Update of permanent FD

Kyoto University
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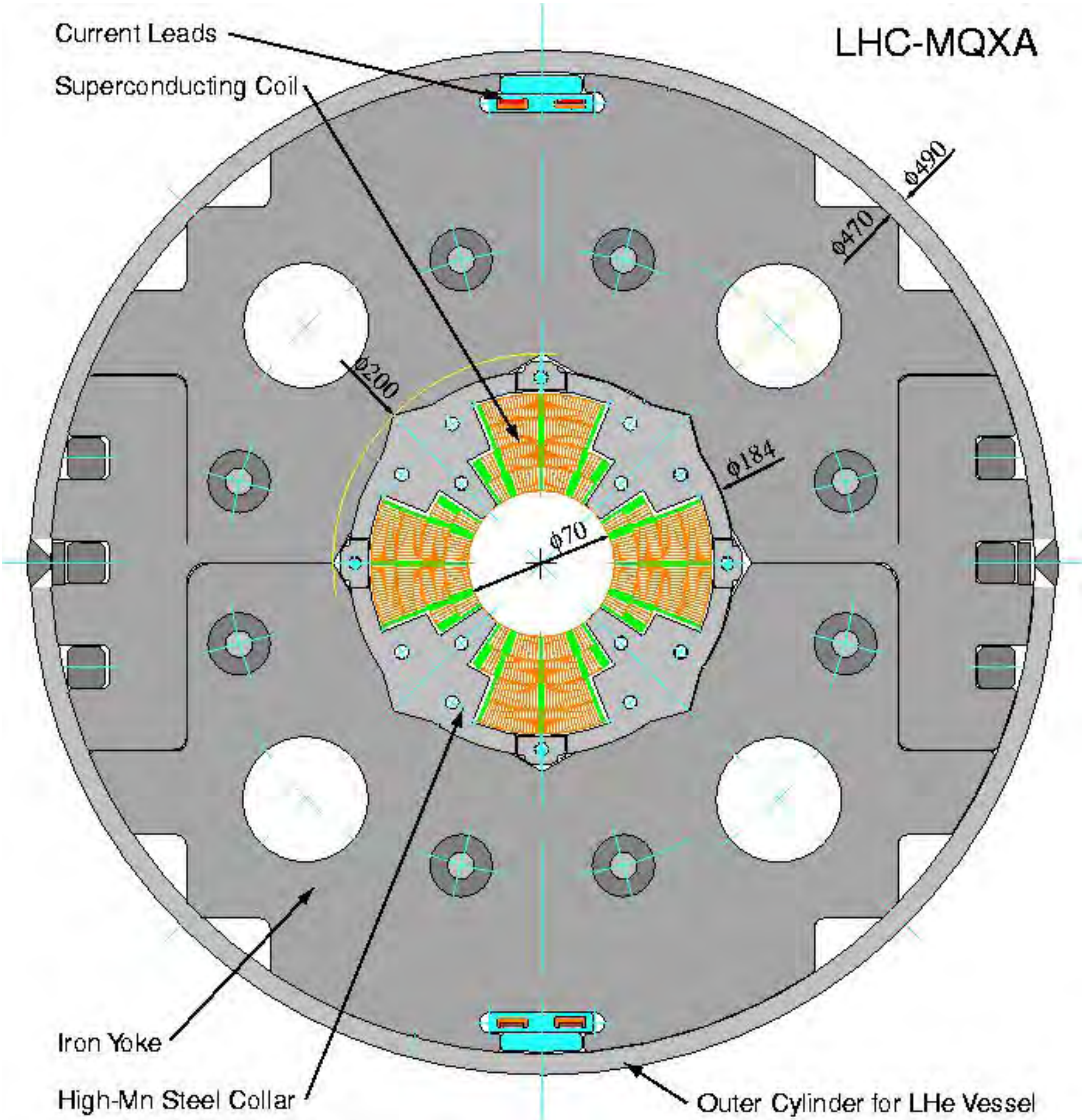
Introduction

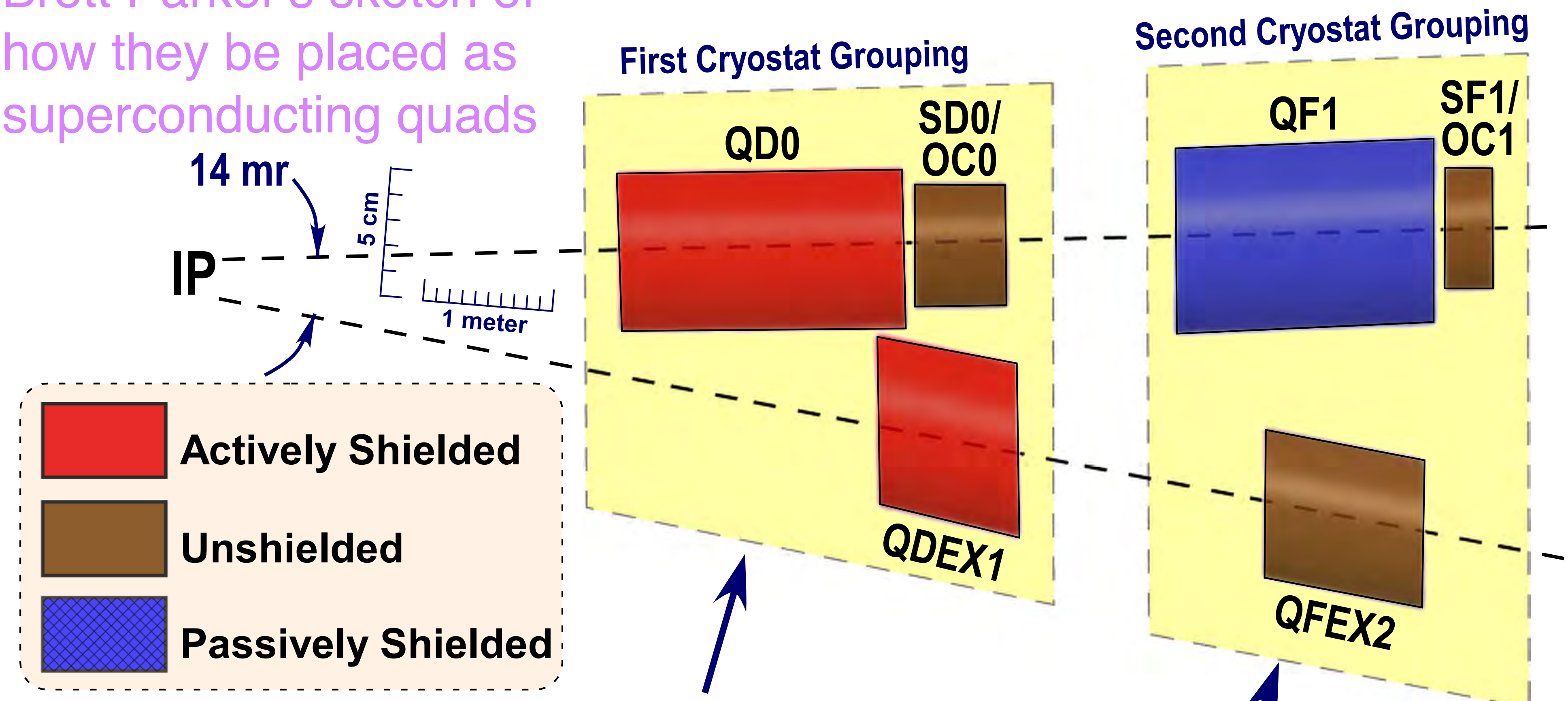
- Standpoint - why do we need this?
  - ➡ anxiety on vibration of Sc-EM (straightforward)
  - ➡ tunability requested (fixed PMQ proven)
  - ➡ new device needs handling experience.
- Brief Review of the history
- What is left to do?

LHC magnet (massive & rigid!)



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).

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

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.

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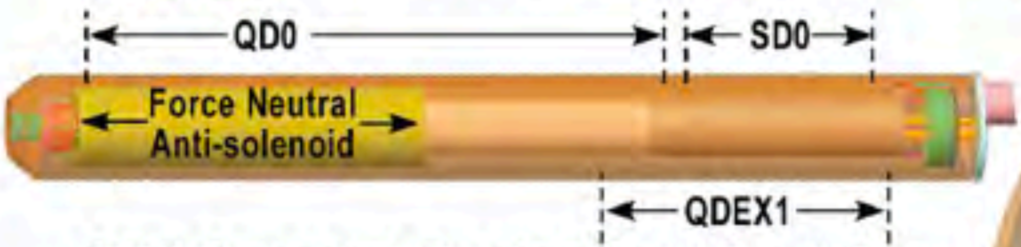
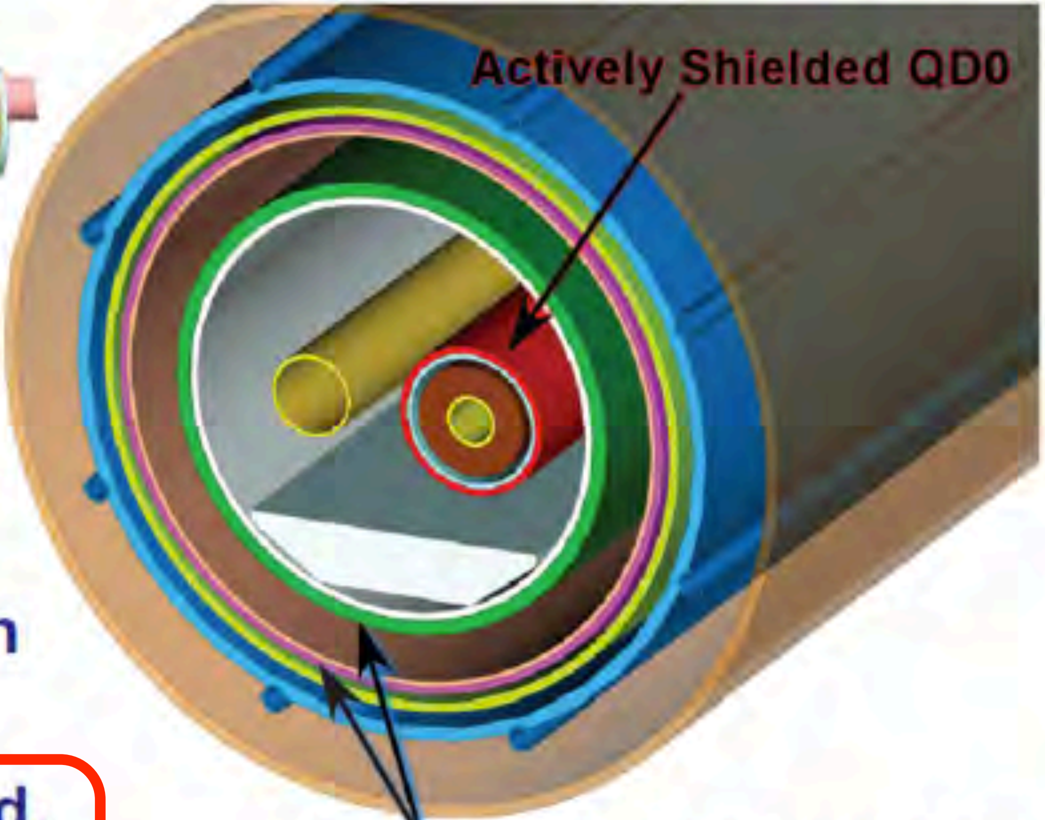
Some ILC FF Magnet Design Challenges.



QD0 Cryostat Design for L* = 4.5 m.

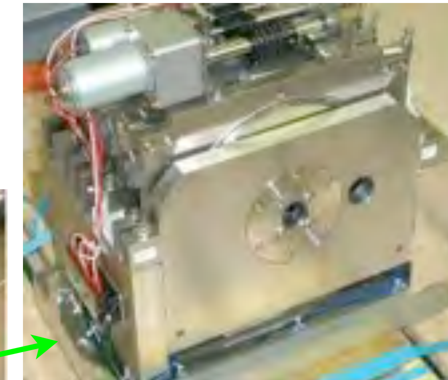


- Space is very tight inside the detector solenoid.
- Magnets must perform in ≈3T background field.
- For the active, beam based, feedback system to work need roughly 50 nm stability.

Present design avoids "flowing" helium; concept will be tested with QD0 R&D Prototype.

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

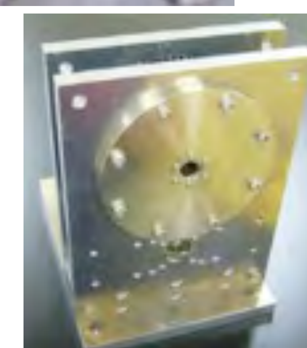
2003 Adjustable PMQ (double ring)

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

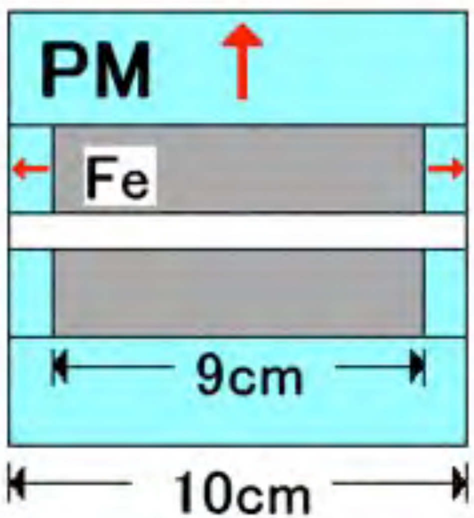
2007 Adjustable PMQ (2nd model) started

2008 Assemble, Measurement and Adjustment

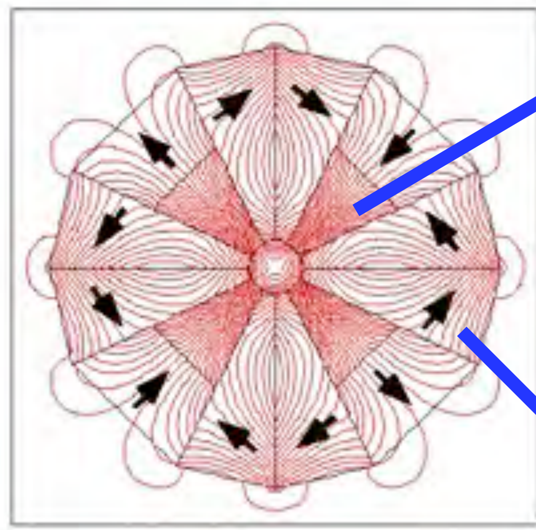
2009 Design and fabrication of Magnet mover

No budget year 2010!

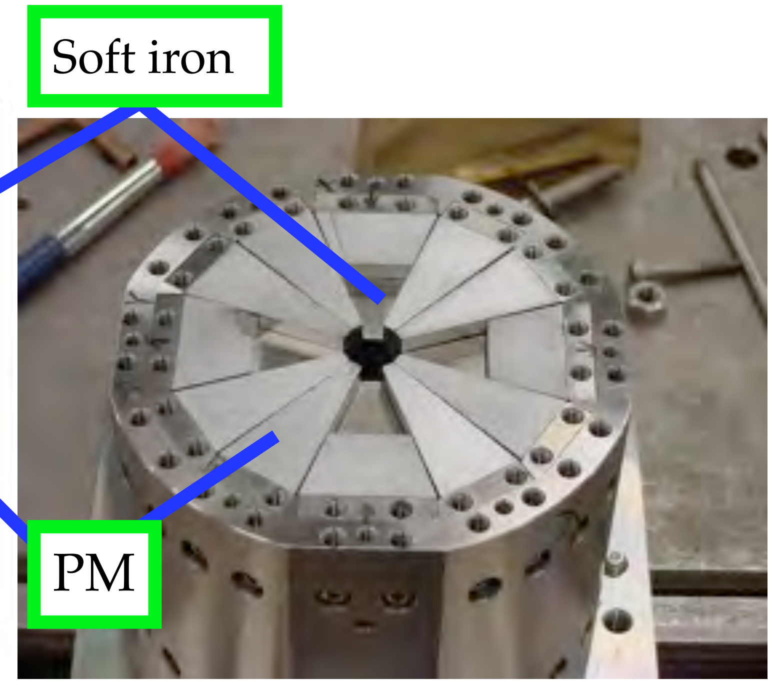
The first prototype of "superstrong" Permanent Magnet Quad.



