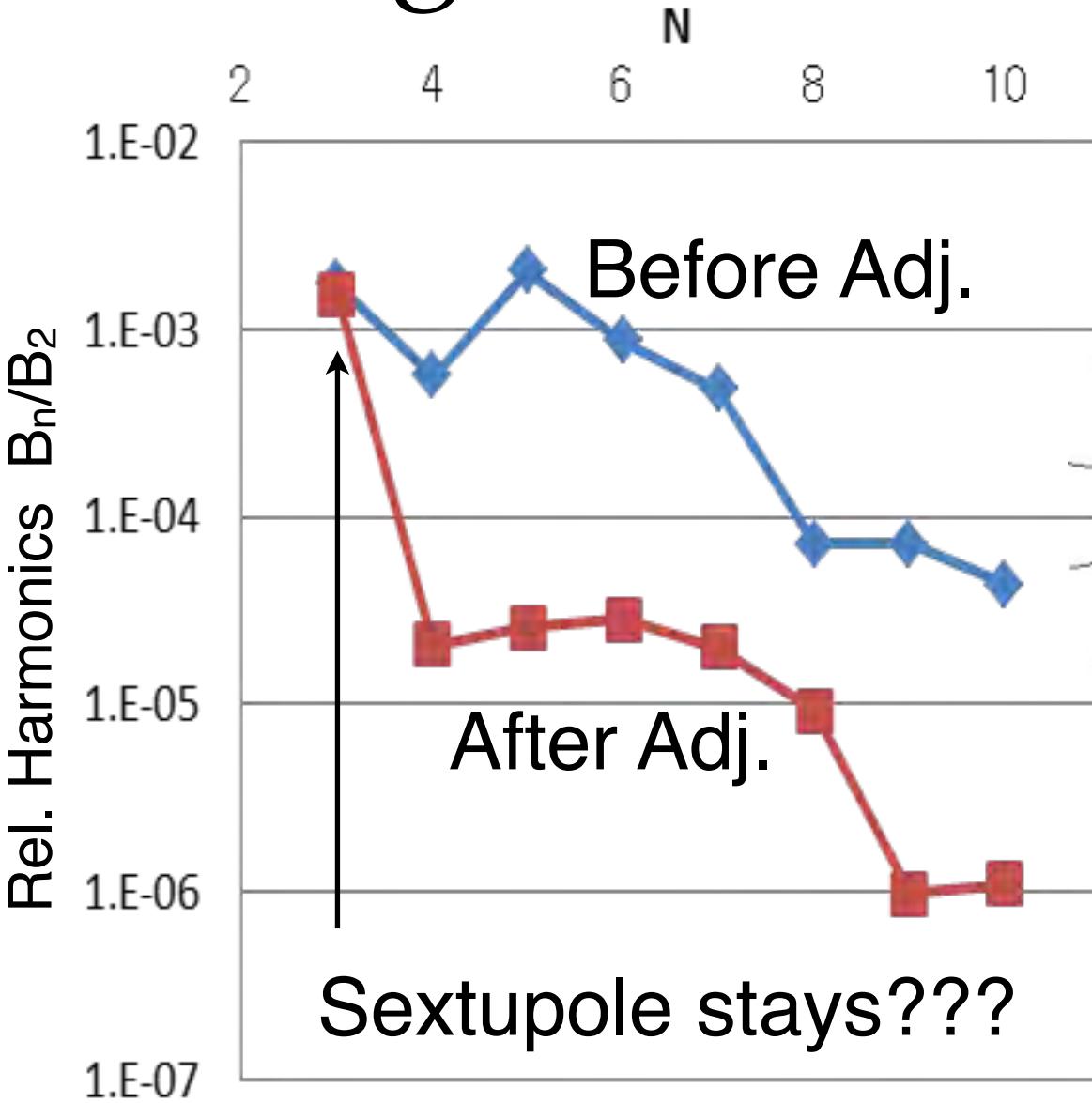
Adjustment Algorithm

- 1) Multipole components (up to 11)
generated by single piece and those with
1mm offset are calculated by PANDIRA.
- 2) The differences (11 Re and Im values) are
obtained for all 20 pieces.
- 3) They consists of total 22×20 values.
- 4) Solve equ.
 δr The equ's correspond to Q should be
replaced by all 1's (to keep circumference)
and the one of 11th.



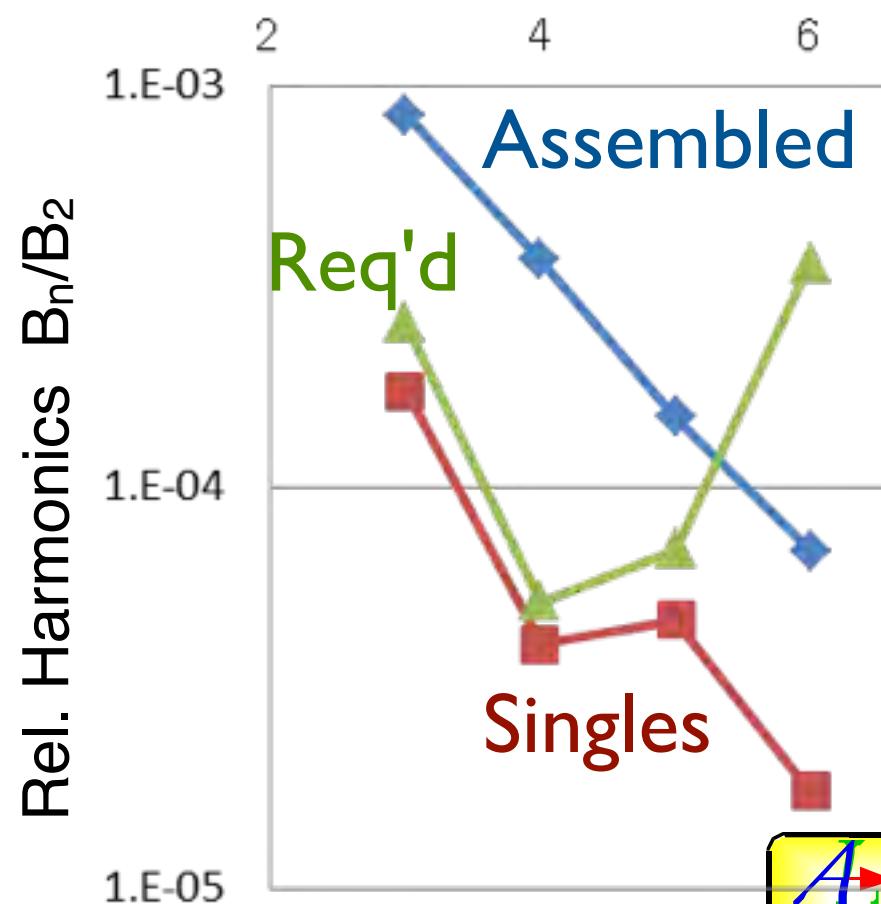
$$\begin{pmatrix} \frac{dC_1}{dr_1} & \frac{dC_1}{dr_2} & \dots & \frac{dC_1}{dr_{20}} \\ \frac{dC_2}{dr_1} & \frac{dC_2}{dr_2} & \dots & \frac{dC_2}{dr_{20}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{dC_{20}}{dr_1} & \frac{dC_{20}}{dr_2} & \dots & \frac{dC_{20}}{dr_{20}} \end{pmatrix} \begin{pmatrix} \Delta r_1 \\ \Delta r_2 \\ \vdots \\ \Delta r_{20} \end{pmatrix} = \begin{pmatrix} C_1 \\ C_2 \\ \vdots \\ C_{20} \end{pmatrix}$$

Magnet Piece Alignment



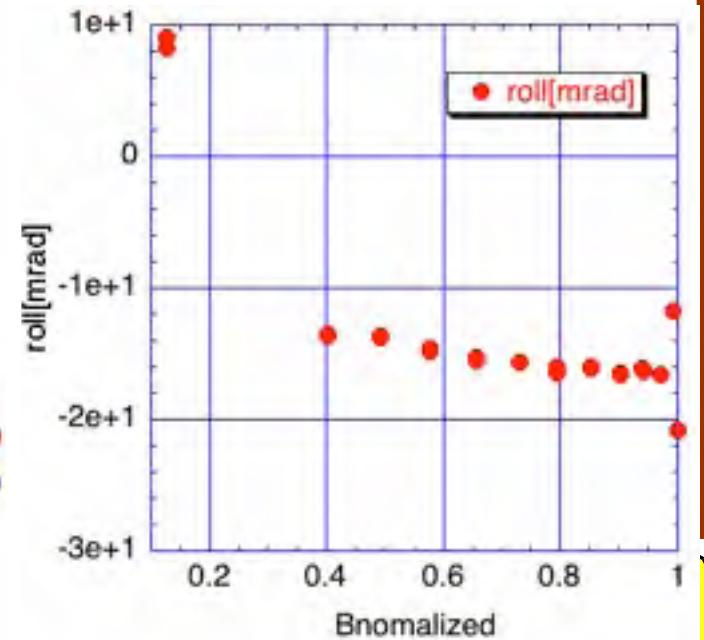
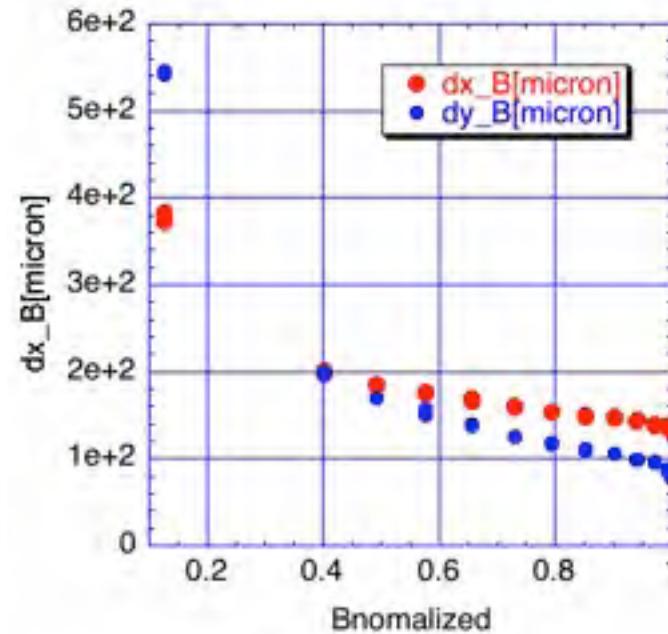
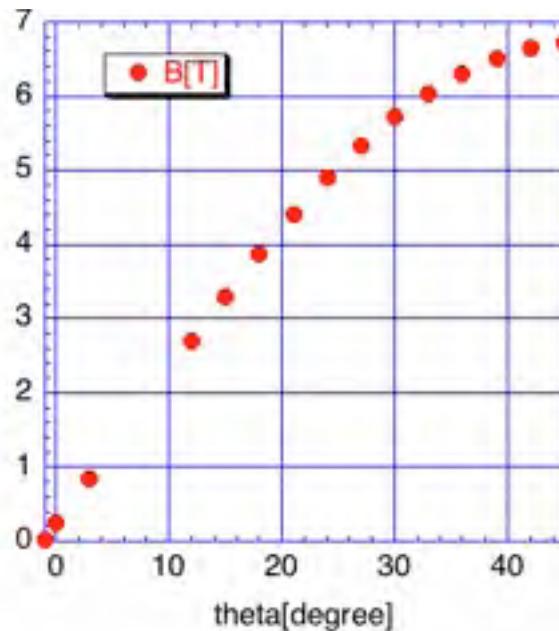
Assembled Lens

- Measured assembled lens.
- Multipoles increased factor 3-10.
- Reproducibility has to be checked.

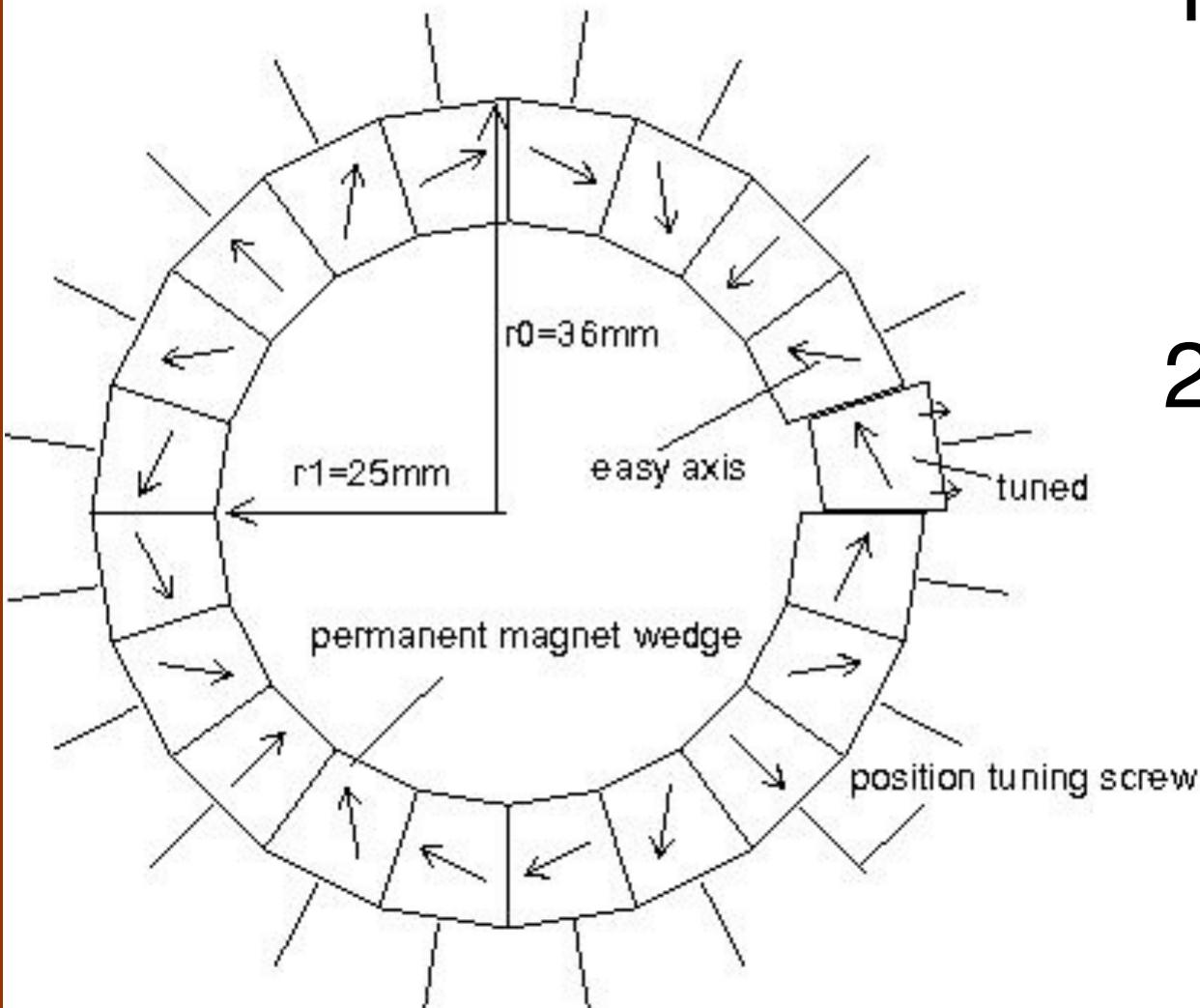


Quadrupole Value

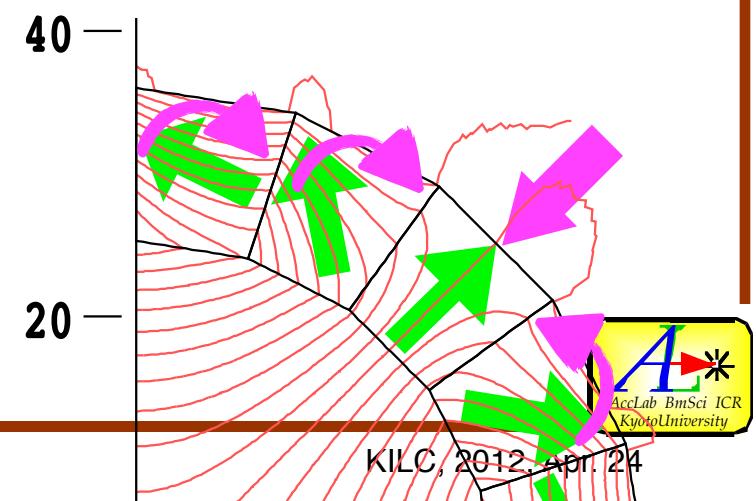
- Maximum GL = 25.7 T
- Minimum GL < 0.3%
- Center axis shift $\delta x \sim 50\mu\text{m}$, $\delta y \sim 100\mu\text{m}$ for GL range of 40-100%
- Less than 5 mrad rotation



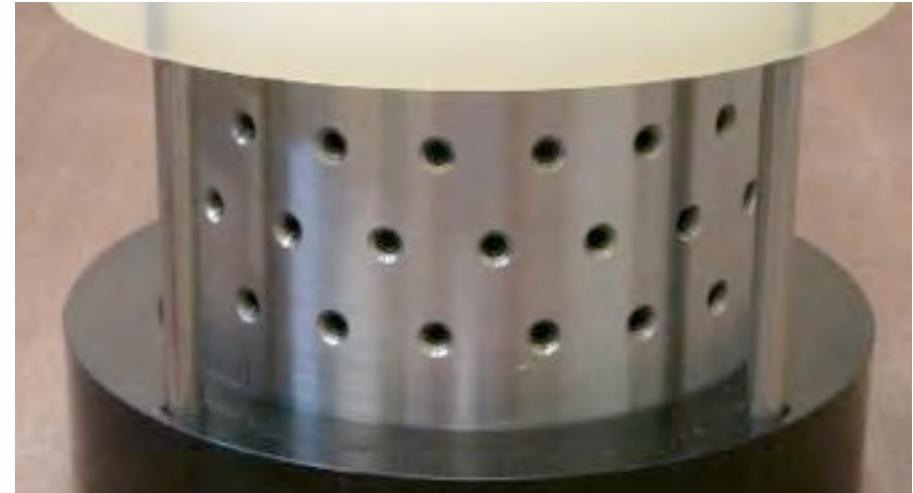
Possible reasons for Sextupole Residue



- 1) Fixed total circumference.
(less DOF)
- 2) Inline tuning screws allow magnet piece rotation.



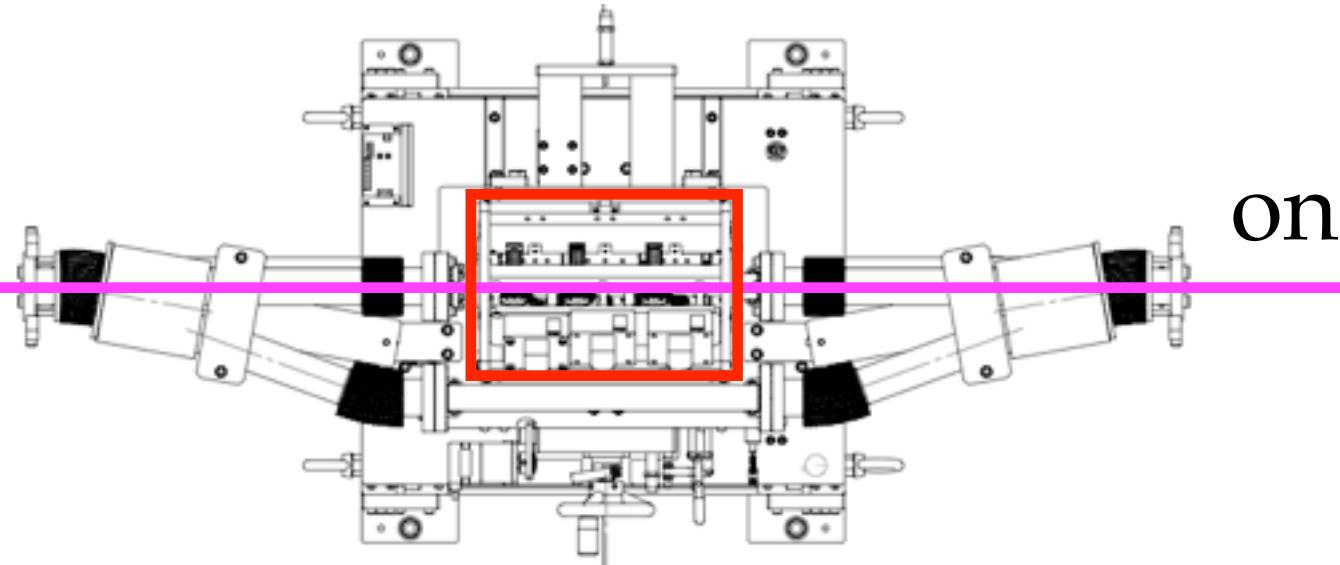
New Magnet Holder



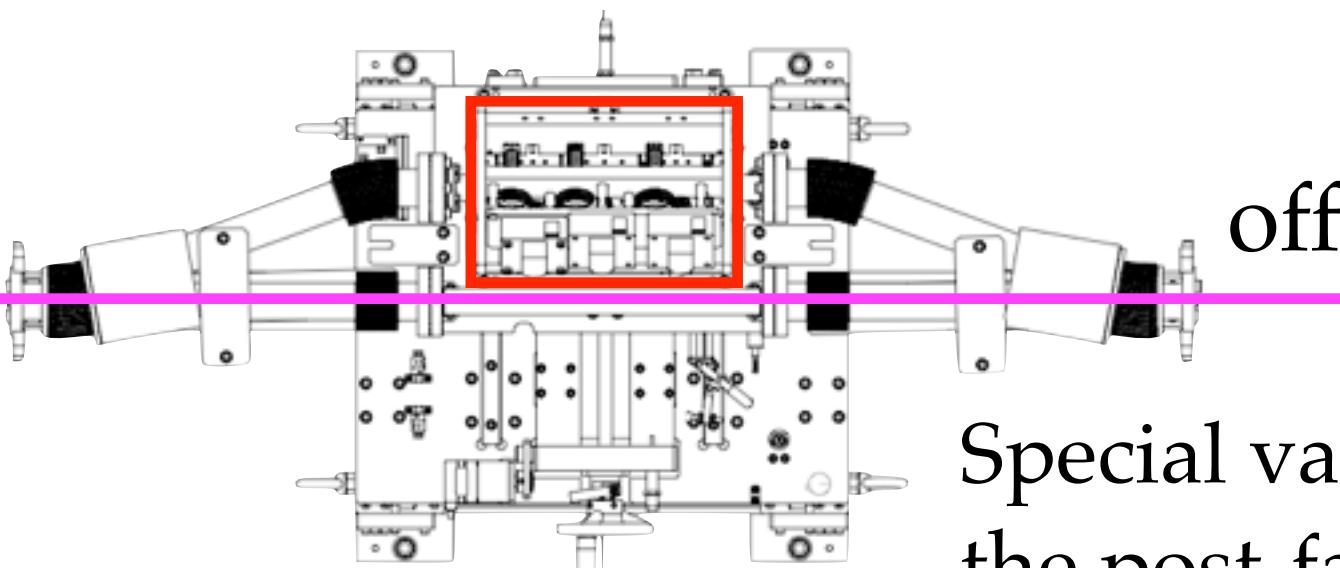
- 1) Control Magnet Rotation
- 2) Magnetic Material for less external stray field.