Cut plane view



Axial view



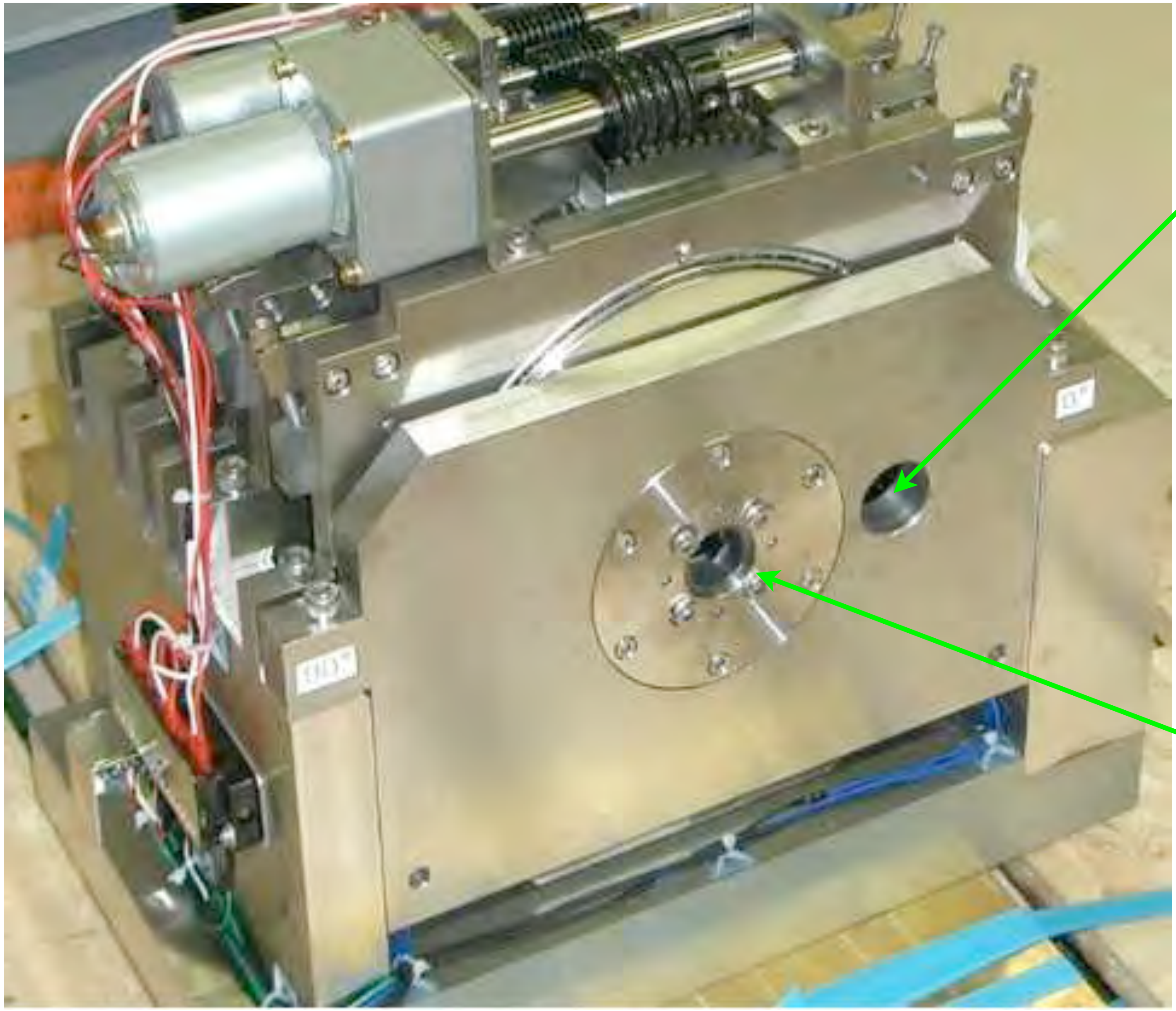
PHOTO

Integrated gradient GL=28.5T (29.7T by calc.)

magnet size.	ø10cm
bore	ø1.4cm
Field gradient	~300T / m

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

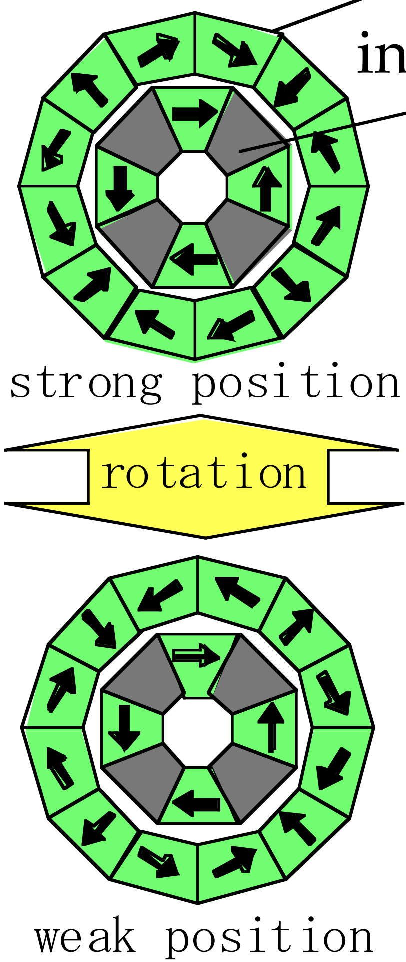
The 20mr Variable FFQ Magnet

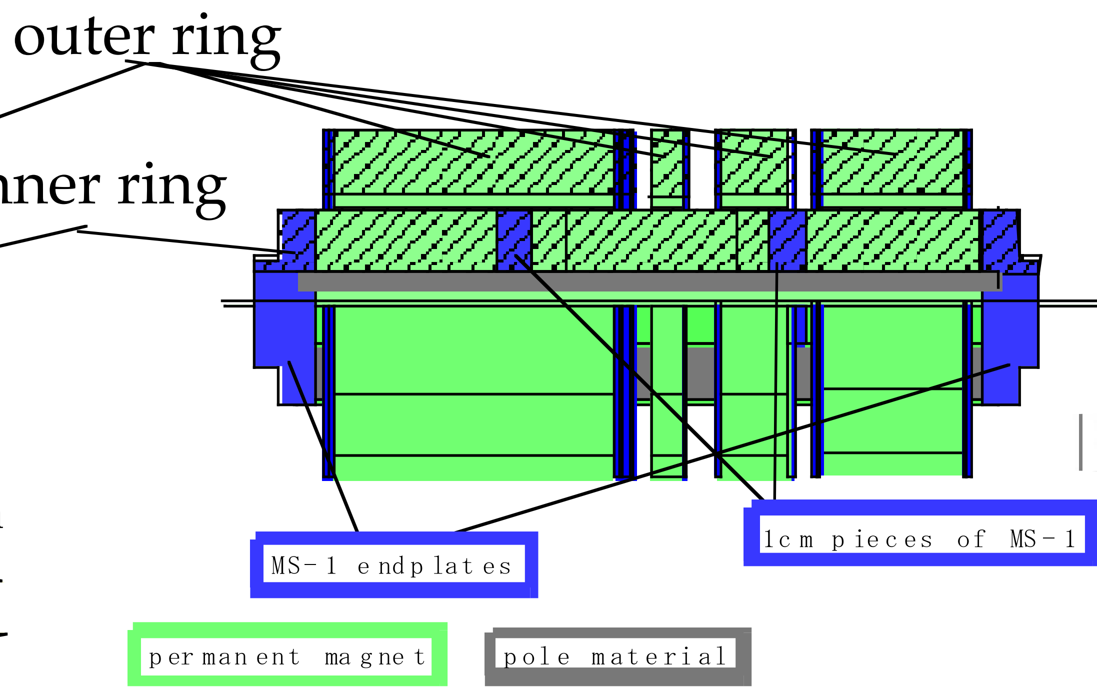


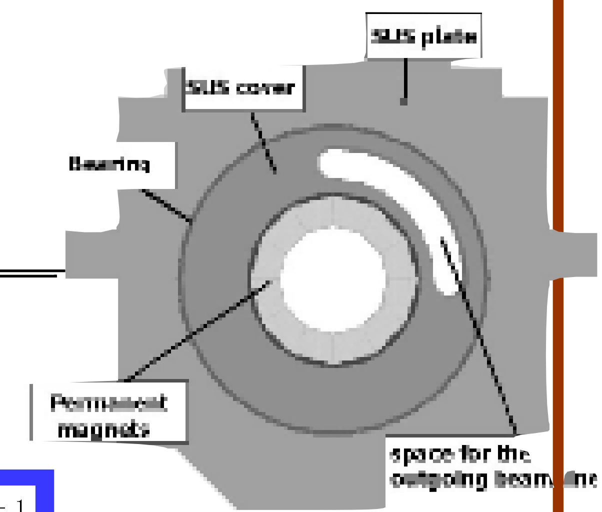
hole for outgoing beam

hole for incoming beam

Adjustable Permanent Magnet Quadrupole

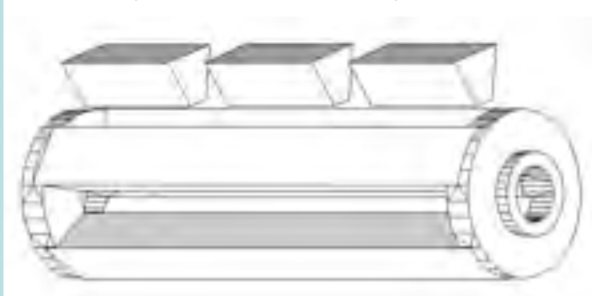




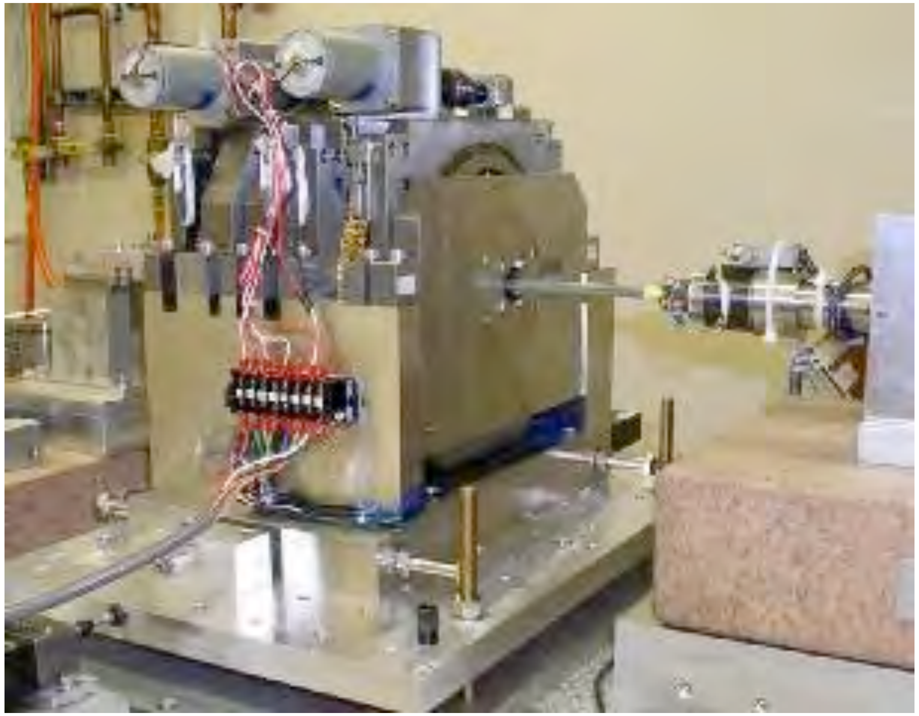


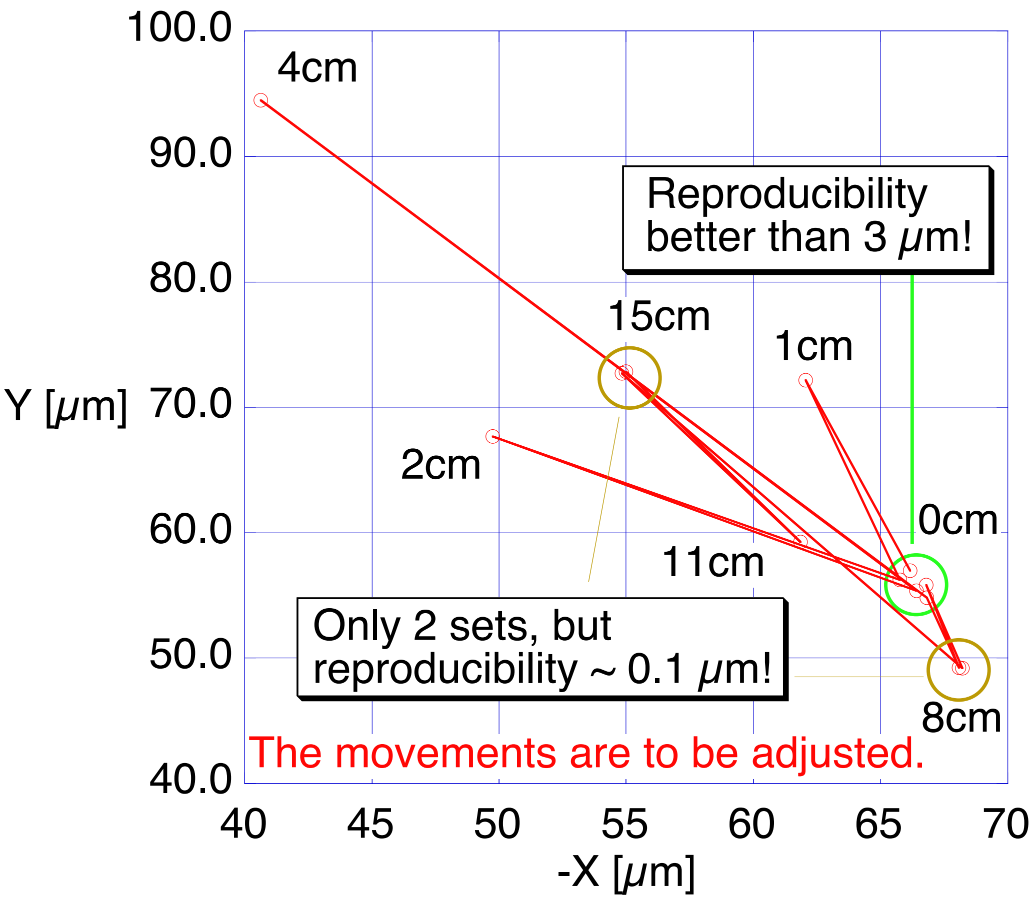
The PMQ is composed of an inner ring and four outer rings (Double Ring Structure). Only the outer rings are rotated in order to change the integrated gradient. The fixed inner ring suppresses any errors caused by rotation of outer rings.

Permanent Magnet (NEOMAX38AH)



Magnetic Center Movement



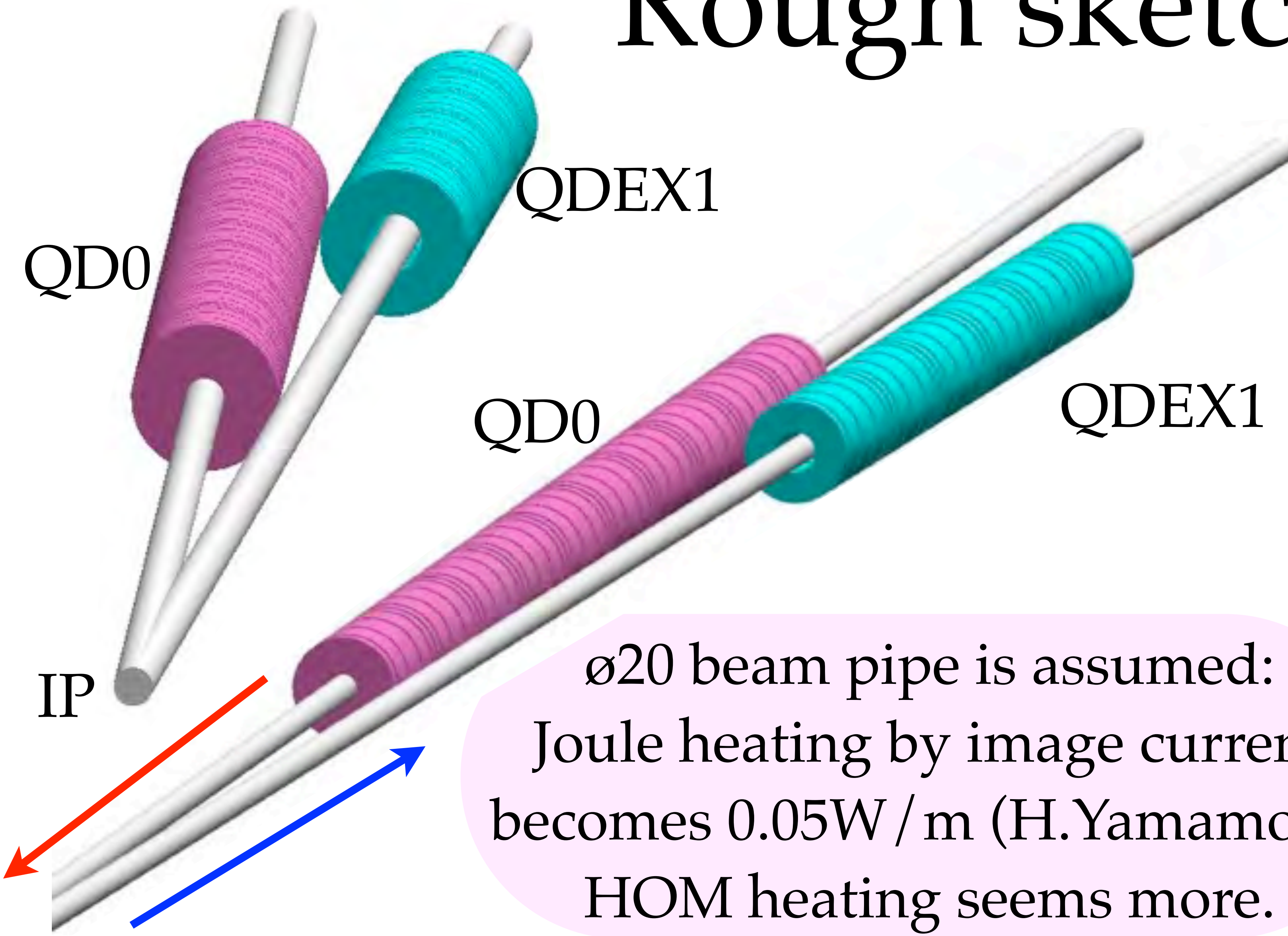


The cm values show the Switched-On-Length

The center moves several μm for 20% strength change.