Mover

The push-pull Mover



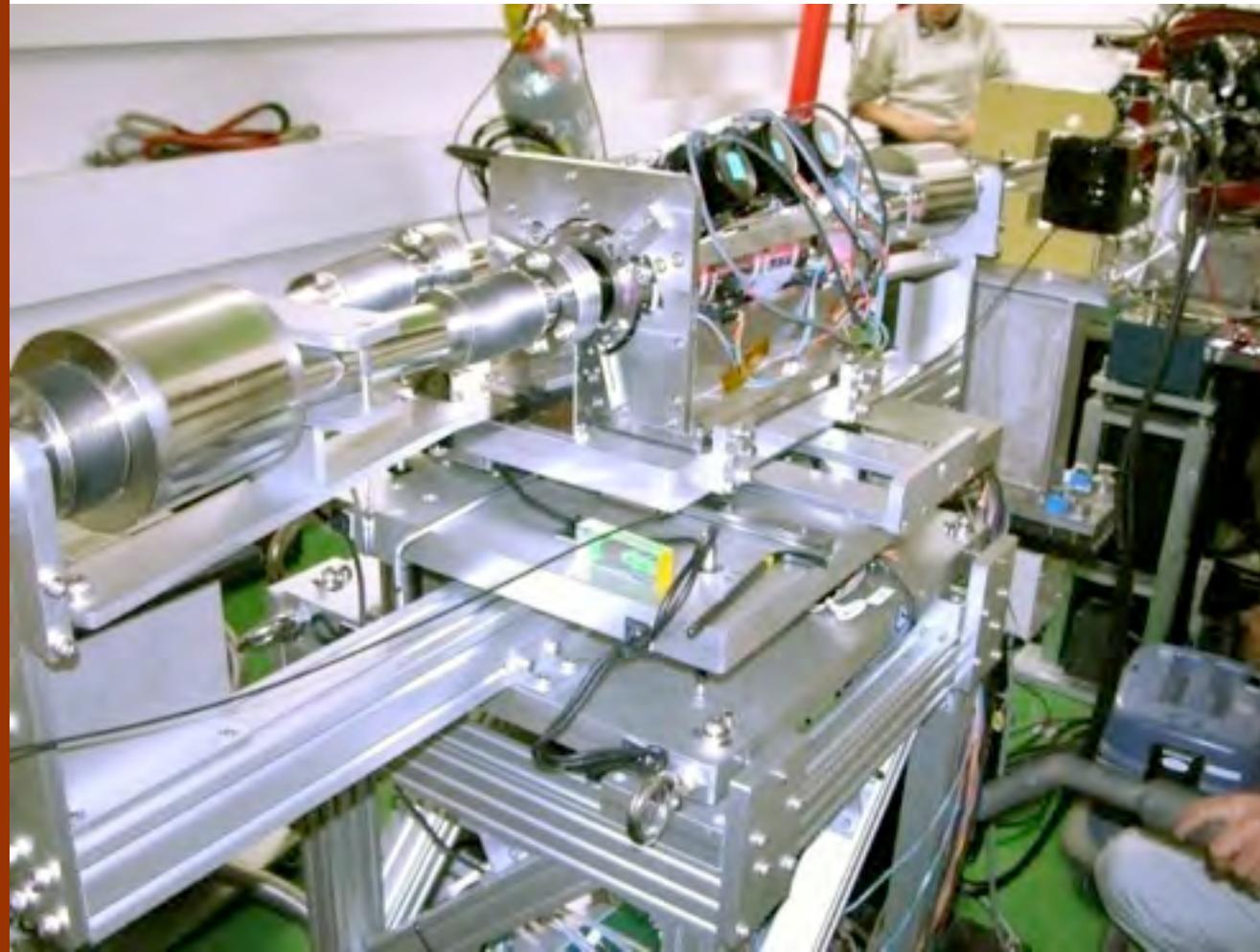
on the Beam line



off the Beam line

Special vacuum flange for
the post-fabrication.

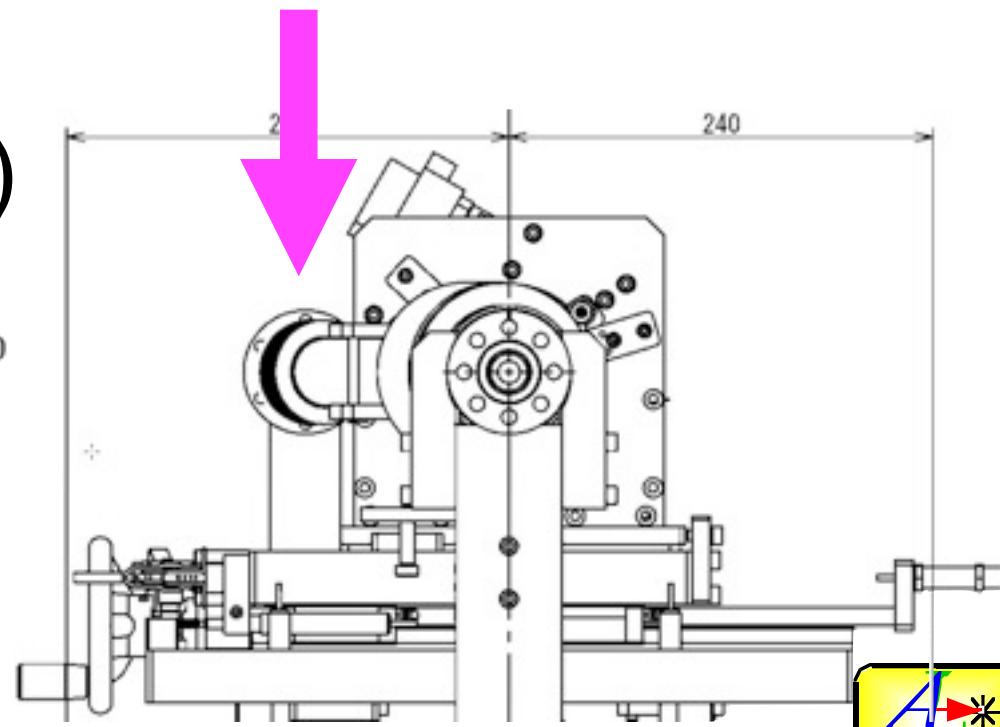
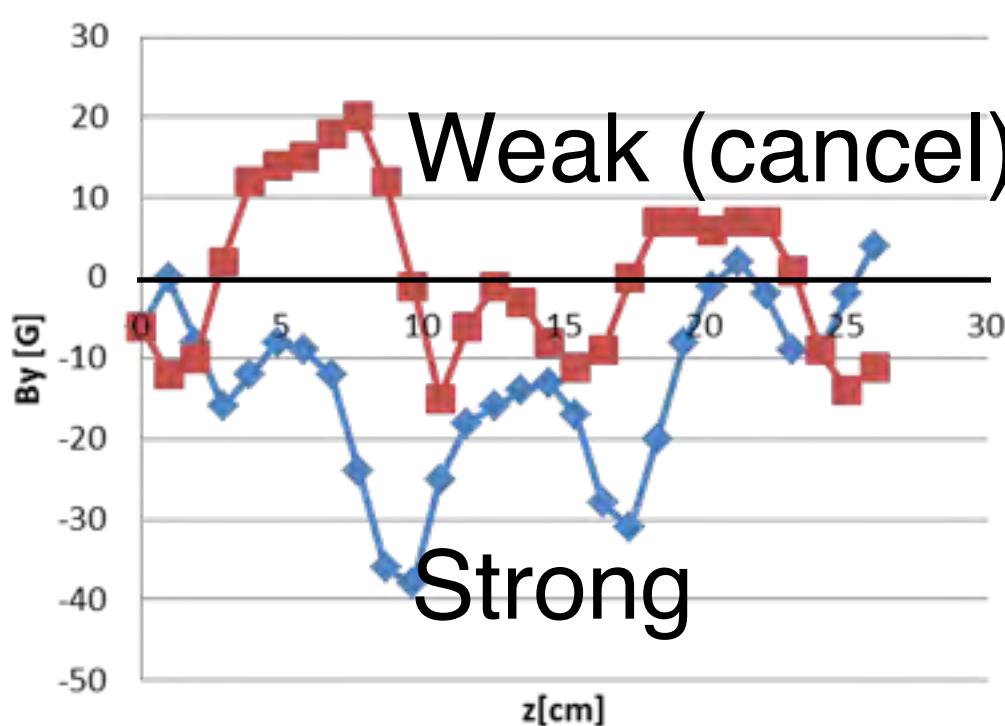
Installed in ATF2



- Up-Down
- Left-Right
- Yawing
(rotate around axis)
- Remote control

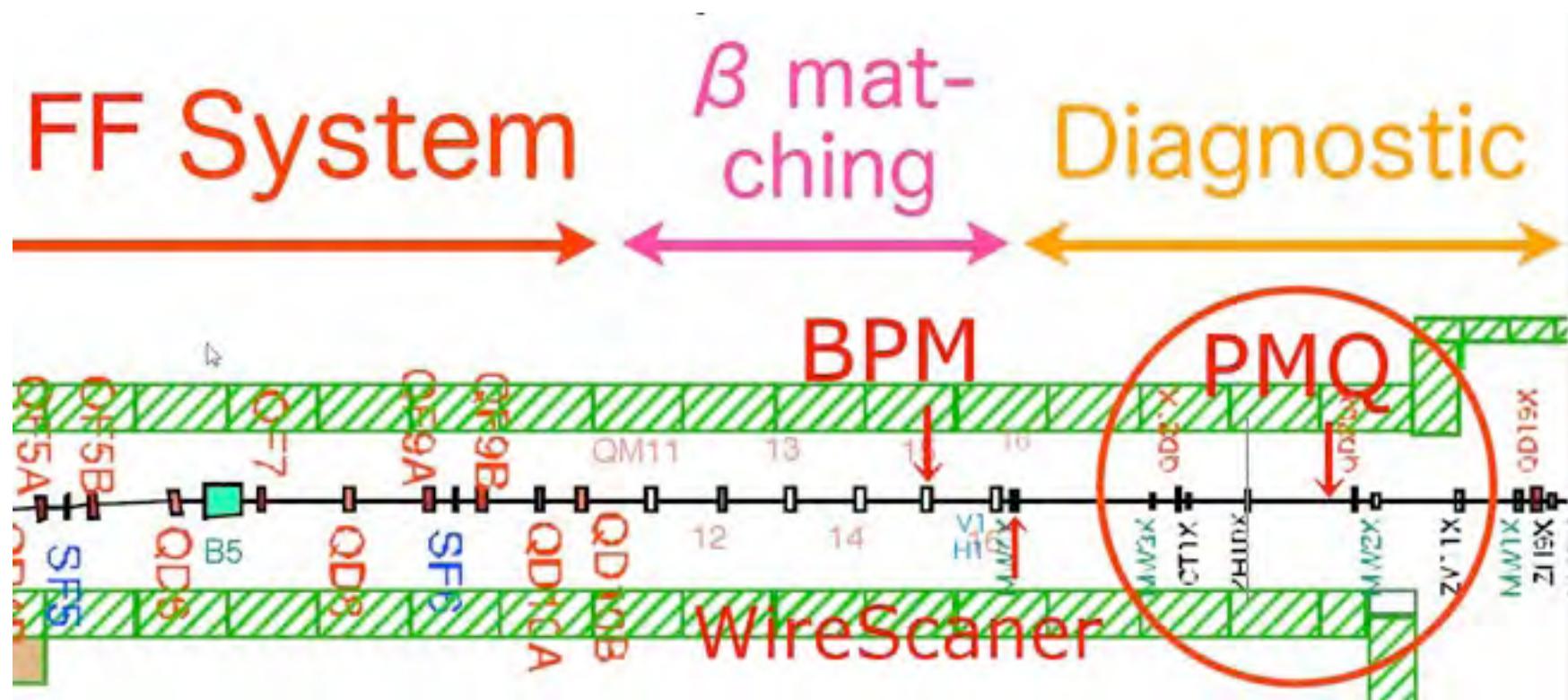
External Stray Field at 10cm

- Measured by Hall probe
- Changes with the lens strength:
362G·cm for the maximum GL
11G·cm for the minimum GL



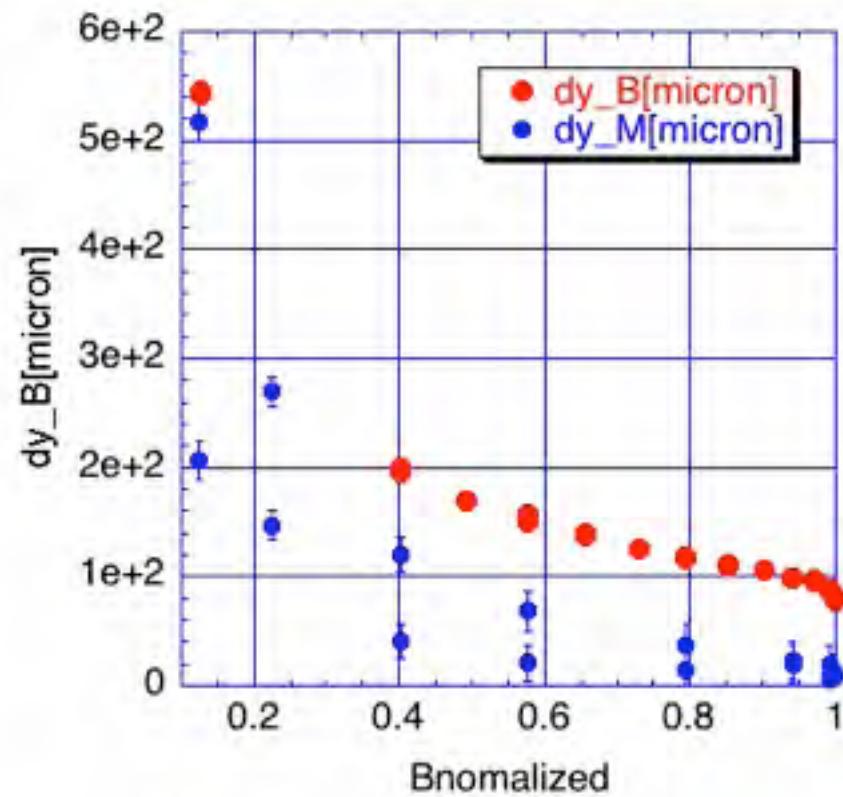
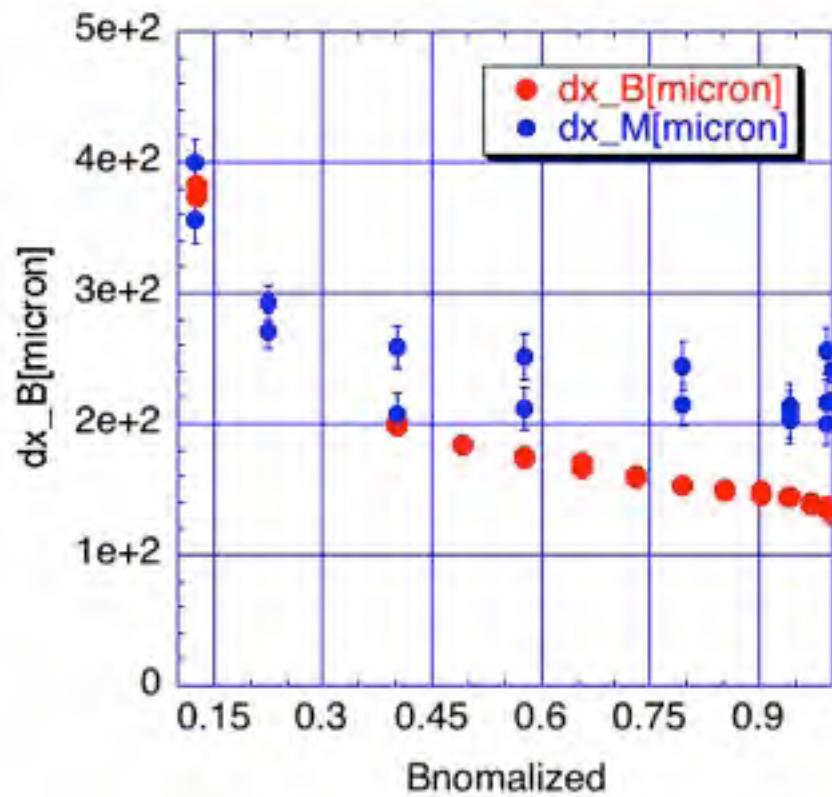
ATF2 Beamline

- Wire scanners locate 5.8m downstream
- BPM's locate 7.9m downstream



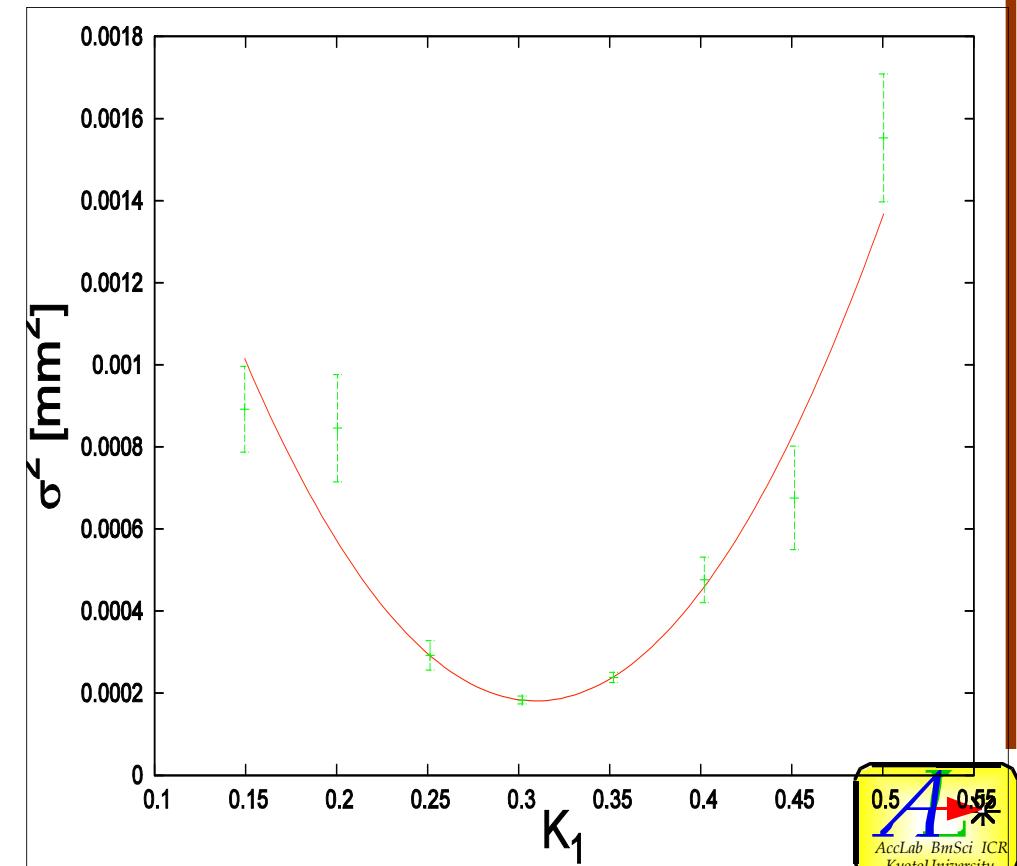
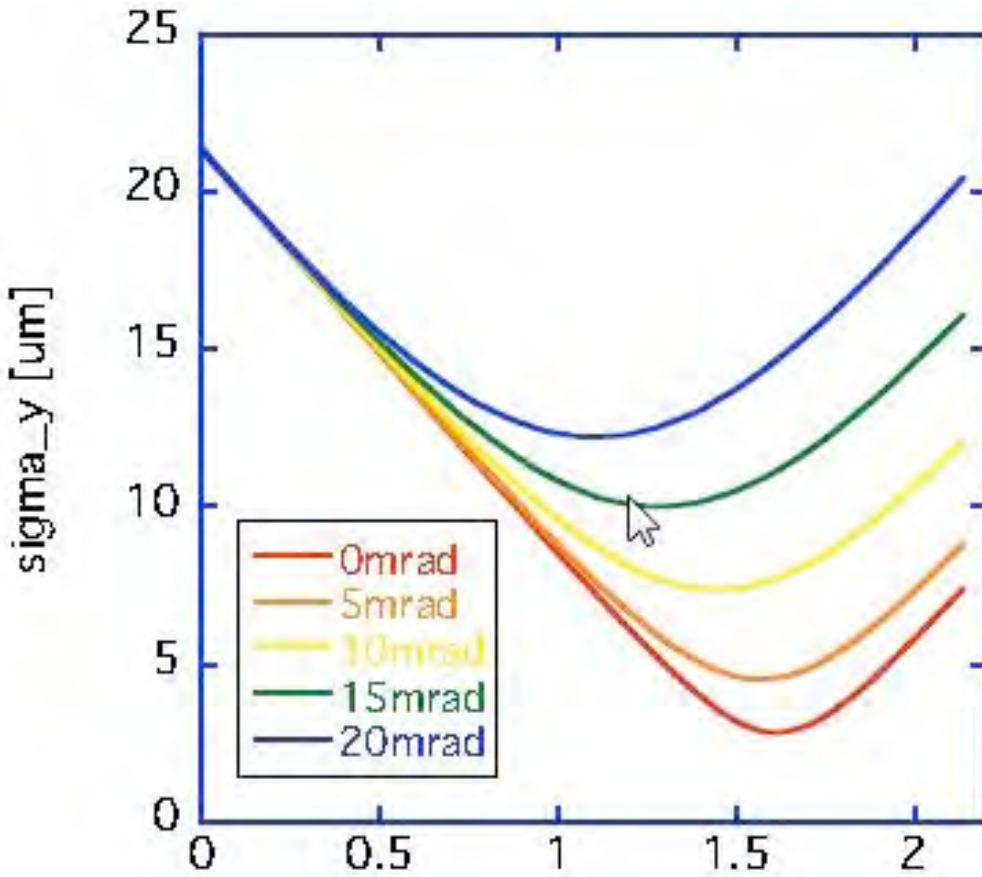
Beam Positions

- Evaluate alignment error by monitoring the beam position during Q-scan.



Q-scan

- Vertical beam size measured by wire scanner.
- Measured emittance was $7e-8 \pi$ mrad (skew?).
- Only one set because of MT limitation.



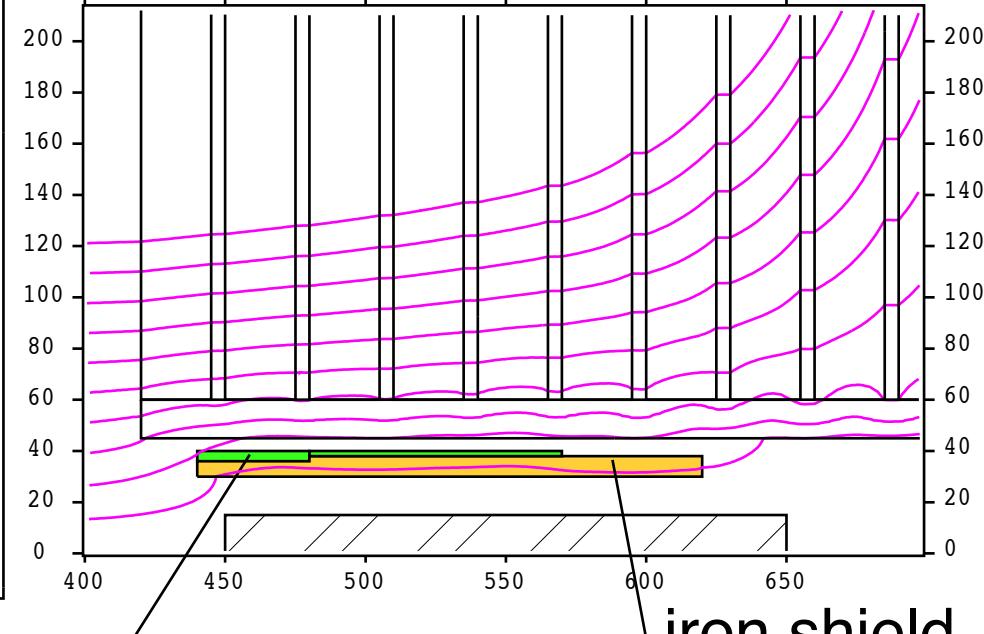
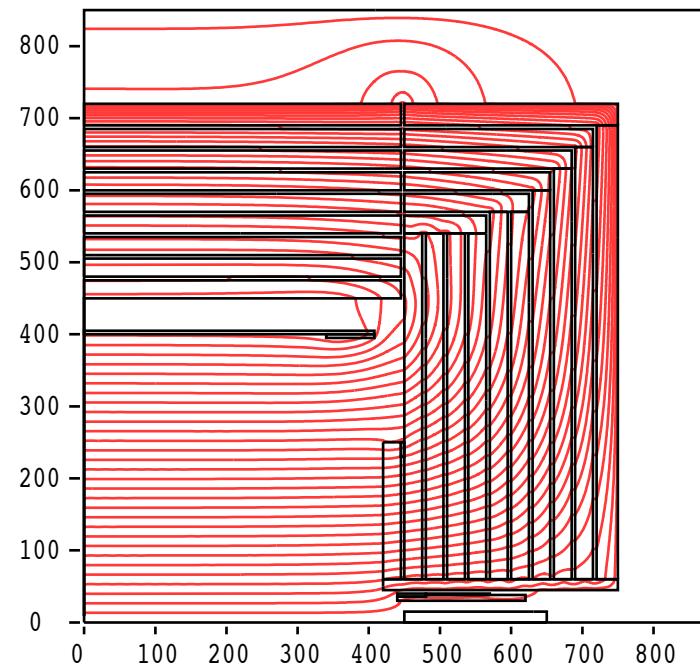
Discussions

- Not bad results for the first time?
- Higher order components can be reduced except sextupole; the reason should be investigated.
- Increases of higher order components have to be suppressed.
- Alignment scheme has to be improved.
- Beam test results had no irregularity.
- Under investigation with new magnet holder.