See http://accelconf.web.cern.ch/AccelConf/l04/PAPERS/TUP81.PDF (LINAC'04)

Rough sketch

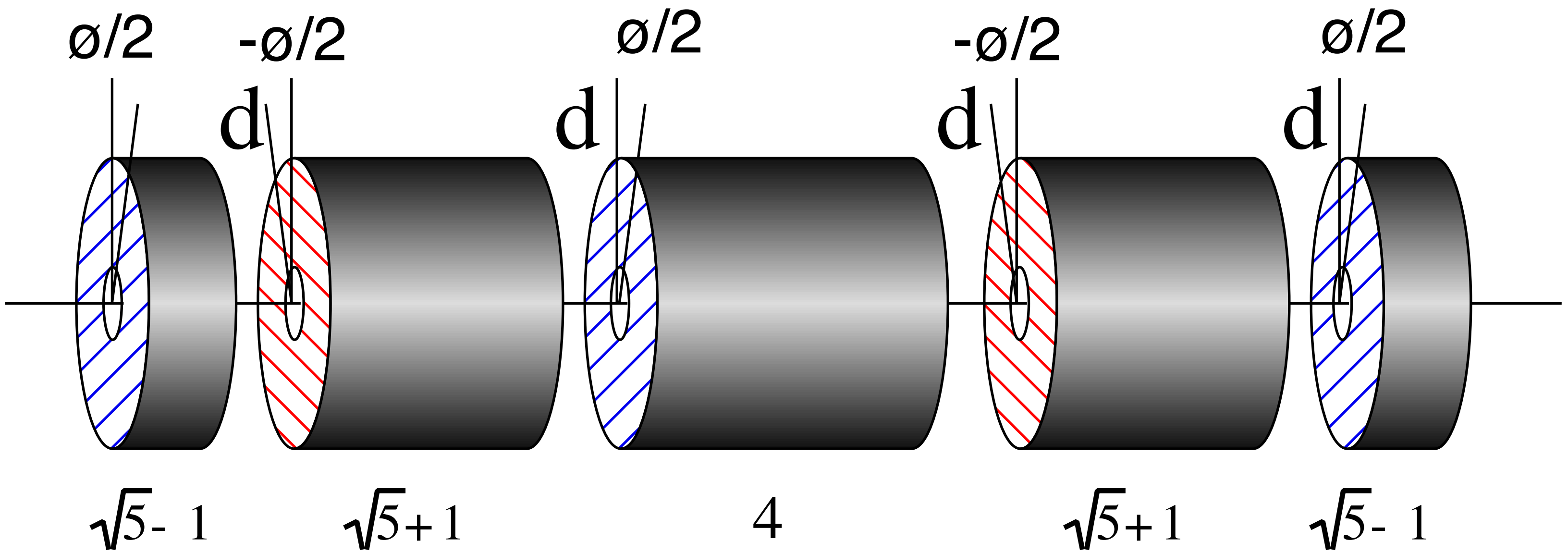


ø20 beam pipe is assumed:
Joule heating by image current
becomes 0.05W / m (H.Yamamoto)
HOM heating seems more.

Gluckstern's Adjustable PMQ – 5-Ring-Singlet –

for ILC Final Focus Doublet

Gluckstern's skewless variable PMQ



$$M = R \bullet M2 \bullet R^{-2} \bullet M1 \bullet R^{2} \bullet M0 \bullet R^{-2} \bullet M1 \bullet R^{2} \bullet M2 \bullet R^{-1}$$

4x4 matrix: $M=\begin{pmatrix} Mxx & O^5 \\ O^5 & Myy \end{pmatrix}$ 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

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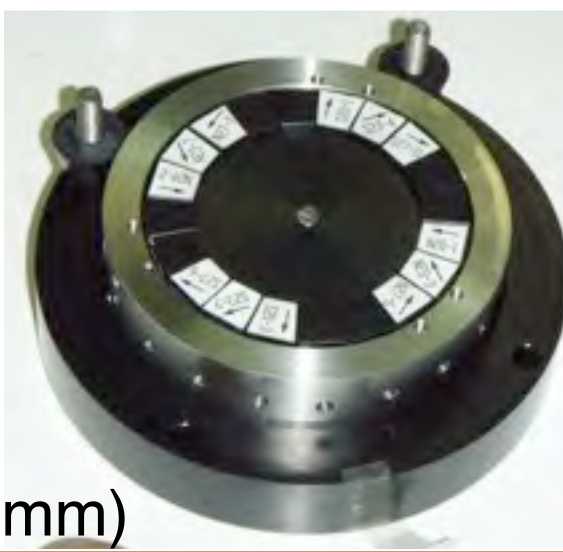
Gluckstern's 5-ring PMQ Singlet:

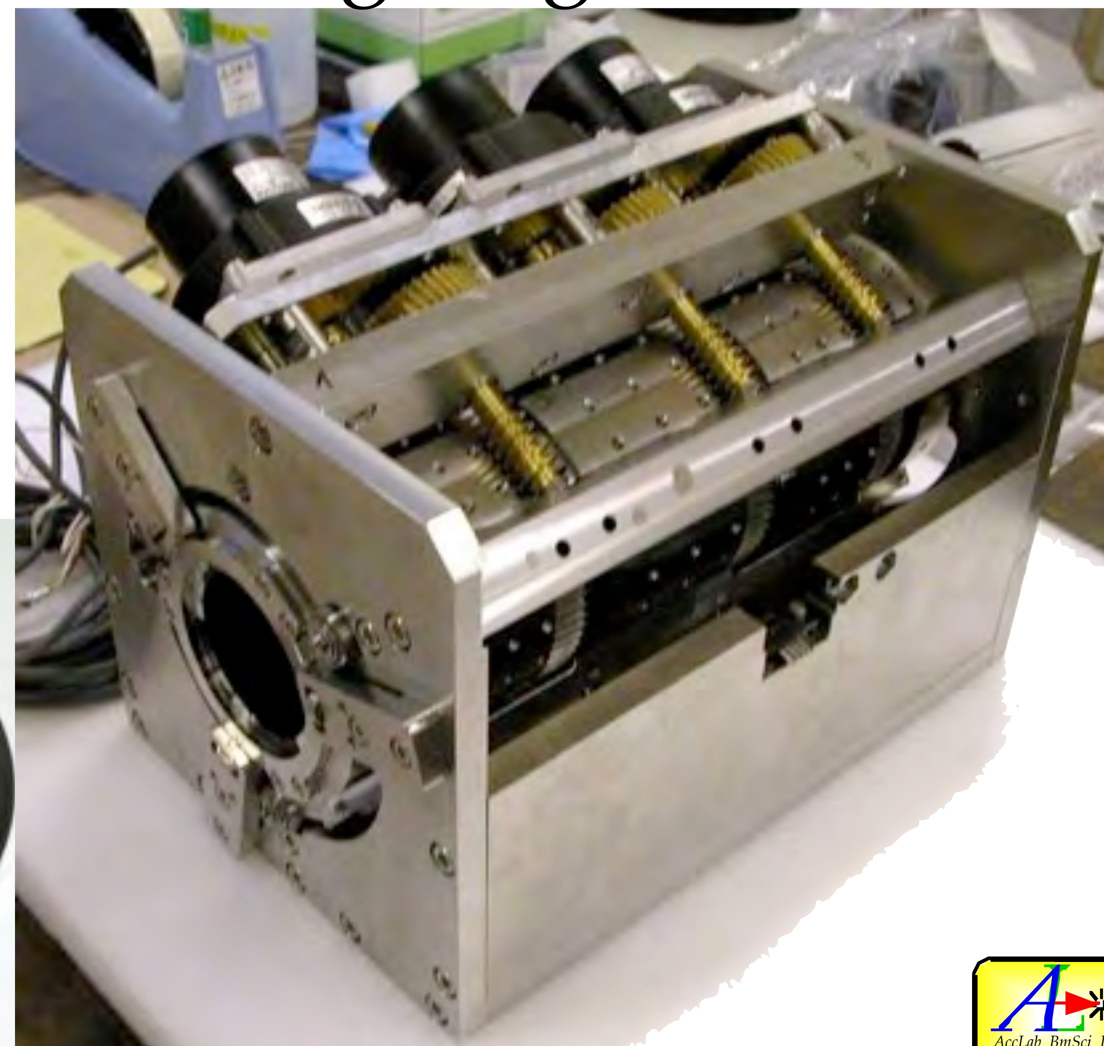
"Continuously Adjustable" PMQ fabricated

Supersonic Motor (nonmagnetic)



Disc(20mm)

The 5-ring singlet PM-FFQ



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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

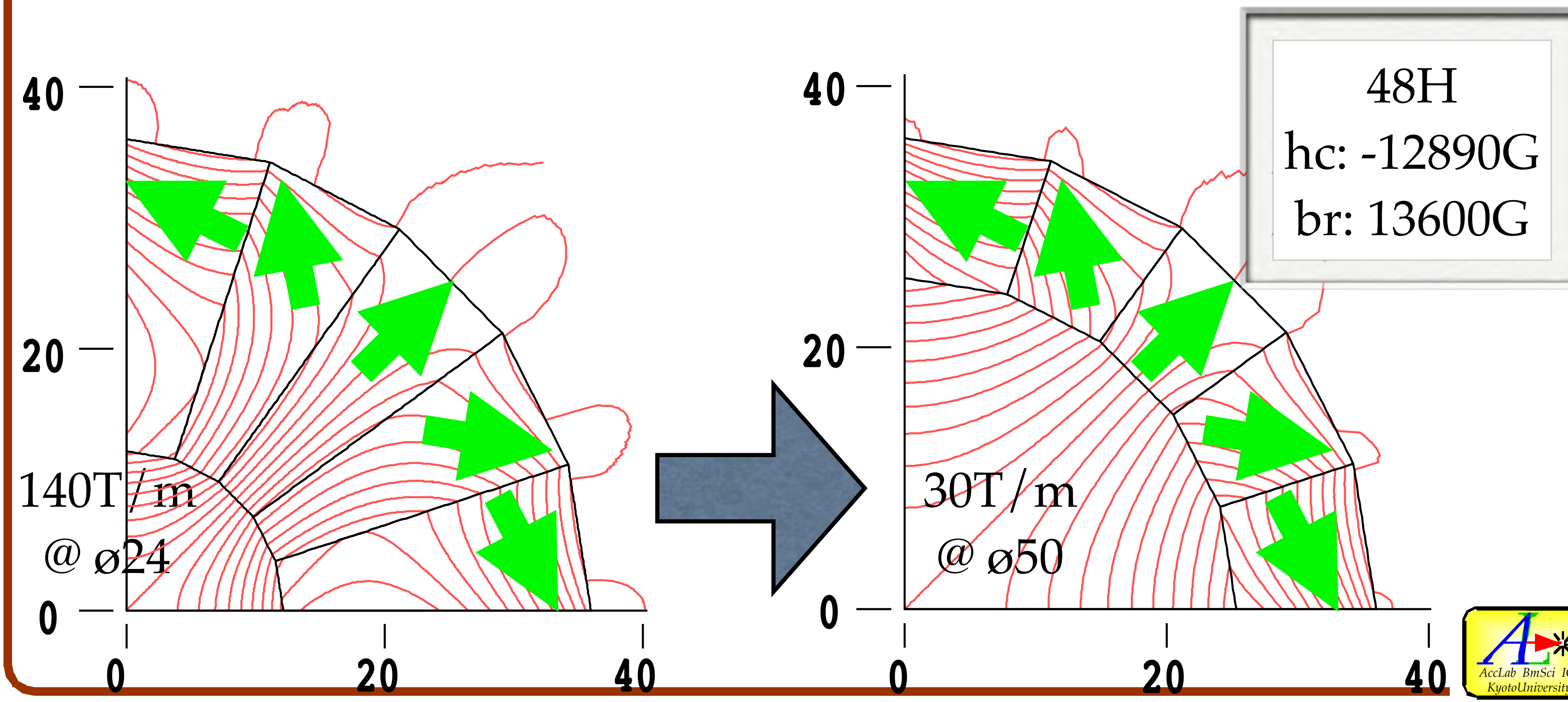
*ATF2 proposal, ATF2 Group, Aug. 11, 2005

Test at ATF2 – replace QD0

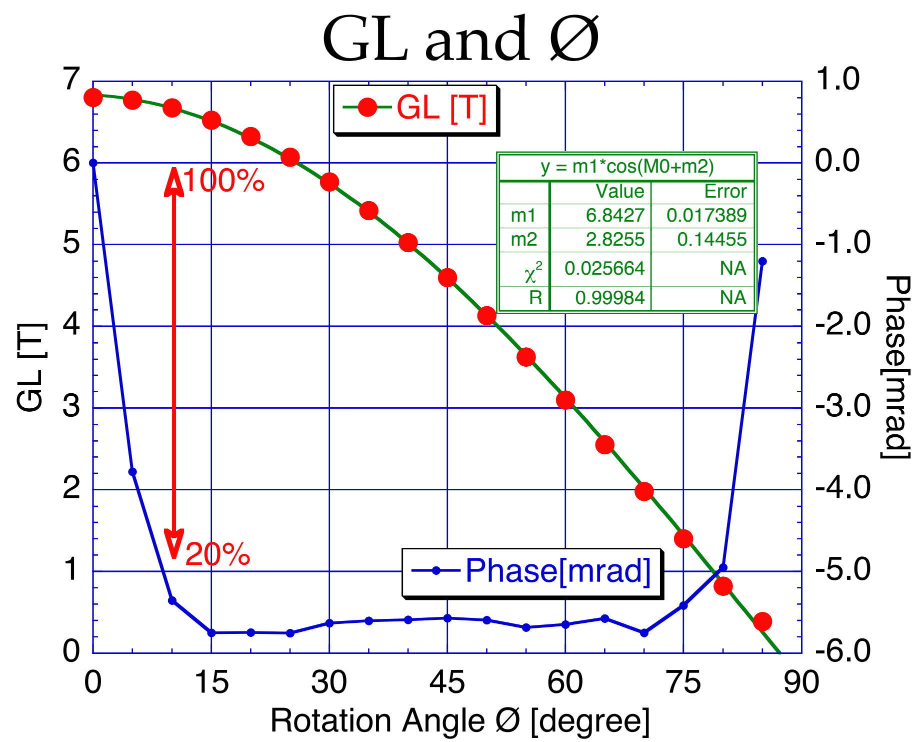
Req'd spec for QD0: L=45cm, ø50mm, G=13T/m

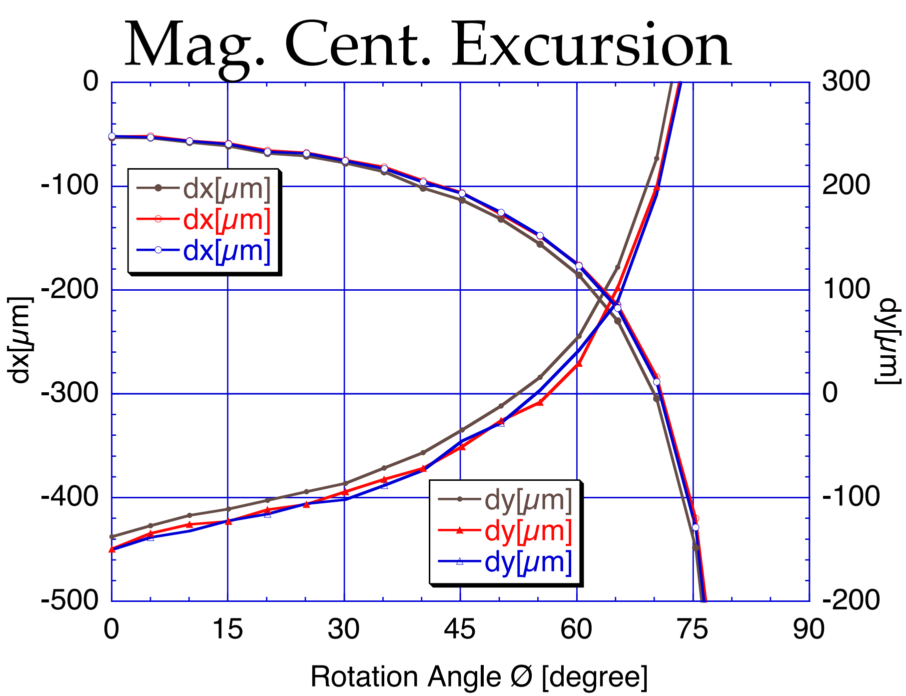
OD: ø72 (=2x(56-20)) GL=5.85 T

ATF2 needs a big bore with less gradient.