Appendix

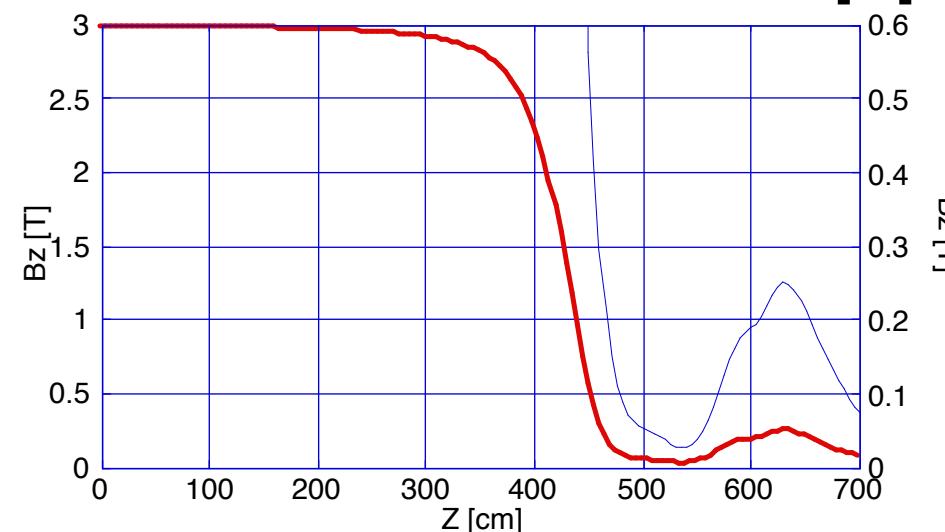
Rough Calculation



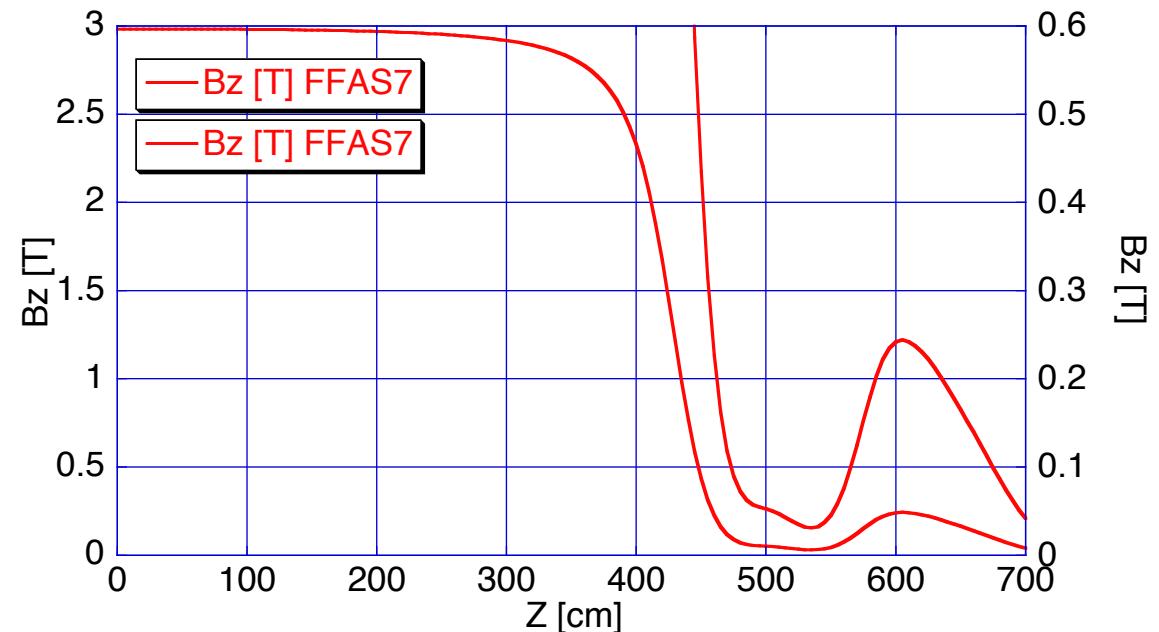
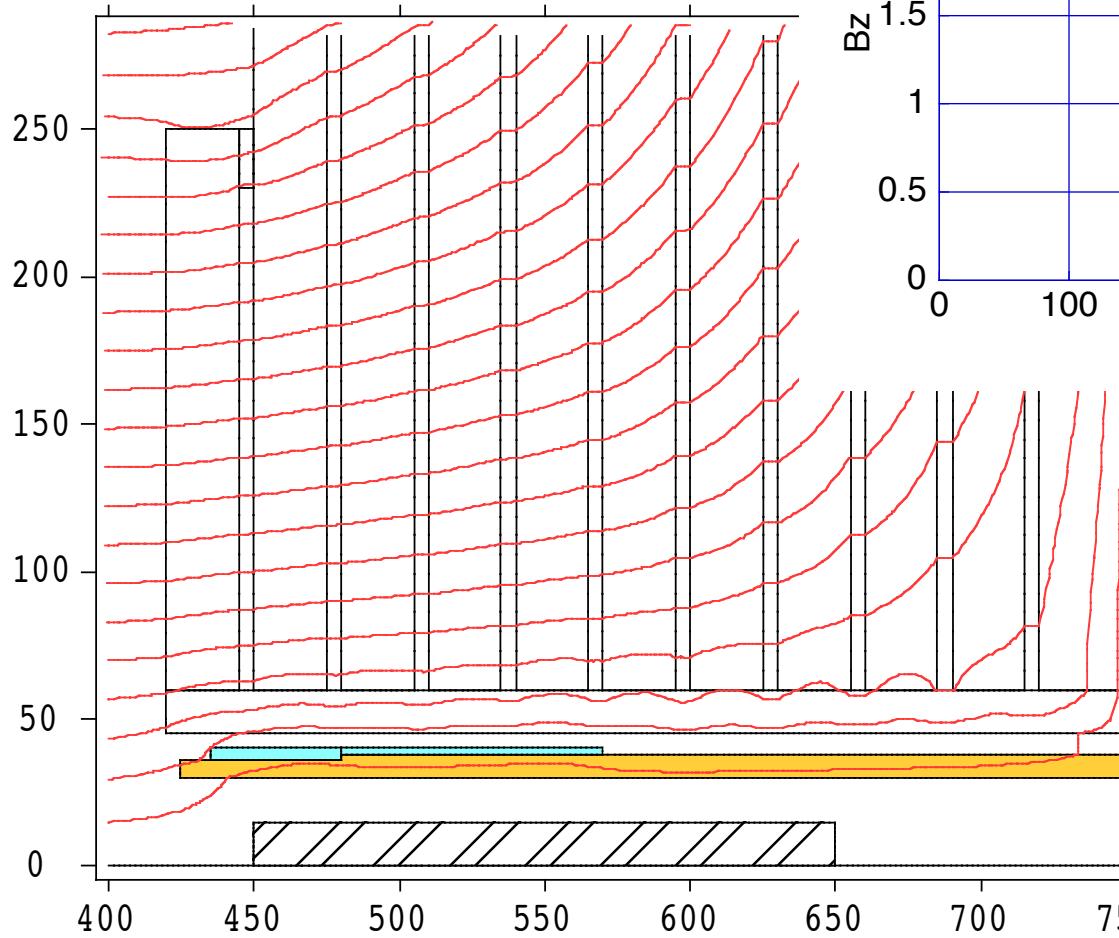
$3\text{kA}/\text{cm}^2 \quad 2.82\text{E}5 \quad -5.31\text{E}4 \quad [\text{N}]$

iron shield
 $-1.08\text{E}5 \quad [\text{N}]$
 $= 12t$

GLDFFAS



Reduced Force Anti-Solenoid



+4.03E5 [N]
-6.07E4 [N]
-3.51E5 [N]
= -0.9t

Demagnetization by Radiation

Energy deposit

	GLD	SiD	SiD (by Takahashi)	neutron
BeamCAL	17mW	13mW	29mW	
QD0	94mW	97mW	147mW	10^5 [n/cm ² s]
SD0	11mW	11mW	11mW	
QF1	16mW	18mW	15mW	
SF1	0.4mW	0.3mW	1mW	

very preliminary results by T.Abe (university of Tokyo),
in private communication

Demagnetization by 14MeV neutron

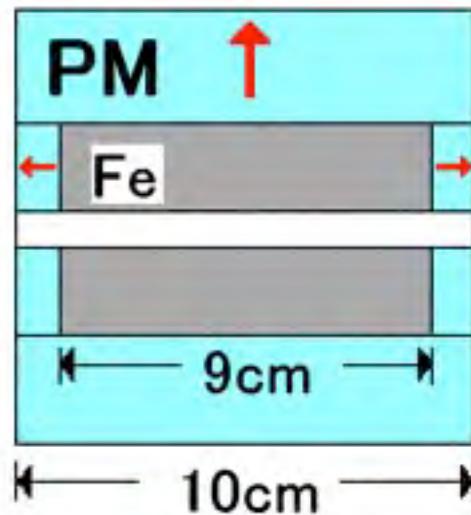
Magnet	Demag. ratio [/1x10 ¹³ n/cm ²]	iHc [Oe]
47H	10.2%	
44H	1.8%	16
39SH	0.7%	21
32EH	0.3%	30

T. Kawakubo, et al., The 14th Symposium on Accelerator Science and Technology, Tsukuba, Japan, November 2003,
pp. 208-210, in Japanese,
<http://conference.kek.jp/sast03it/WebPDF/1P027.pdf>

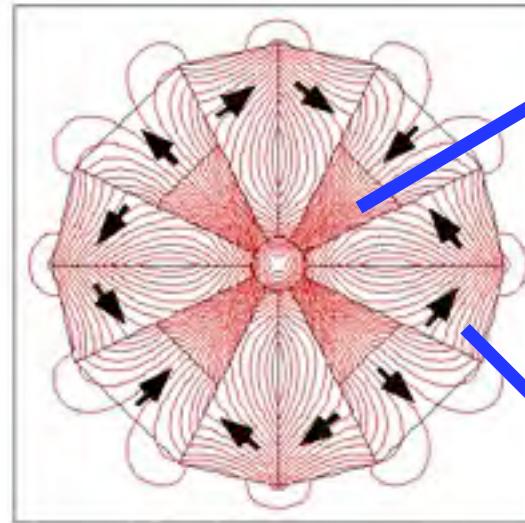
Continuous 1mo.(2.6×10^6 s) operation may cause about 0.01[%] of (reversible?) demagnetization on NEOMAX 32EH.
(1% for 10 years) ... needs more info.



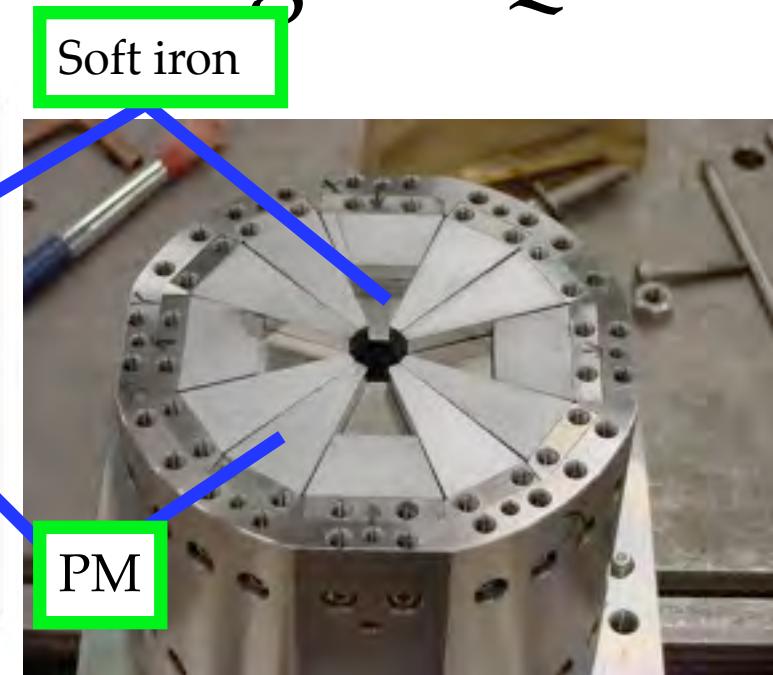
The first prototype of “superstrong” Permanent Magnet Quad.



Cut plane view



Axial view



PHOTO

Integrated gradient $GL=28.5\text{T}$ (29.7T by calc.)

magnet size.