Adjustment





First observations

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

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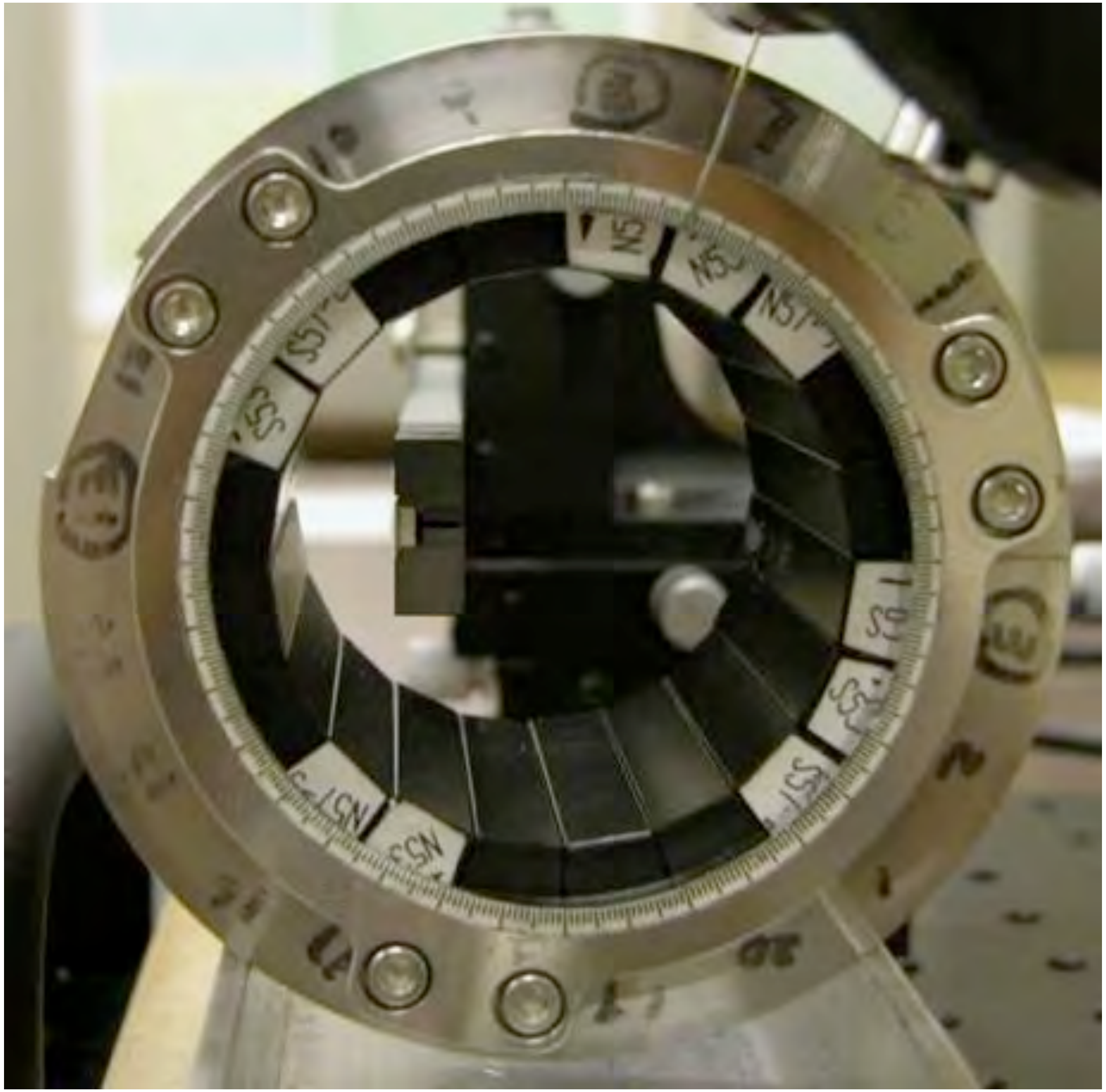
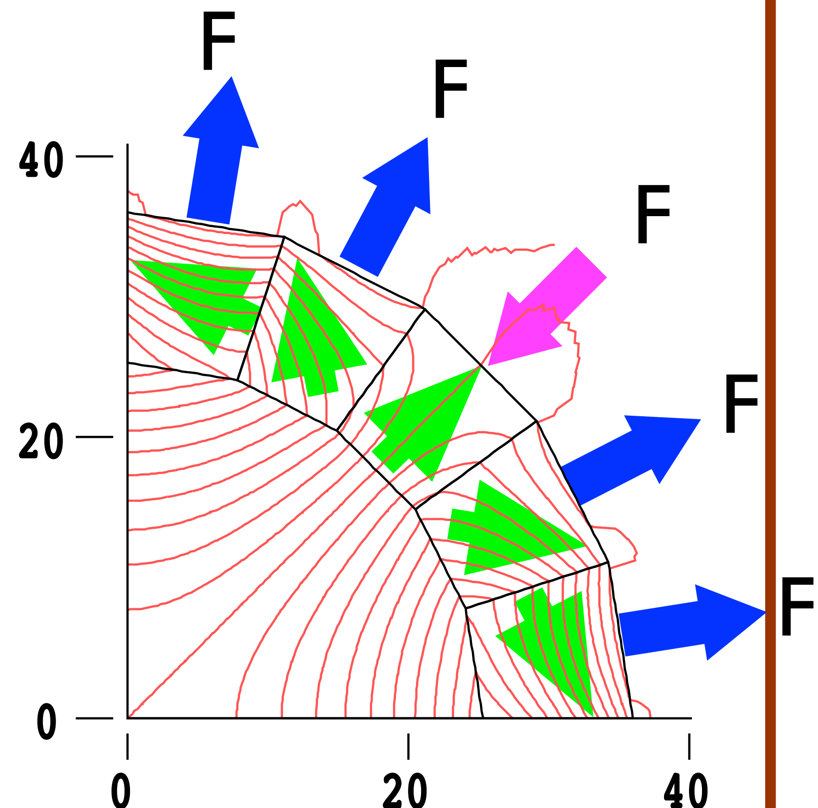
Magnet Bore



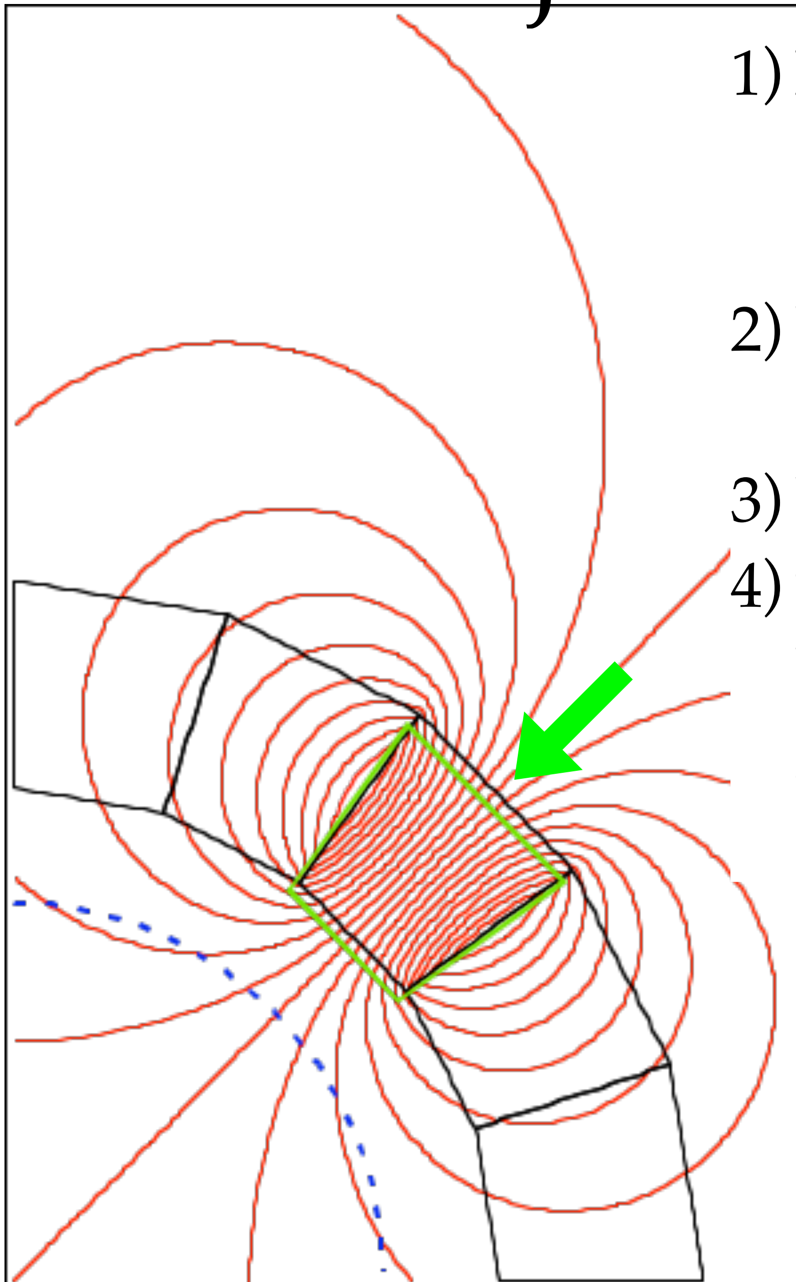
Pole magnets are attracted.



Others are repulsive.

Alignment Jig

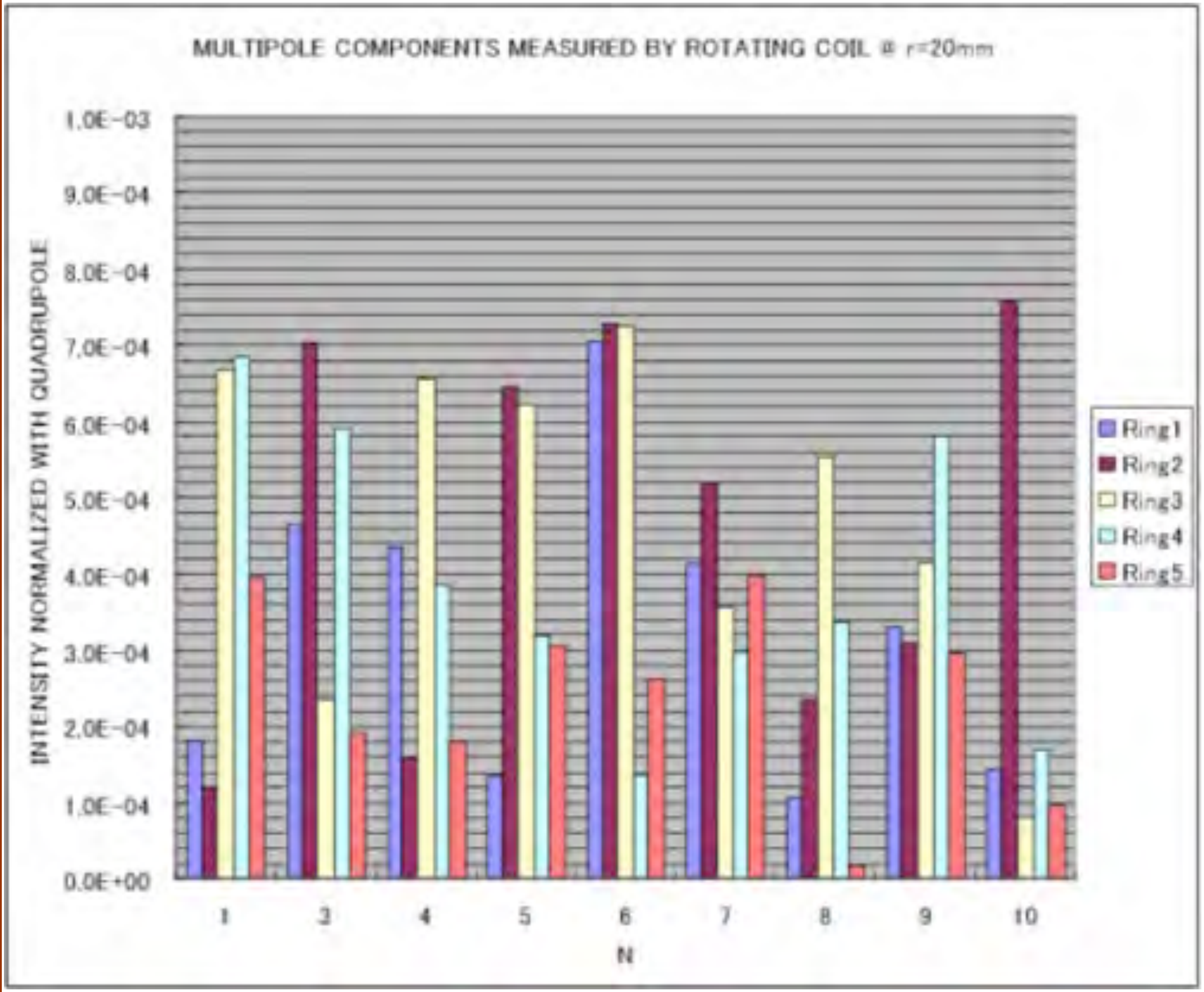
Adjustment Algorithm



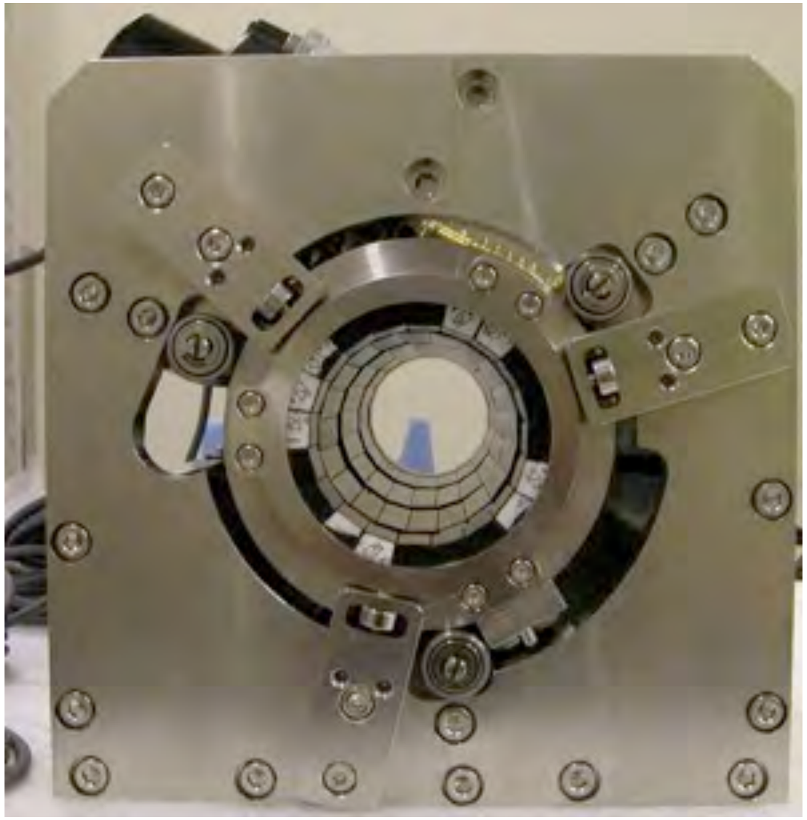
1) Multipole components (up to 11) generated by single piece and those with 1mm offset are calculated by PANDIRA.
2) The differences (11 Re and Im values) are obtained for all 20 pieces.
3) They consists of total 22x20 values.
4) Solve equ.
   The equ's correspond to Q should be replaced by all 1's (to keep circumference) and the one of 11th.

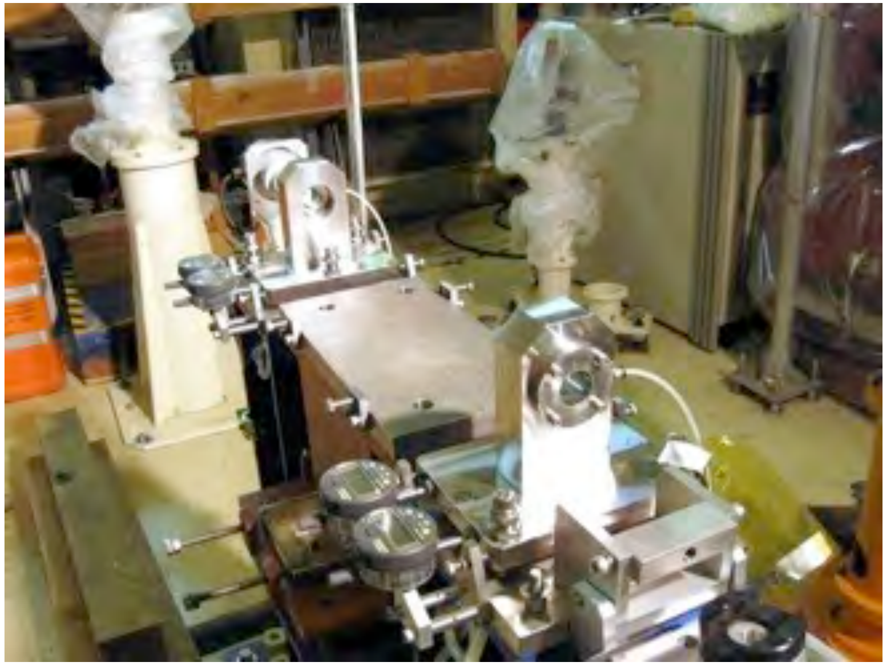
$$\begin{pmatrix} \frac{dC_1}{dr_1} & \frac{dC_1}{dr_2} & \cdots & \frac{dC_1}{dr_{20}} \\ \frac{dC_2}{dr_1} & \frac{dC_2}{dr_2} & \cdots & \frac{dC_2}{dr_{20}} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{dC_{20}}{dr_1} & \frac{dC_{20}}{dr_2} & \cdots & \frac{dC_{20}}{dr_{20}} \end{pmatrix} \begin{pmatrix}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

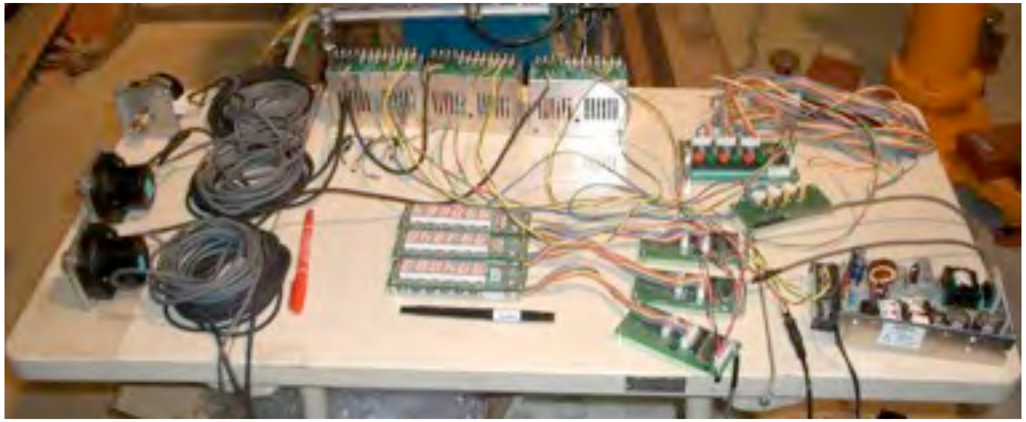
Harmonics @ r=20mm



By Rotation Coil







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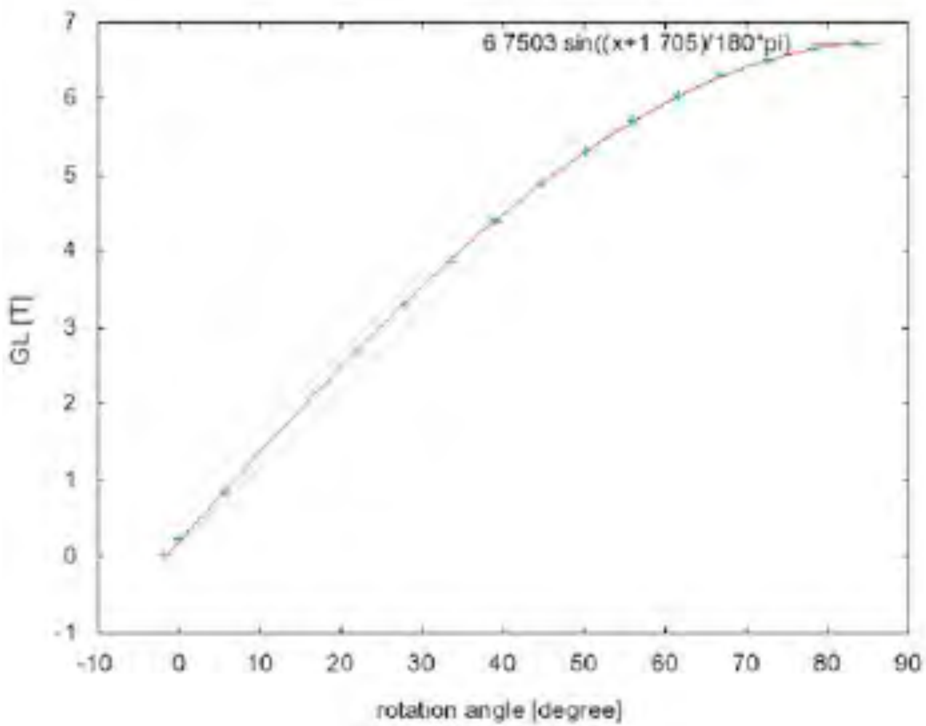
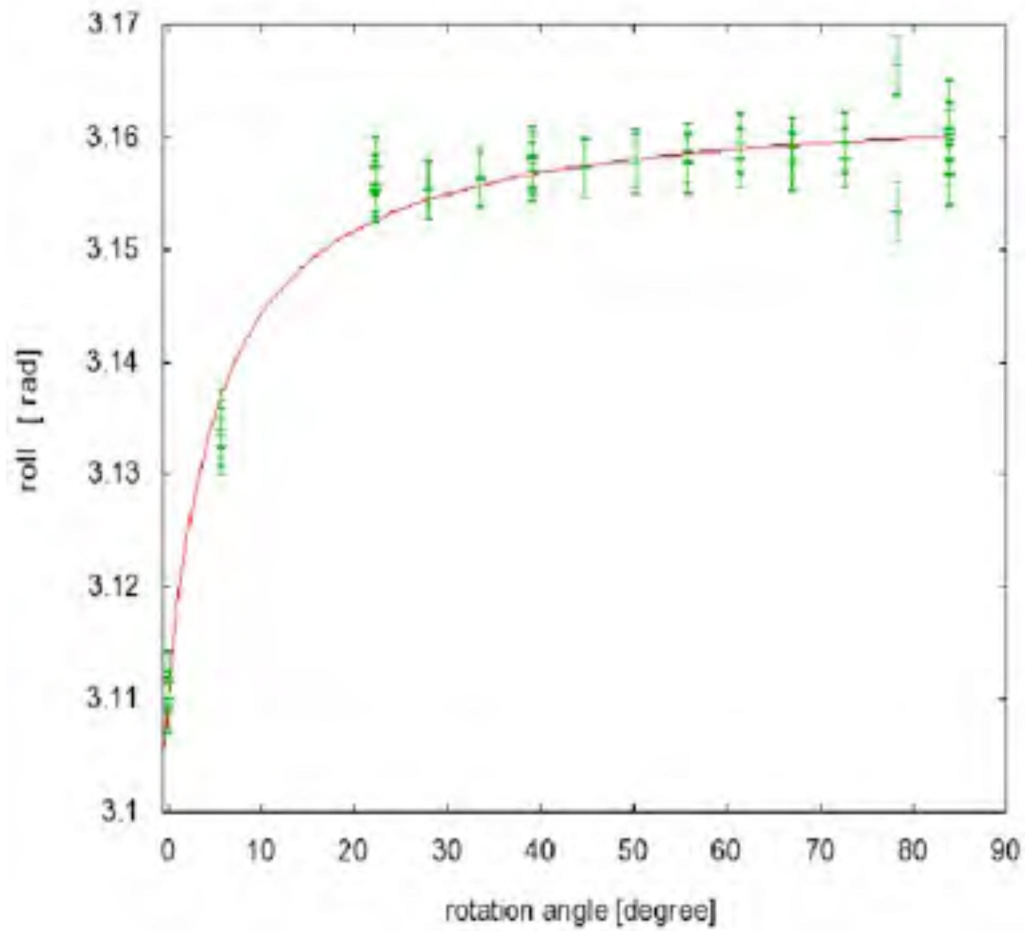
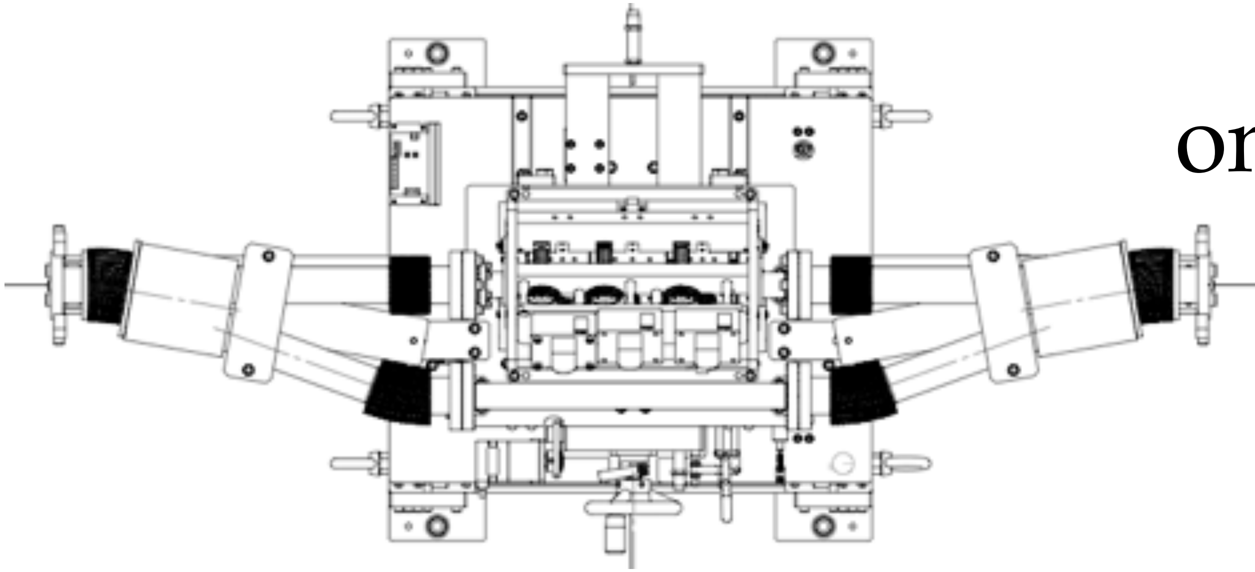
Preliminary Results



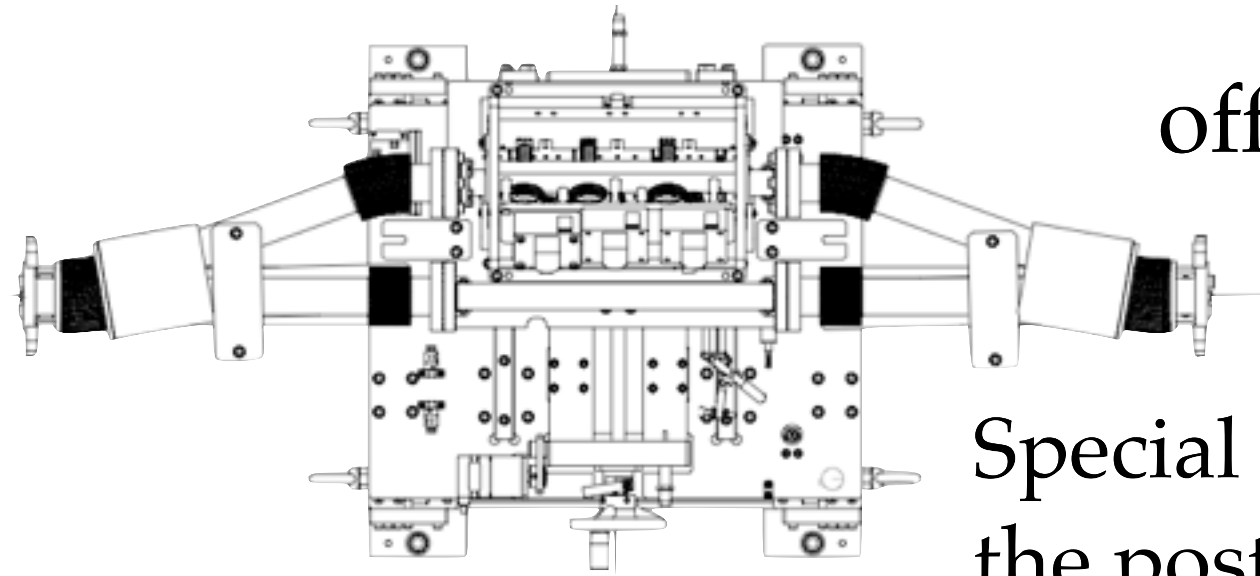


Mover

The push-pull Mover



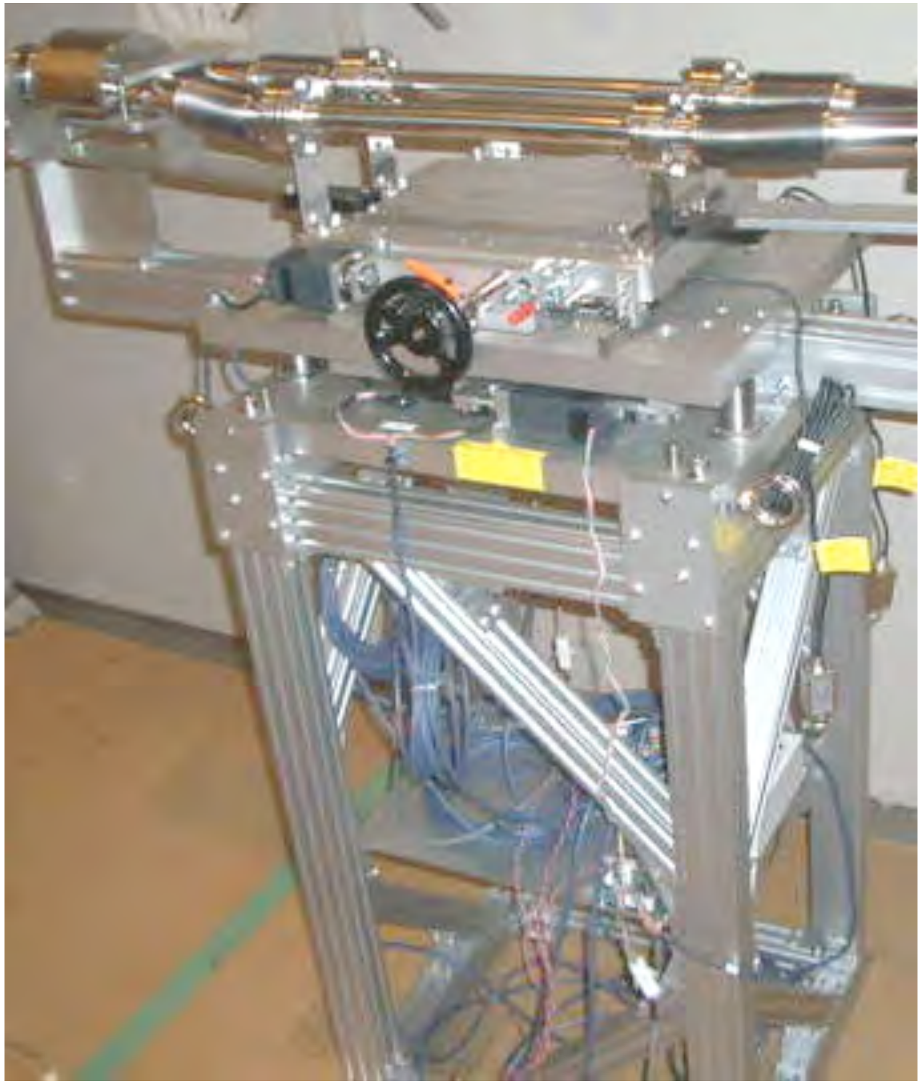
on the Beam line



off the Beam line

Special vacuum flange for the post-fabrication.

Three DOF's

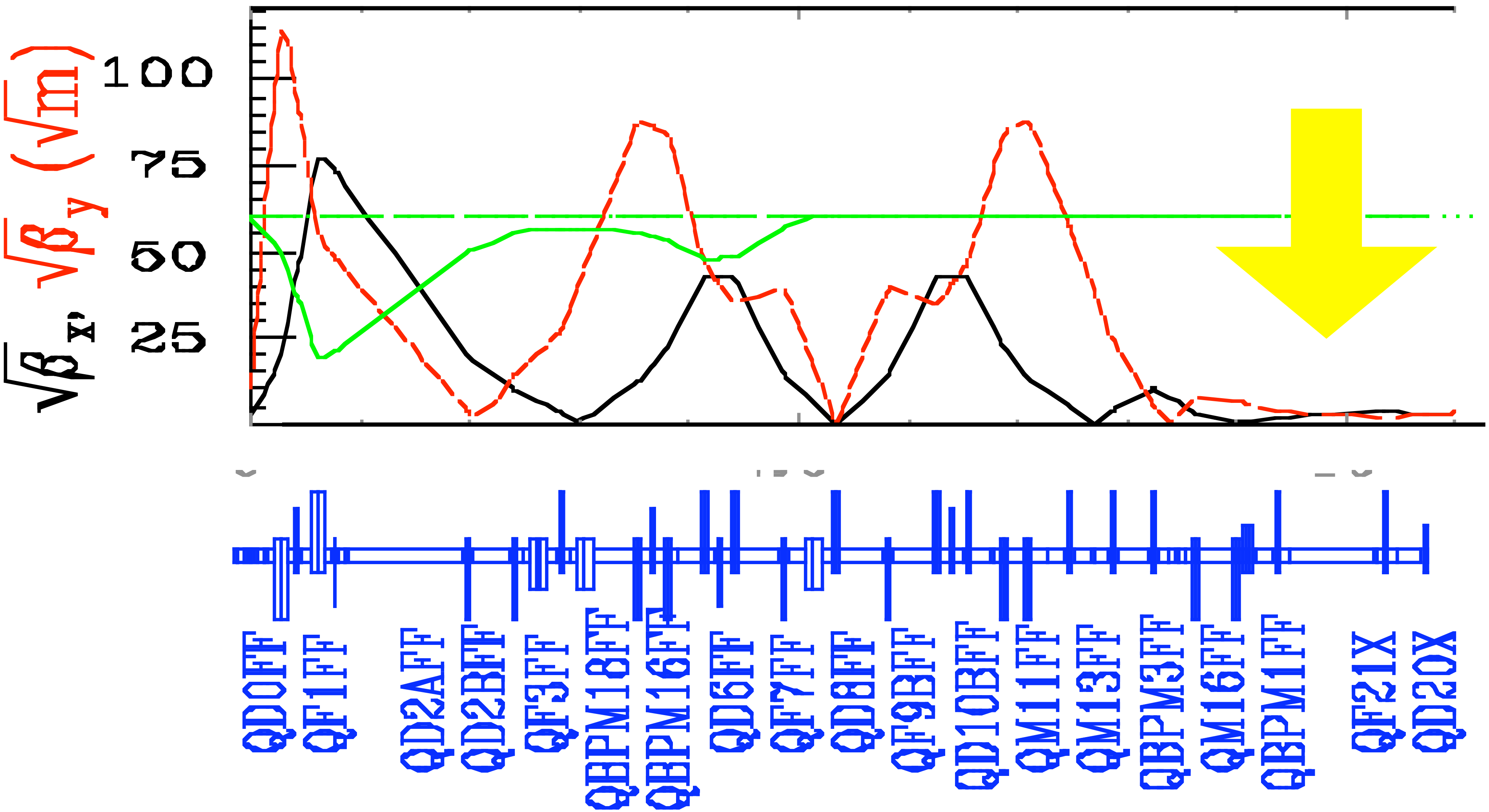


- Up-Down
- Left-Right
- Yawing
  (rotate around axis)

Remote control system delayed (next month?).