$\varnothing 10\text{cm}$

bore

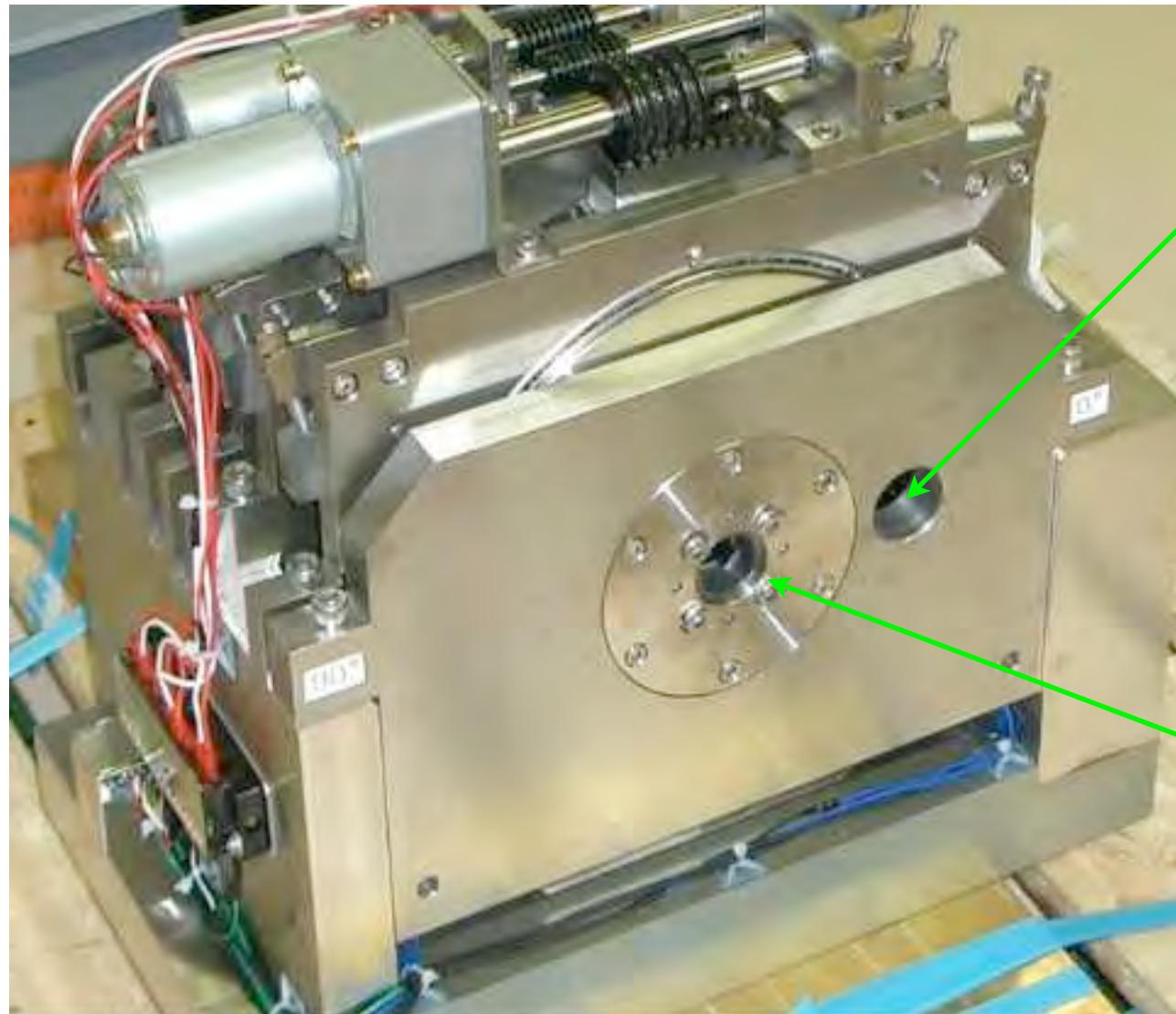
$\varnothing 1.4\text{cm}$

Field gradient

$\sim 300\text{T/m}$

$$GL = \int \frac{dB}{dr} dz$$

The 20mr Variable FFQ Magnet

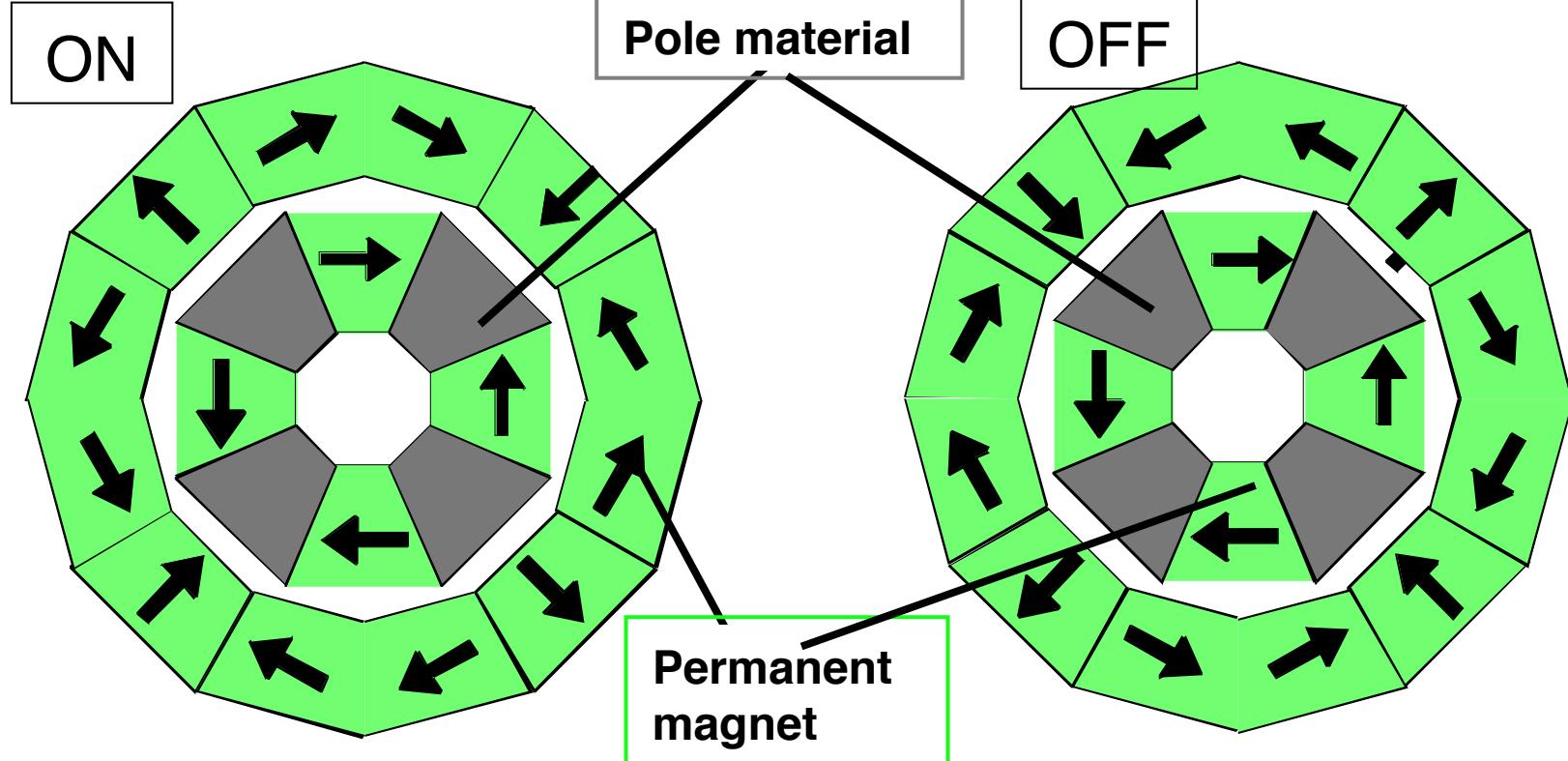


hole for
outgoing
beam

hole for
incoming
beam

Double Ring Structure

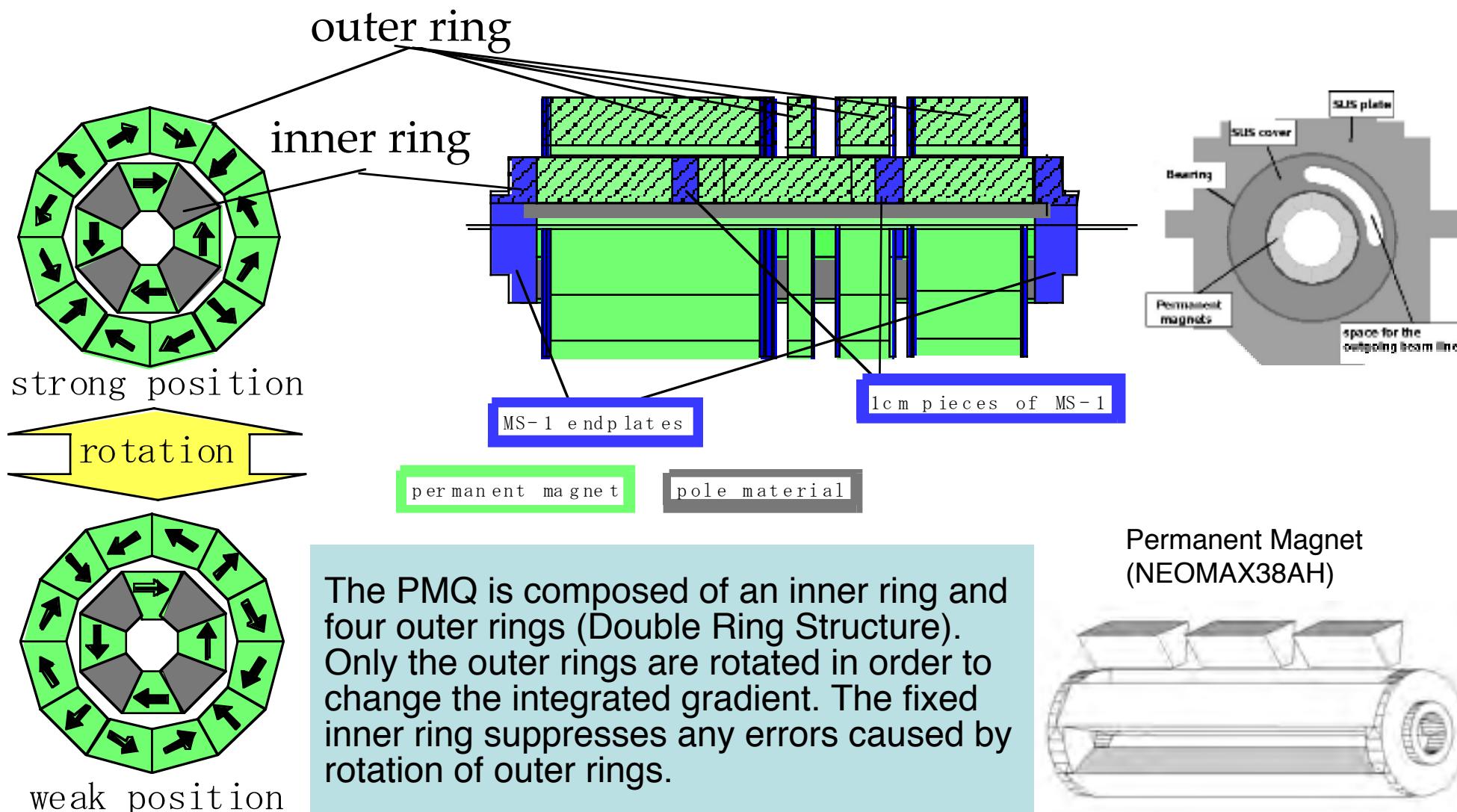
First Quadrant shows the flux plot.



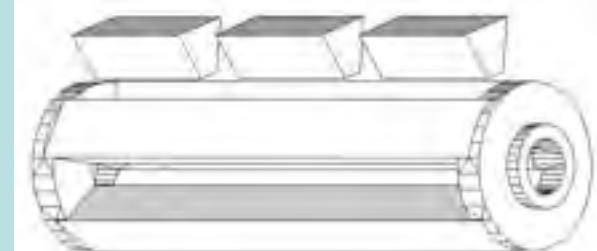
The double ring structure

PMQ is split into inner ring and outer ring. Only the outer ring is rotated 90° around the beam axis to vary the focal strength.