Test at ATF2 Beam Line

Optics



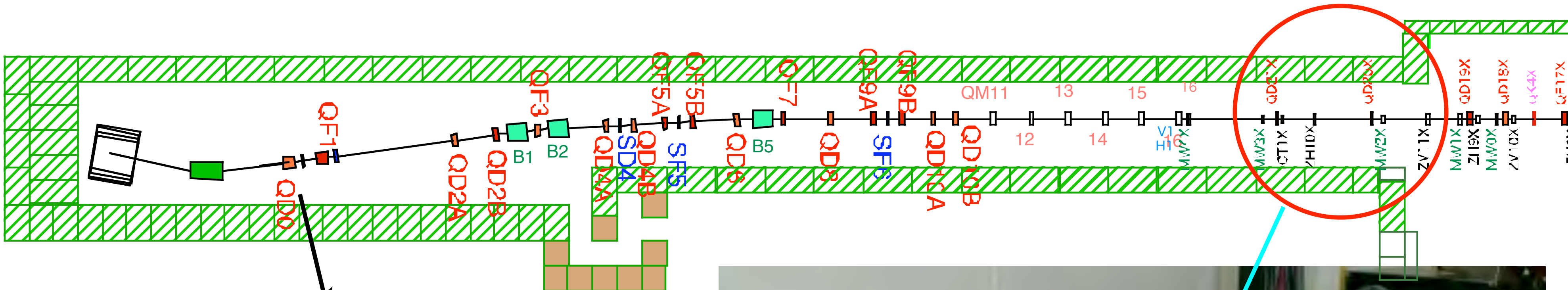
$\sqrt{\beta_x}$, $\sqrt{\beta_y}$ ($\sqrt{m}$)
100
75
50
25
QD0FF
QF1FF
QD2AFF
QD2BFF
QF3FF
QBPM18FF
QBPM16FF
QD6FF
QF7FF
QD8FF
QF9BFF
QD10BFF
QM11FF
QM13FF
QBPM3FF
QM16FF
QBPM1FF
QF21X
QD20X

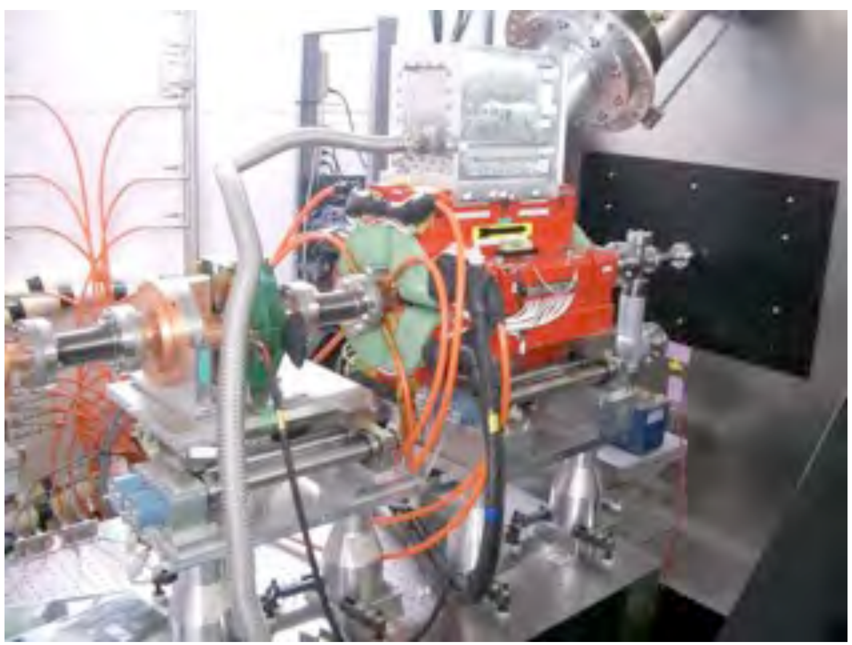
Test at ATF2

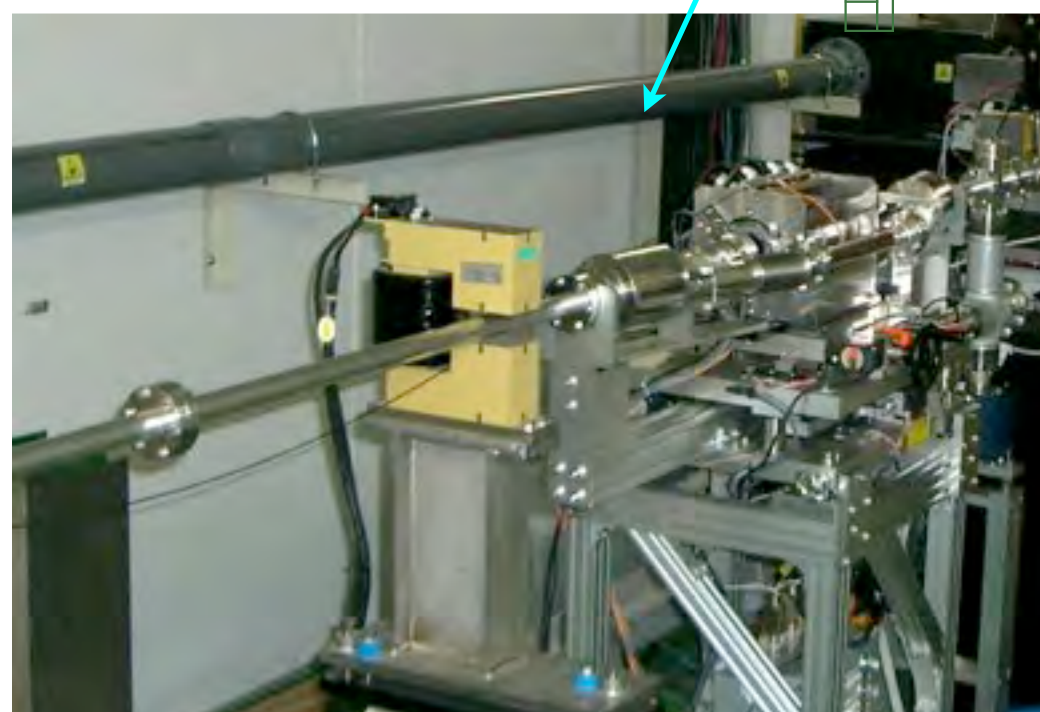
Final Focus System

β matching

Diagnostic







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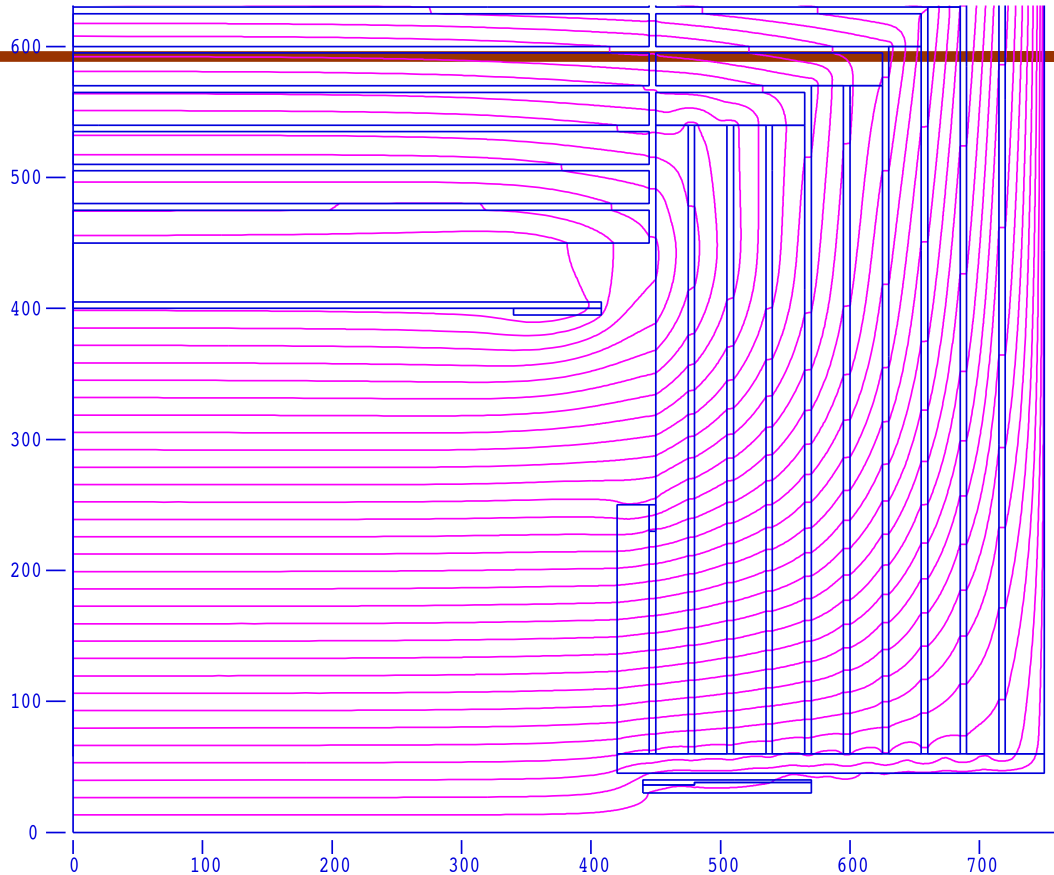
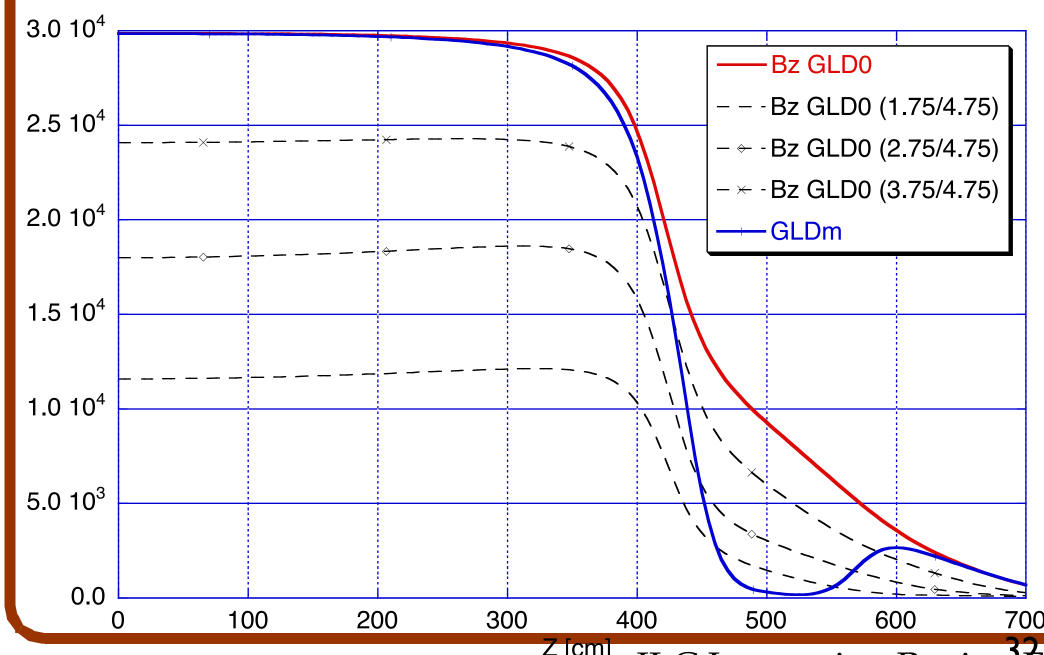
Further test

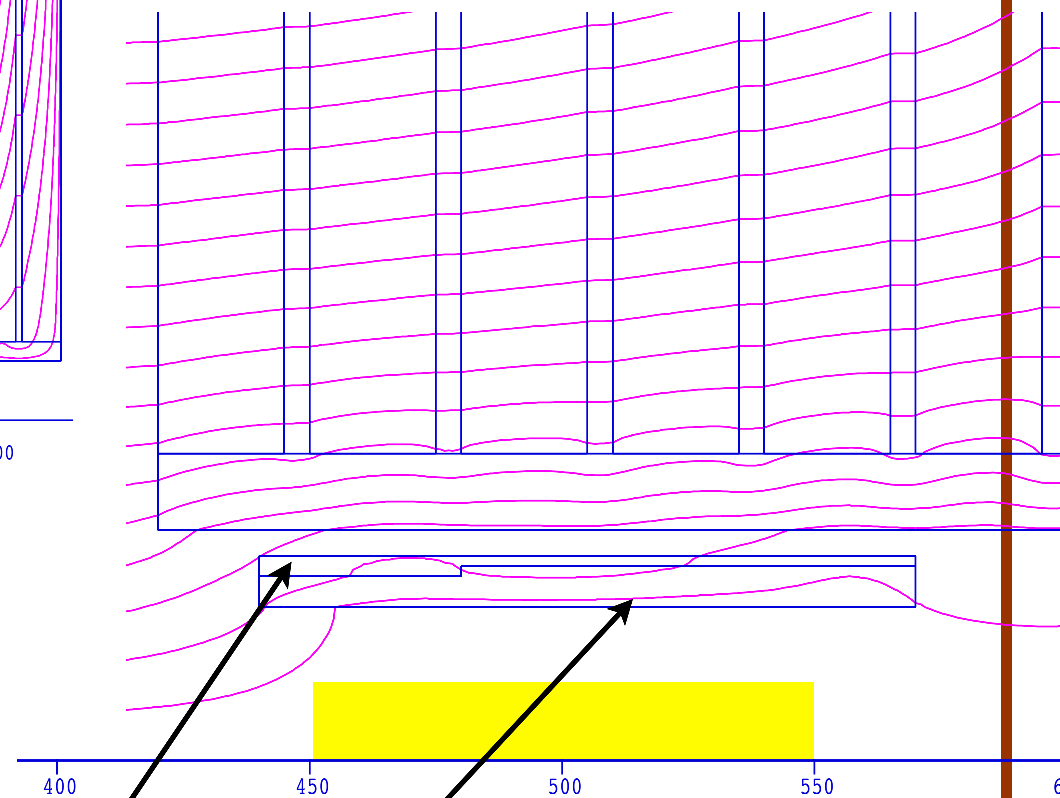
- — Profile (size) by wire scanner
  — Position by BPM
  — (Size by Shintake Monitor downstream)
- Evaluation:
  x-y coupling, high order, stability ,
  Vibration evaluation (<50nm?),
  reproducibility, etc.
- Practical experience:
  handling, installation, stability...
- Comments ?!

http://www-conf.slac.stanford.edu/ireng07/

Magnetic Field around QD0





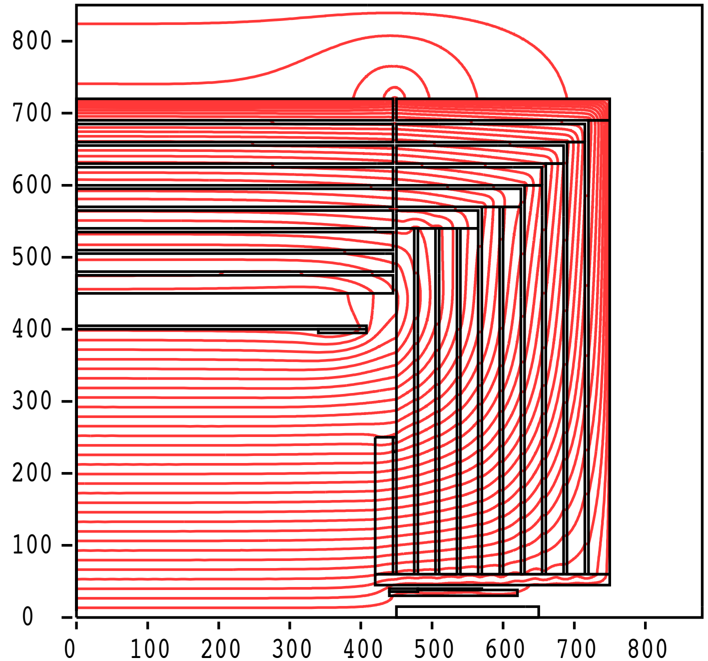


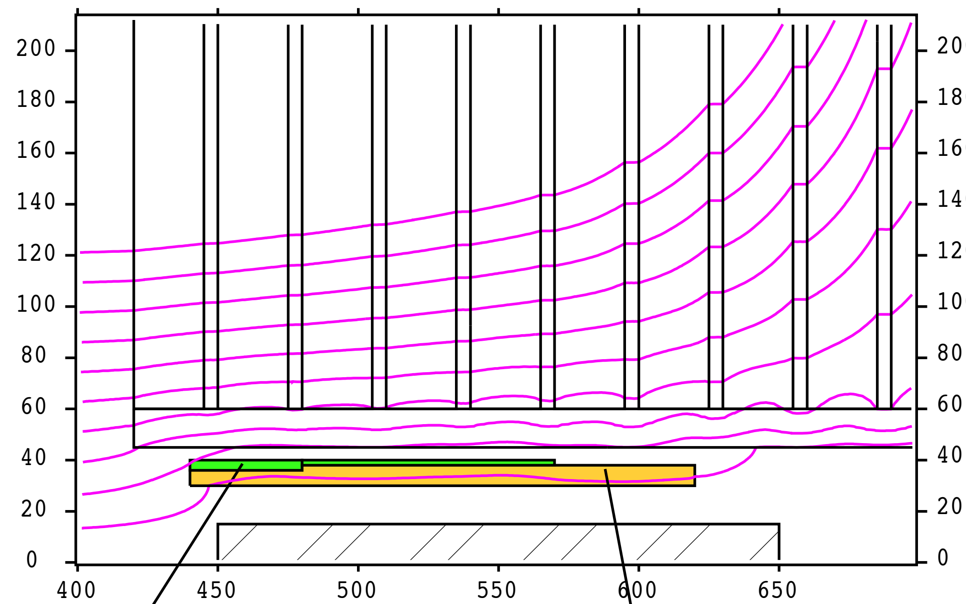
Fe - passive mag. field shield

Antisolenoid: I = 3e4A / cm2

Force cancellation?