Adjustable Permanent Magnet Quadrupole



Permanent Magnet
(NEOMAX38AH)



The 20mr Variable FFQ Magnet



Inner Ring



Inside View of Outer Ring



Bore radius	1cm
Inner ring radii	In 1cm out 3cm
Outer ring radii	In 3.3cm out 5cm
Outer ring section length	1cm, 2cm, 4cm, 8cm
Physical length	23cm
Pole material	Permendur
Magnet material (inner ring)	NEOMAX38AH
Magnet material (outer ring)	NEOMAX44H
Integrated gradient (strongest)	24.2T
Integrated gradient (weakest)	3.47T
Int. gradient step size	1.4T

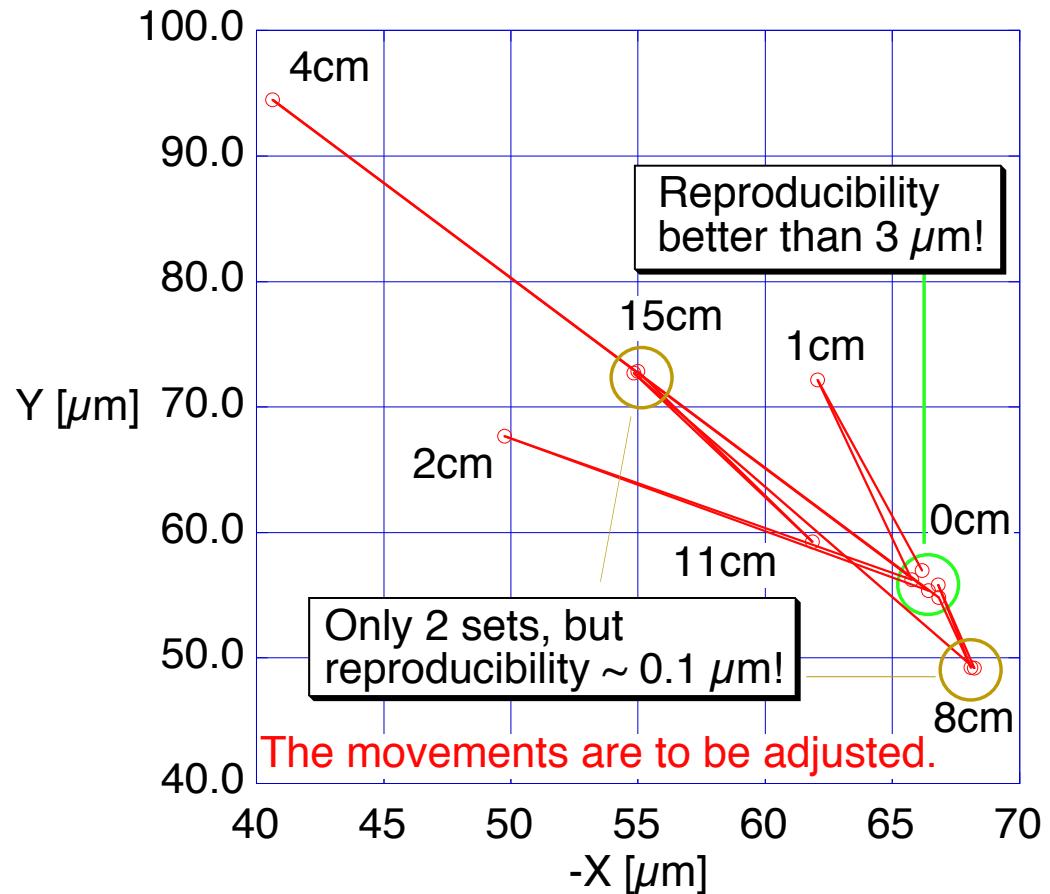
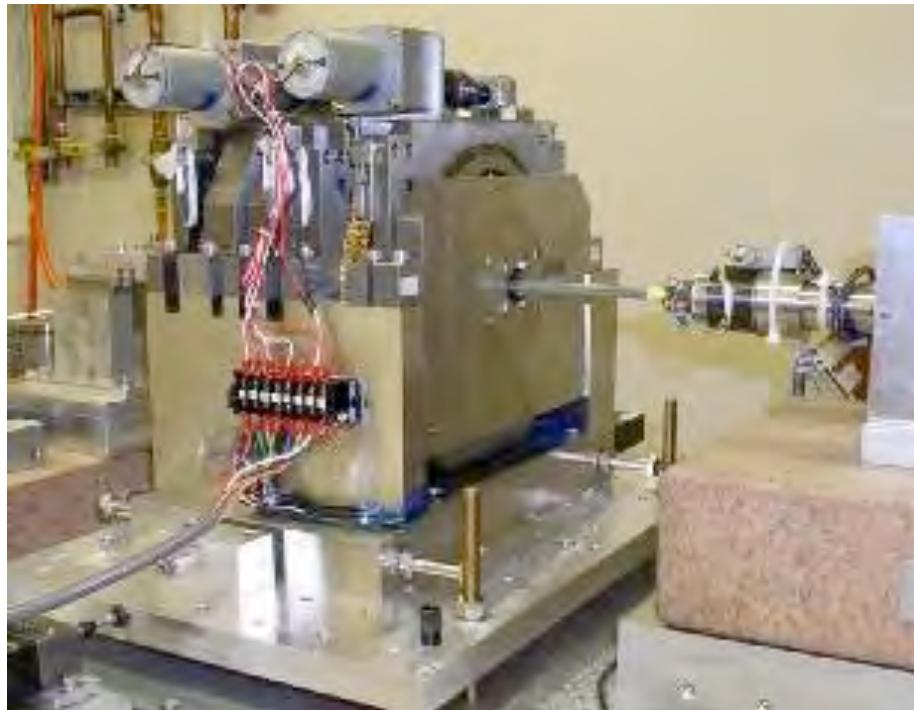
Extra beam hole



Base plate

← Before assembly →

Magnetic Center Movement



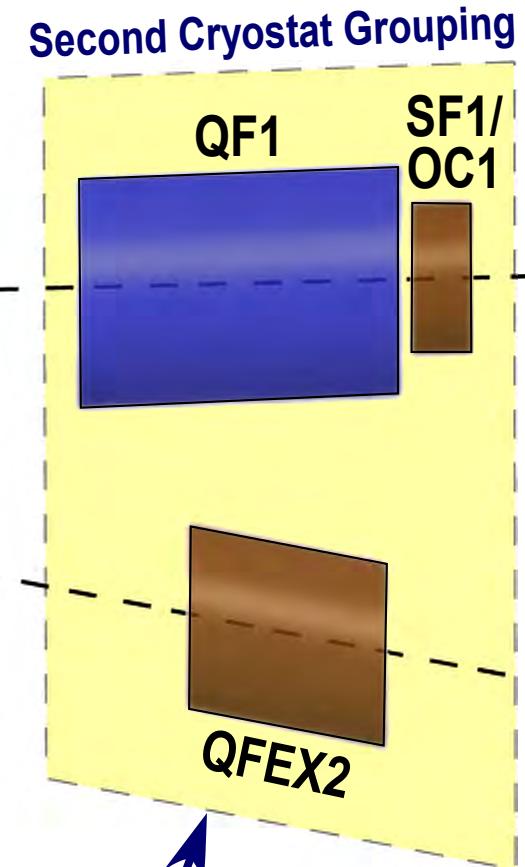
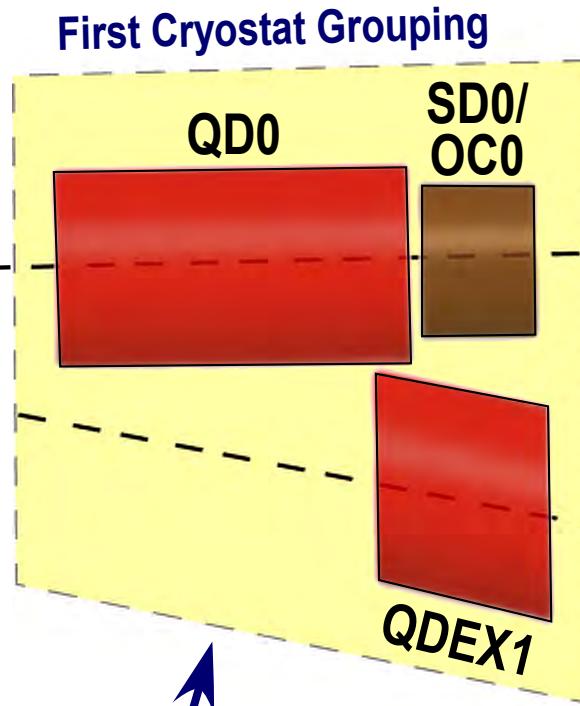
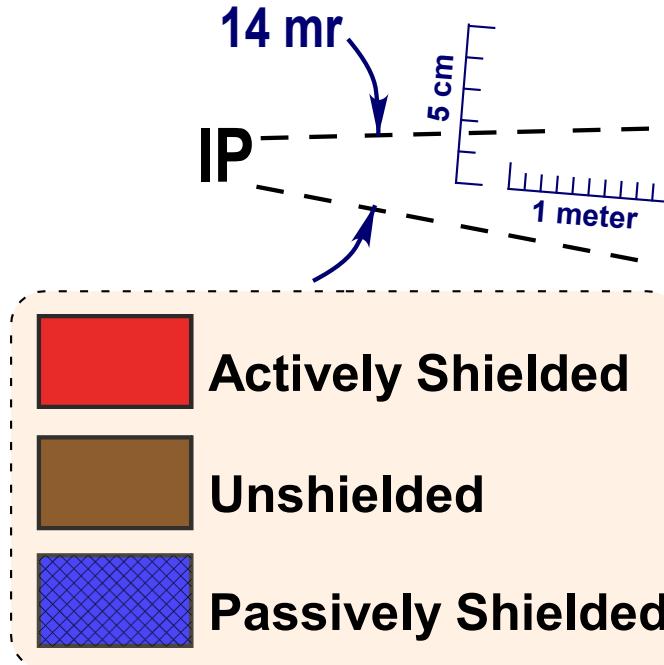
The cm values show the Switched-On-Length

The center moves several μm for 20% strength change.

See <http://accelconf.web.cern.ch/AccelConf/104/PAPERS/TUP81.PDF> (LINAC'04)

Post Valencia 14 mr Magnet Layout Compatible with Push-Pull

Brett Parker's sketch of
how they be placed as
superconducting quads



One of these magnet groups is needed in both ends of each detector (move with experiment, not shared).

For actively shielded coils the shield is run in series with the main quadrupole current but with a trim circuit shunt power supply for fine adjustment.

One of these magnet groups is needed on each side of the common push-pull IR hall (fixed position, experiments share).

ATF2 and ILC

Para. at IP	ATF2	ILC
Beam Energy [GeV]	1.3	250
Length to the FFQ [m]	1	3.5-4.2
$\gamma \varepsilon_x$ [m-rad]	3×10^{-6}	1×10^{-5}
$\gamma \varepsilon_y$ [m-rad]	3×10^{-8}	4×10^{-8}
β_x [mm]	4.0	21
β_y [mm]	0.1	0.4

*ATF2 proposal, ATF2 Group, Aug. 11, 2005



Tolerances

To keep beam size $\Delta X < X/10$

★ Rotation Error

→ see table

★ Length Error

→ $< 100\mu\text{m}$

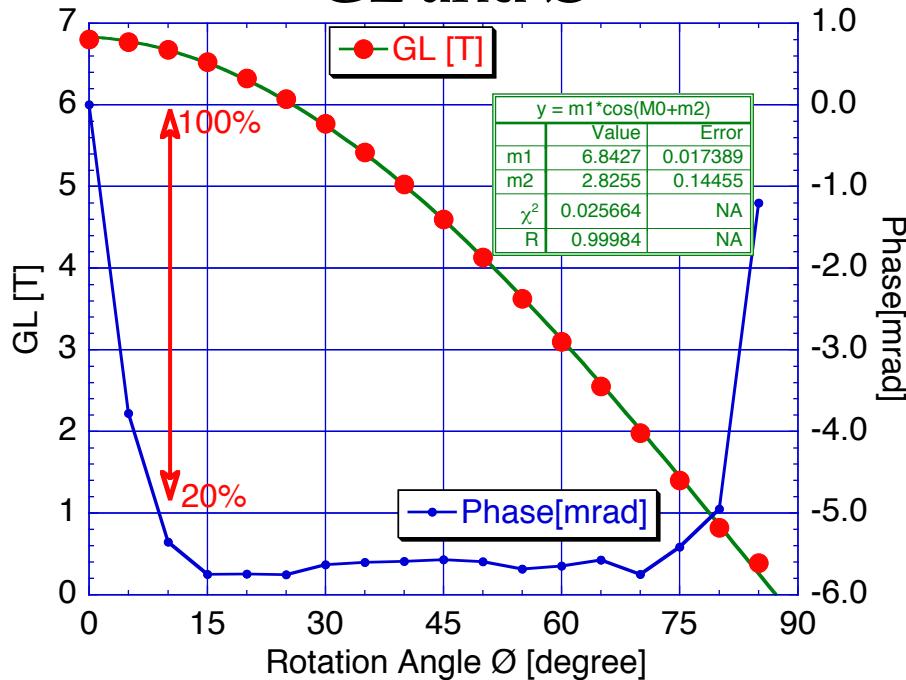
★ Position Error

→ No effect on beam size.

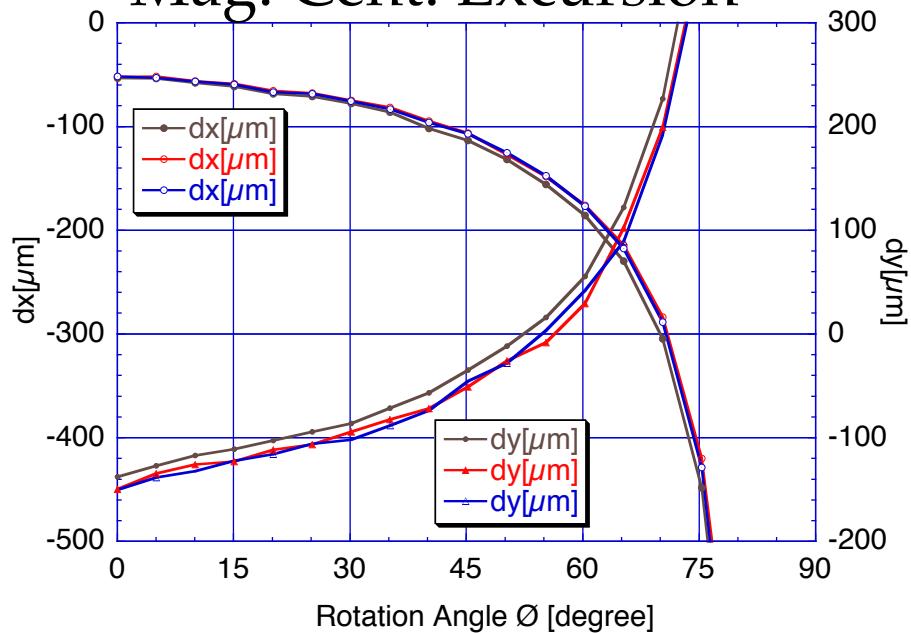
→ 1 μm tolerance of FFQ for 1nm shift at IP

Disc	Length[mm]	Tolerance [rad]
1st	17.33	$< 2.2 \times 10^{-4}$
2nd	55.00	$< 7.0 \times 10^{-5}$
3rd	75.34	$< 5.3 \times 10^{-5}$
4th	55.00	$< 7.6 \times 10^{-5}$
5th	17.33	$< 2.5 \times 10^{-4}$

GL and \emptyset



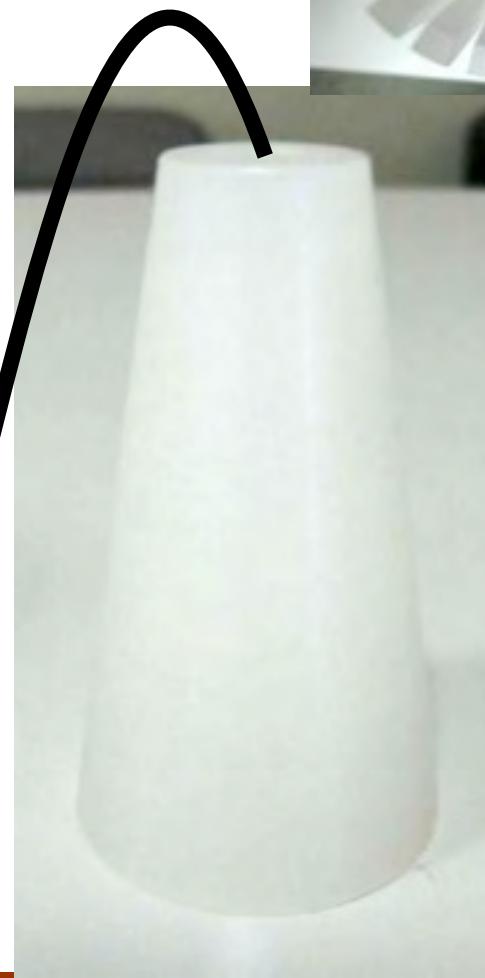
Mag. Cent. Excursion



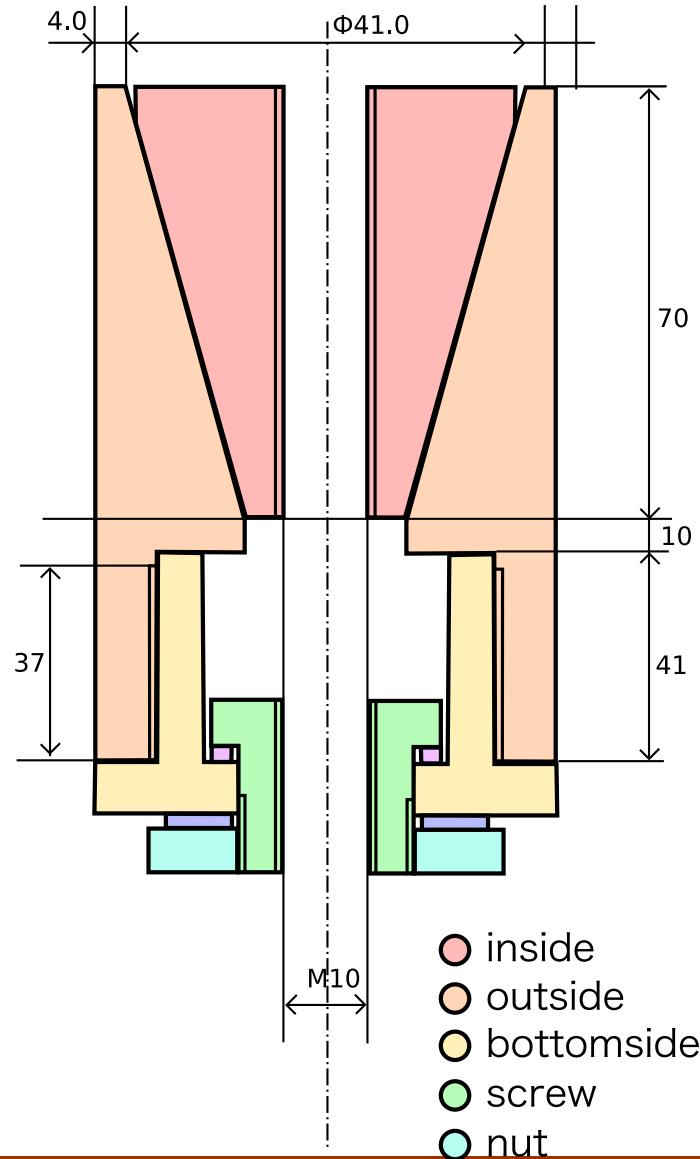
Observations

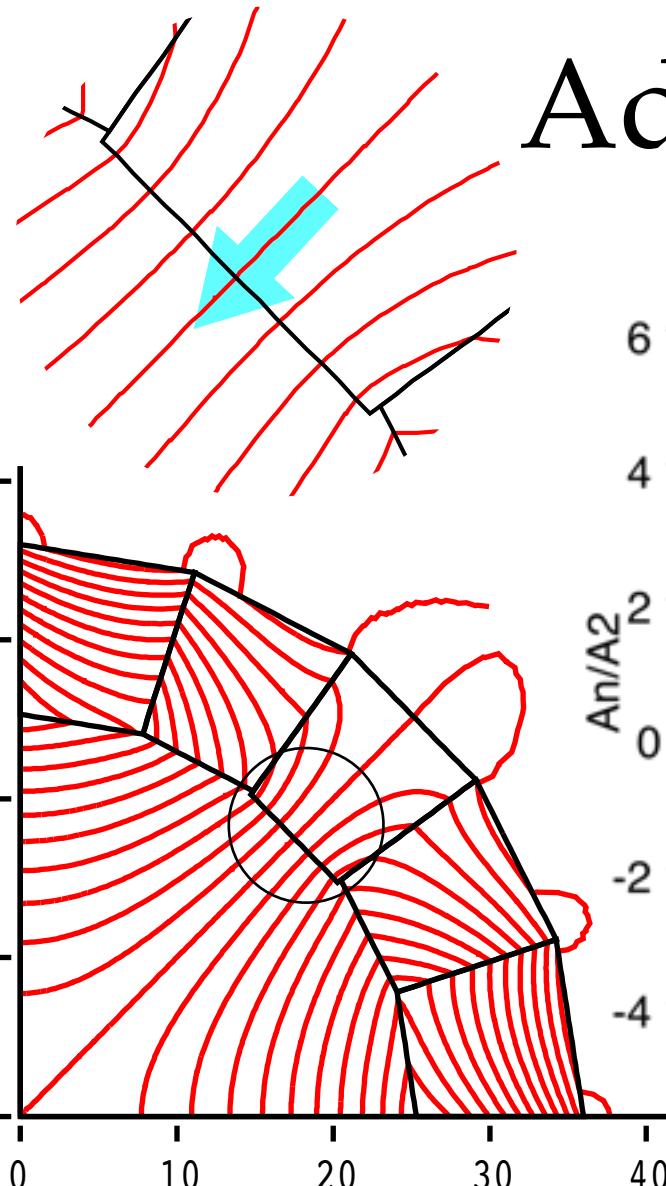
- ➊ GL (100~20%) can be covered.
- ➋ Angle adjustment needed.
- ➌ Reproducible magnet center excursion.
- ➍ But the value is big – needs adjustment.
- ➎ Minor mechanical modification will improve the excursion.

Alignment Jig

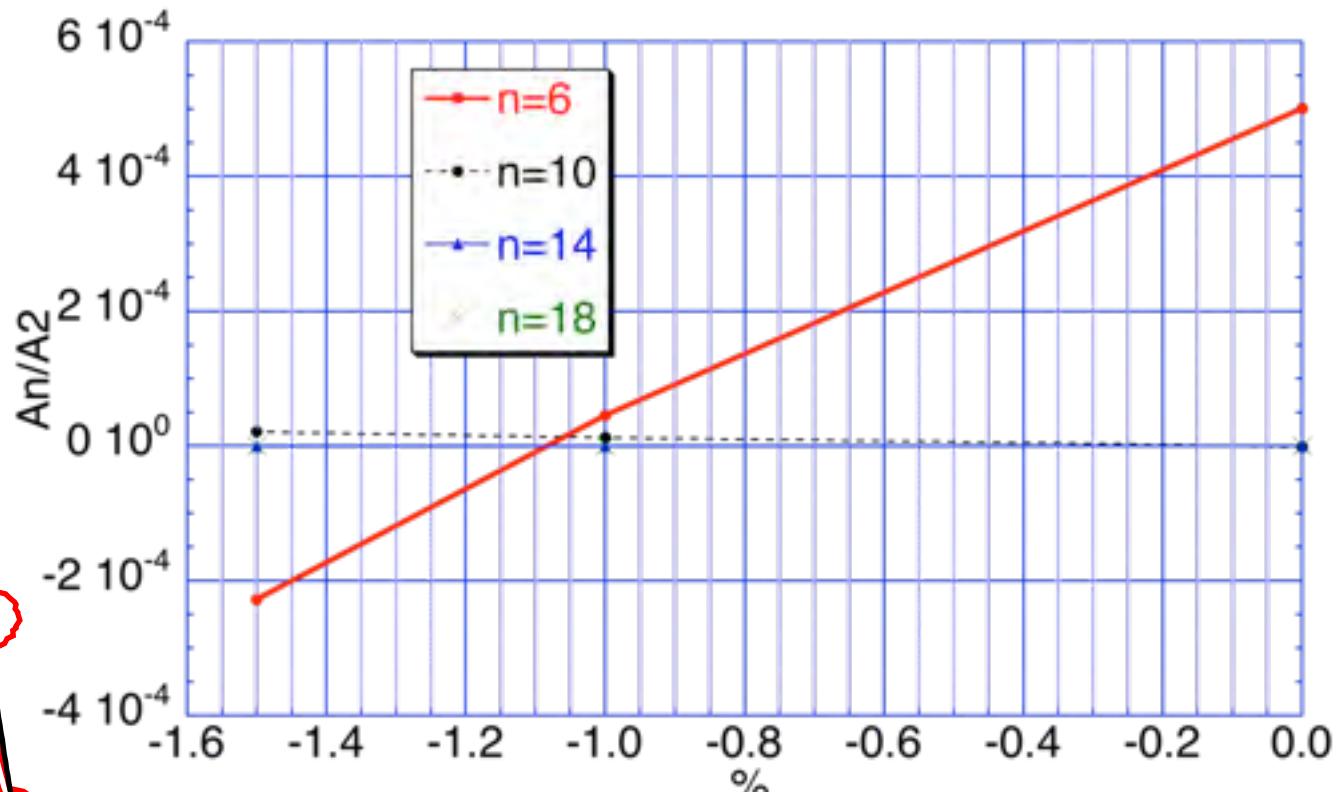


Adjustment: Jig for placing magnet parts





Adjusting n=6



Displacing magnet pieces at pole positions (4 out of 20).

$r=25\text{mm} \rightarrow 24.7\text{mm}$

What can be Tested?

- What can be monitored (with / without PMQ)?
 - Profile (size) by wire scanner
 - Position by BPM
 - (Size by Shintake Monitor downstream)
- Evaluation:
 - x-y coupling, high order, stability ,
 - Vibration evaluation (<50nm?),
 - reproducibility, etc.
- Practical experience:
 - handling, installation, stability...
- Comments ?!