Rough Calculation

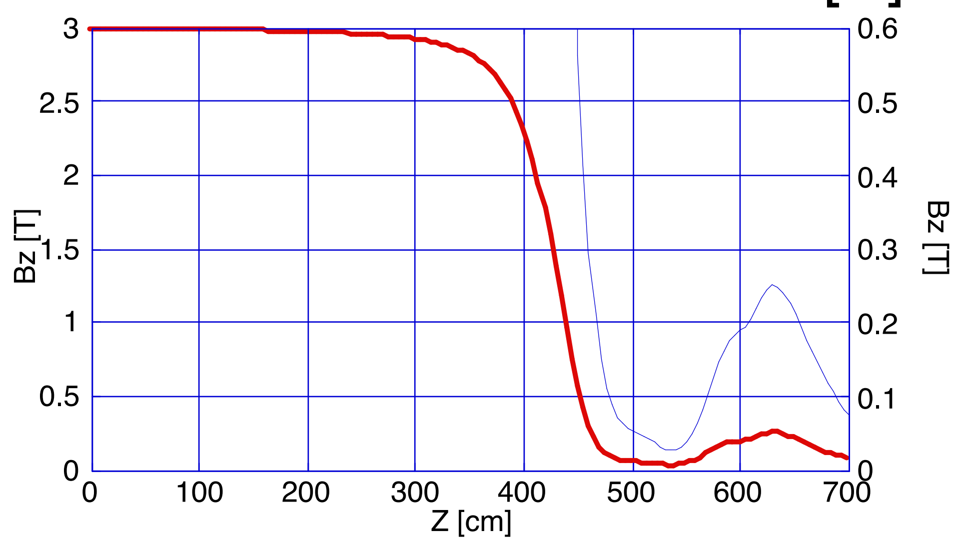




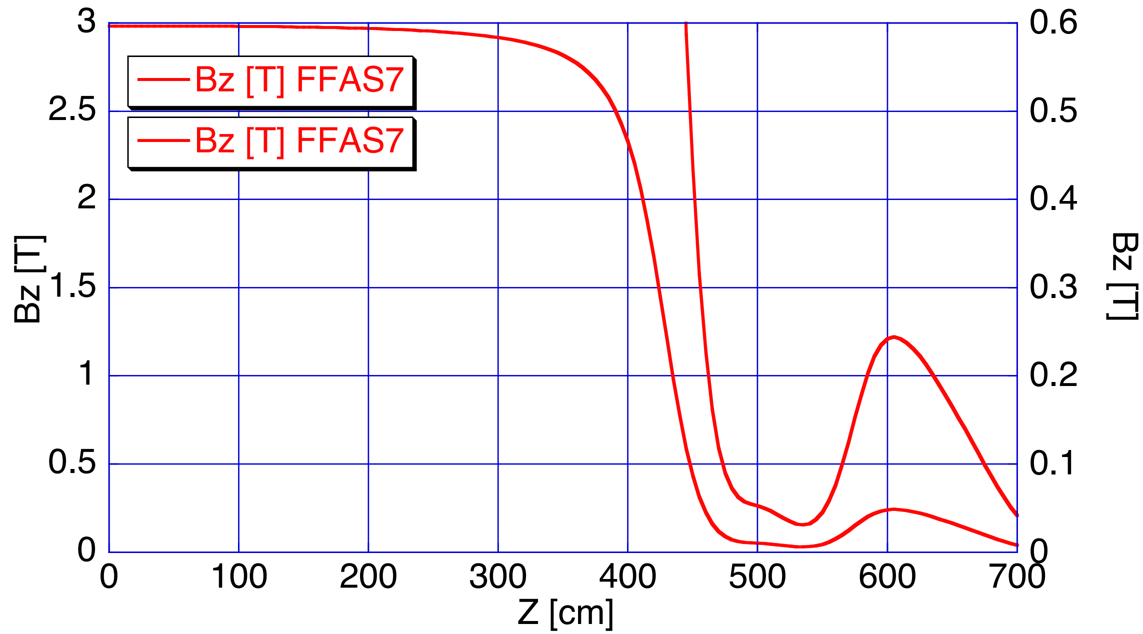
3kA/cm² 2.82E5 -5.31E4 [N]

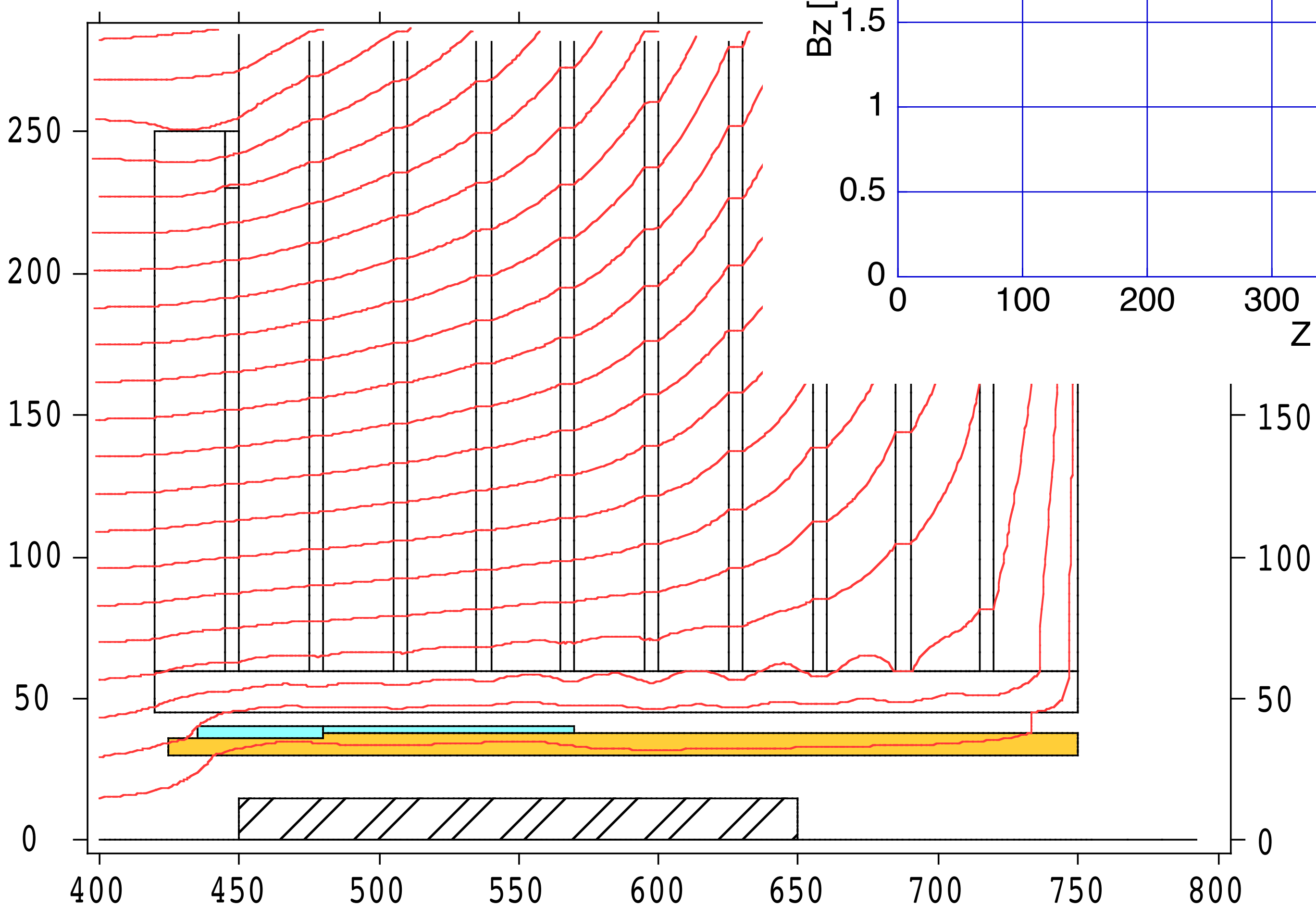
iron shield
-1.08E5 [N]
= 12t

GLDFFAS



Reduced Force Anti-Solenoid





+4.03E5 [N]

-6.07E4 [N]

-3.51E5 [N]

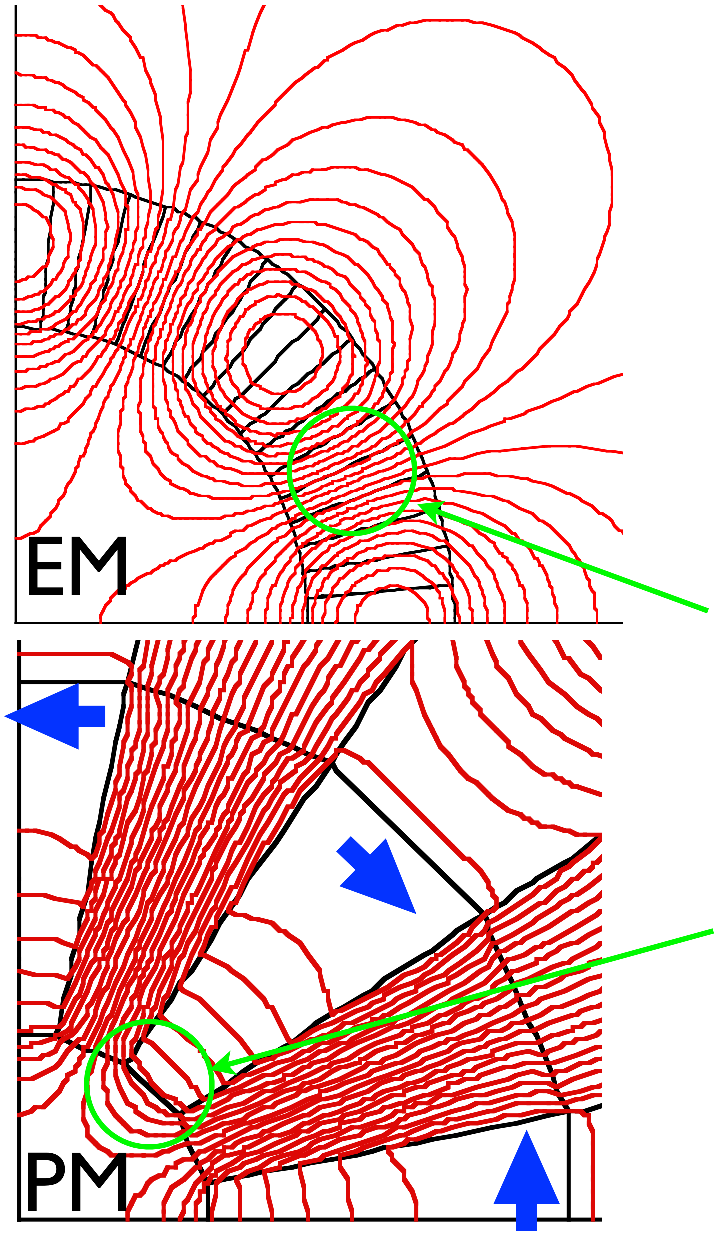
=-0.9t

Remarks

- PMQs' with the DR (double ring) and the FRS (5-ring-singlet) configurations have been developed.
- DR has good stability, but has iron pieces in. (can be affected by external field)
- FRS consists of only magnets and has continuous adjustability.
- Use FRS for near and DR for far region?
- Need different tuning procedure?

Backups

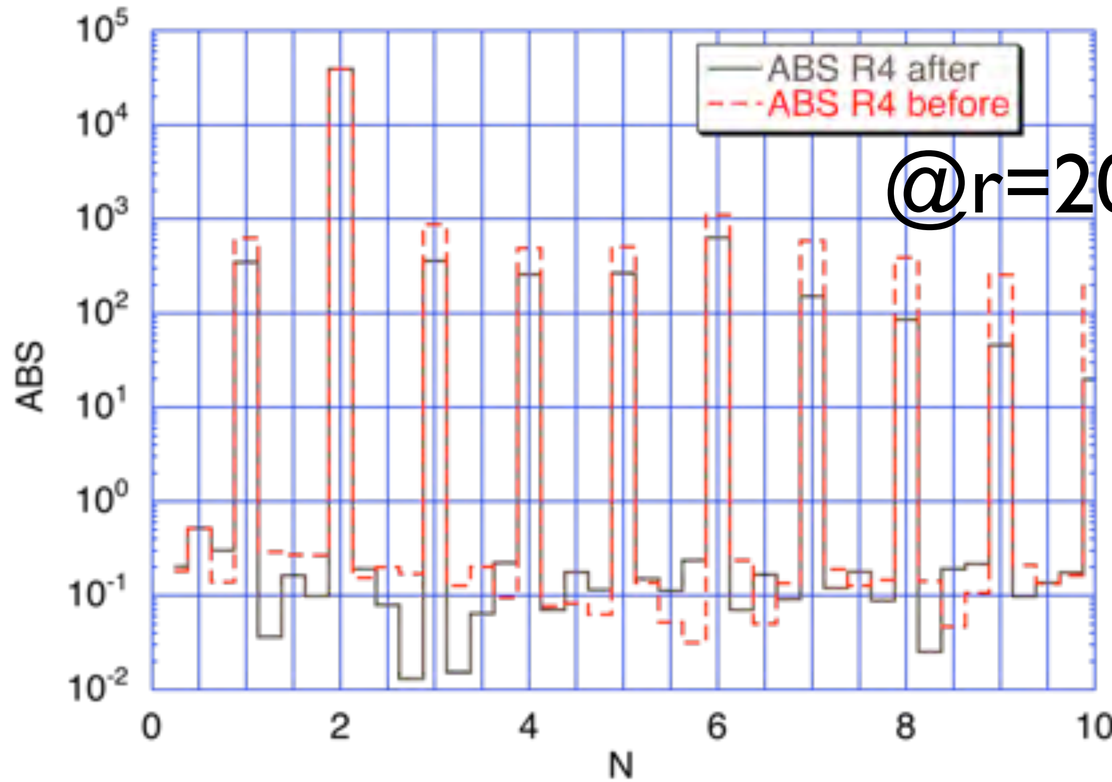
PM can be stronger for multipoles



- B increase rapidly for 2n-poles: $\sim r^{n-1}$ (n=4 for octupole)
- Max B appears beyond the bore radius for EM's.
- Max reverse B at the bore radius for PM's.

Measurement on each PMQ

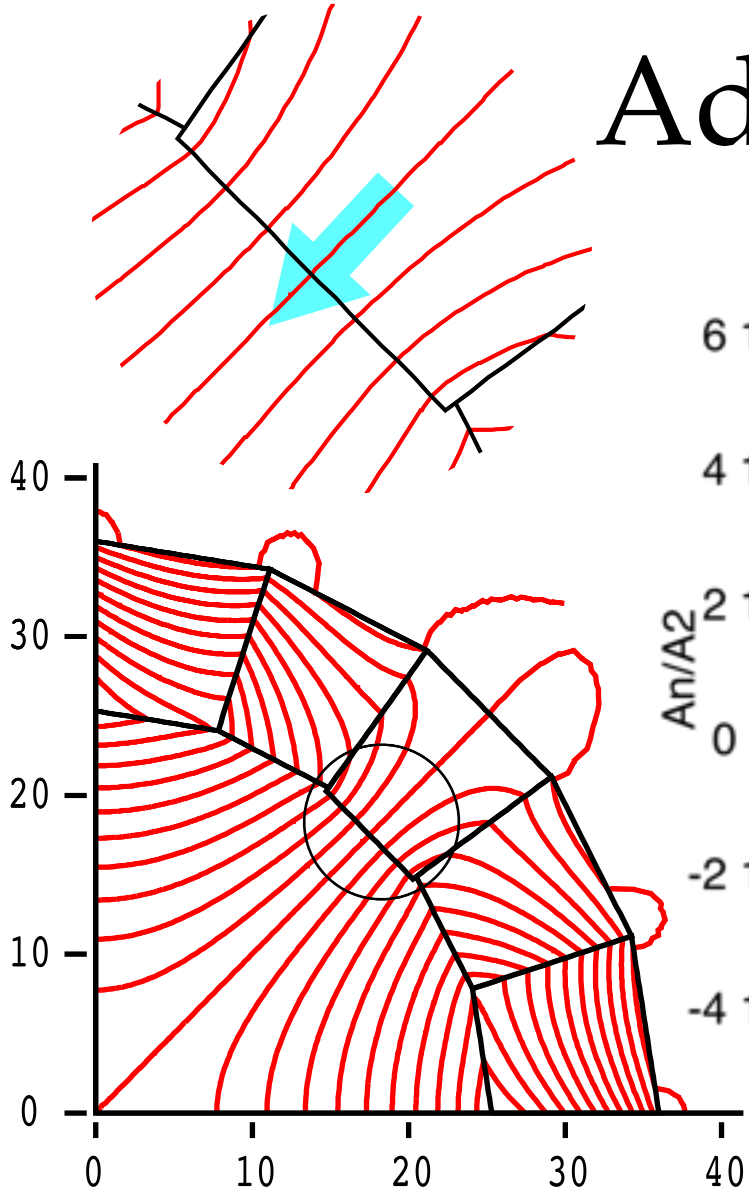
Just before and after a wrong magnet piece replacement

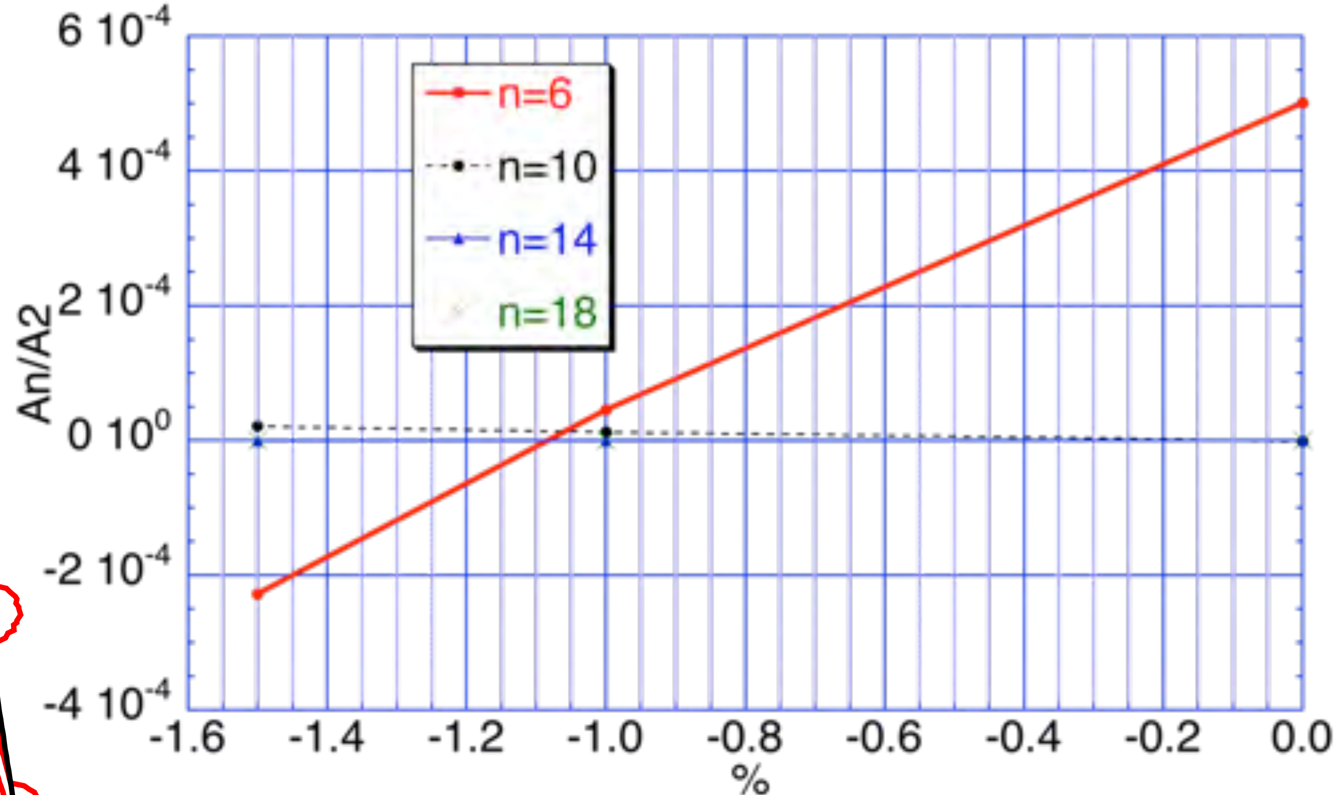


@r=20mm

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

Adjusting n=6

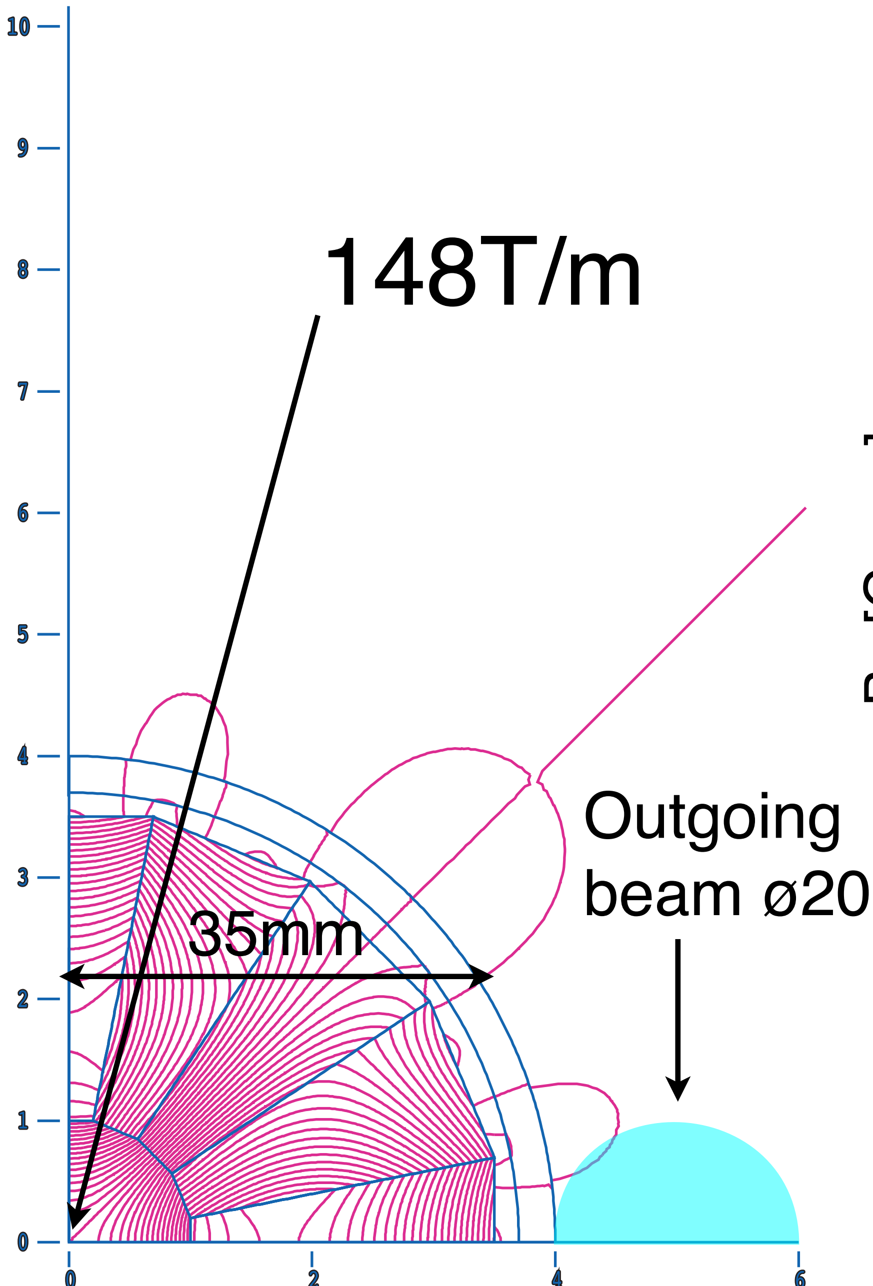


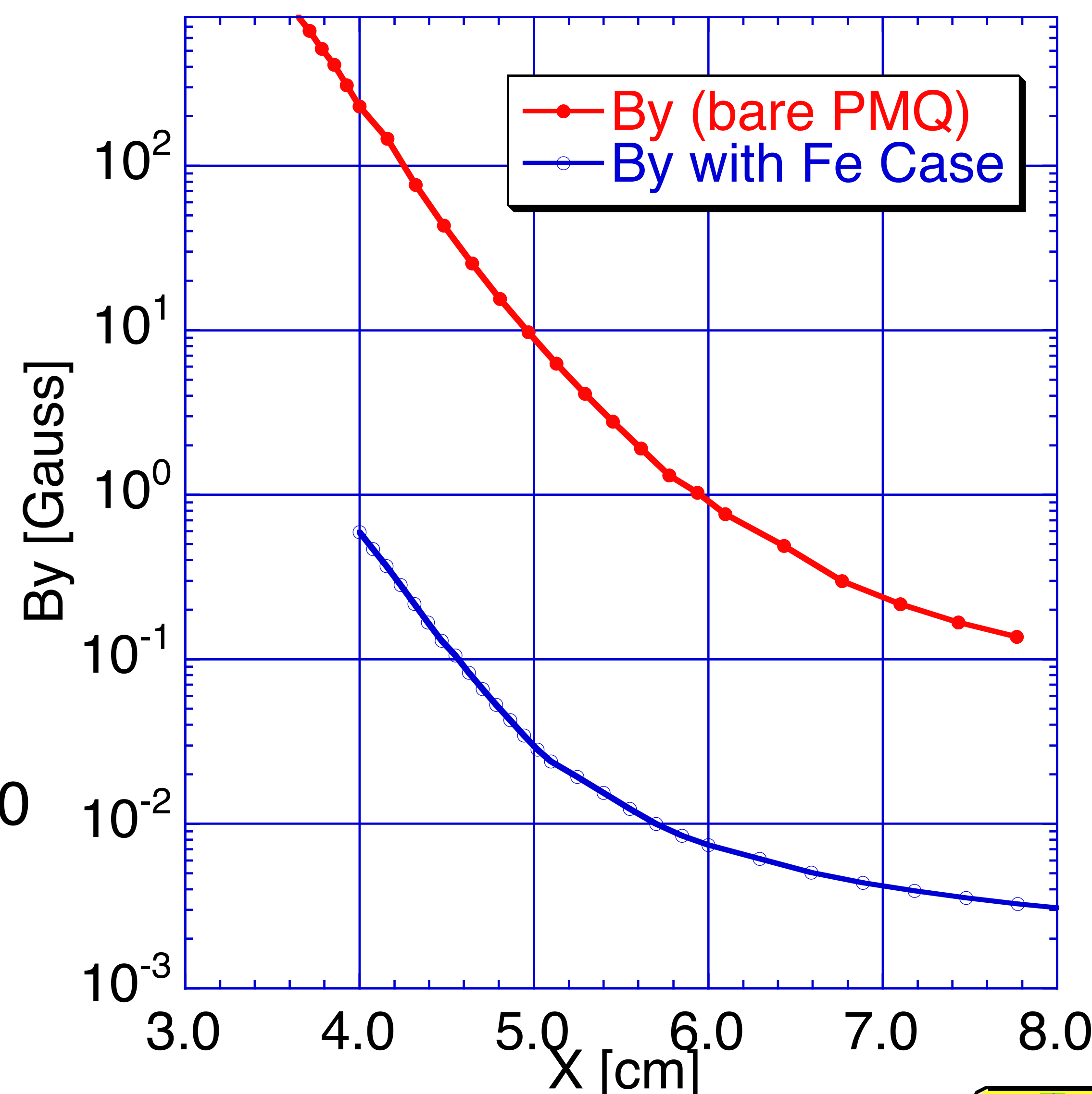


Displacing magnet pieces at pole positions (4 out of 20).

r=25mm -> 24.7mm

External Stray Field





Tolerances

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

★Rotation Error

➡ see table

★Length Error

➡ <100μm

★Position Error

➡ No effect on beam size.

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

Disc	Length[mm]	Tolerance [rad]
1st	17.33	$< 2.2\times10^{-4}$
2nd	55.00	$< 7.0\times10^{-5}$
3rd	75.34	$< 5.3\times10^{-5}$
4th	55.00	$< 7.6\times10^{-5}$
5th	17.33	$< 2.5\times10^{-4}$

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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.(2.6x10^{6}s) operation may cause about 0.01[%] of (reversible?) demagnetization on NEOMAX 32EH.
(1% for 10 years) ... needs more info.

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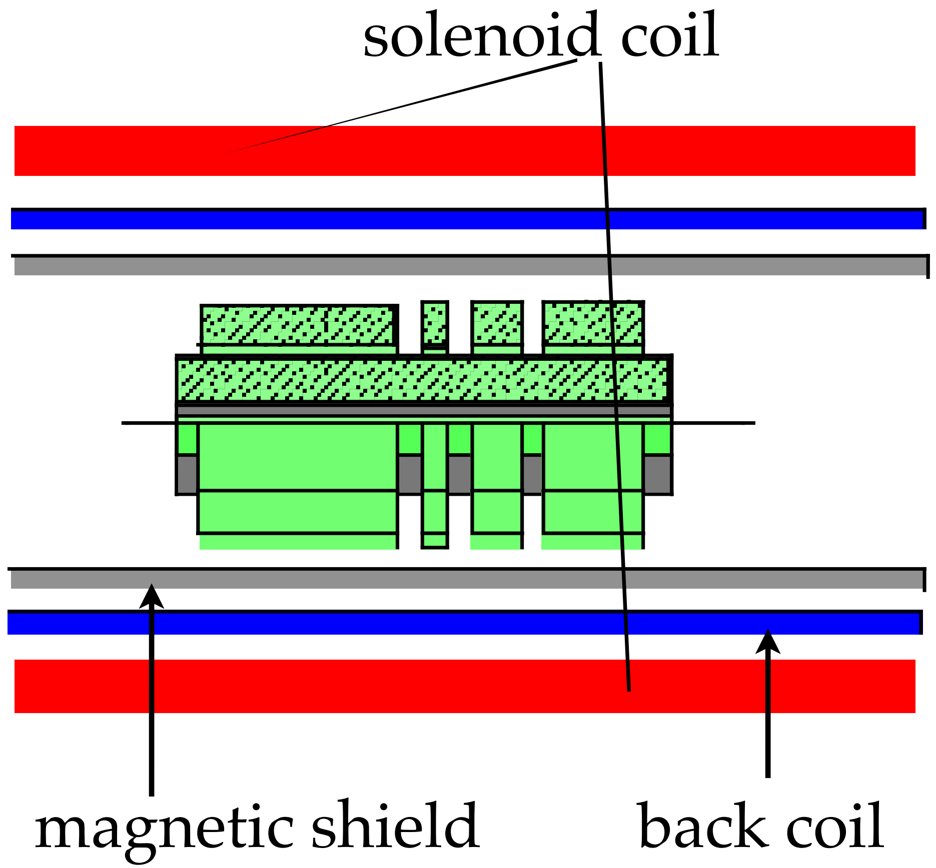
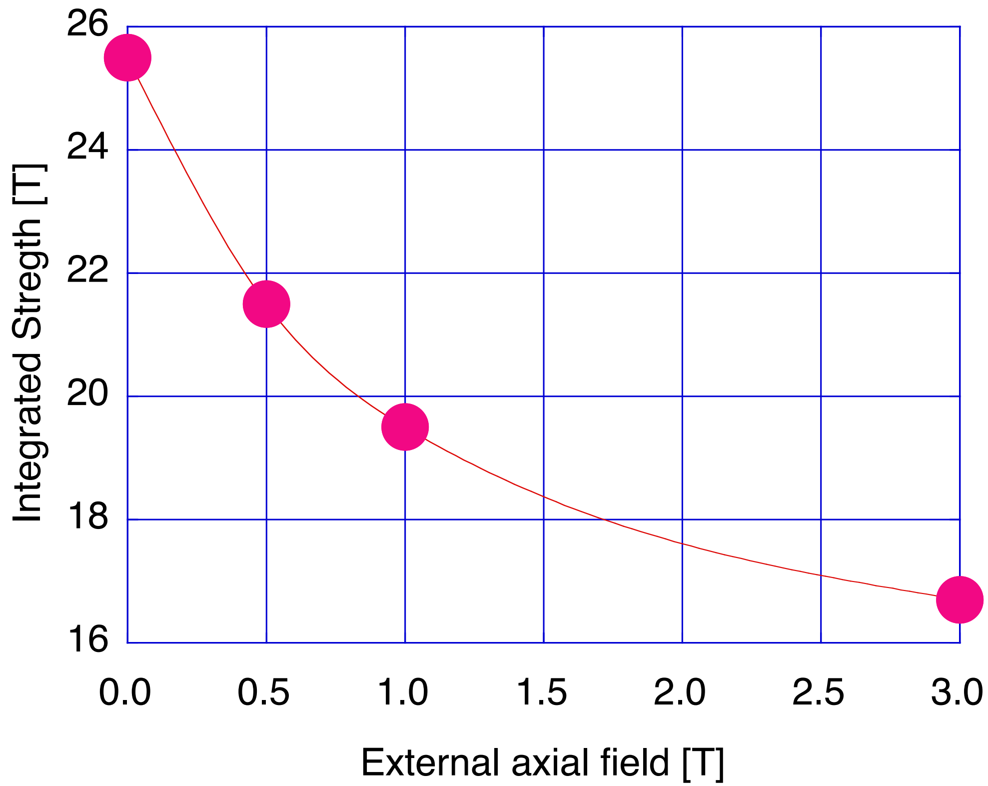
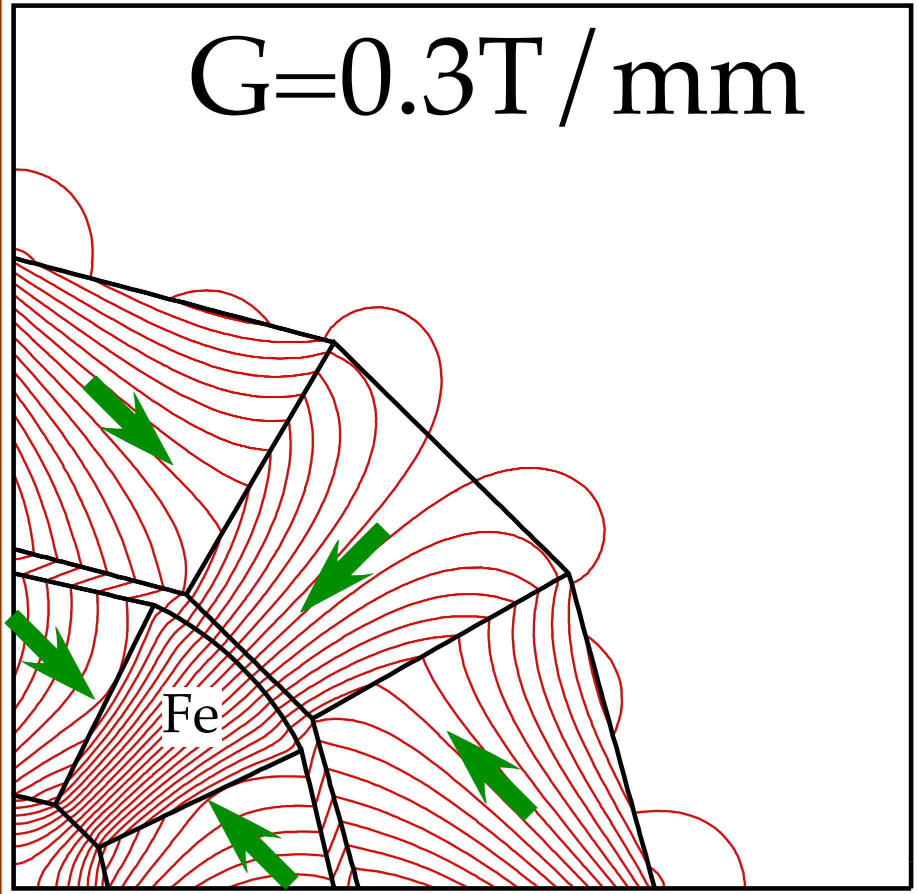
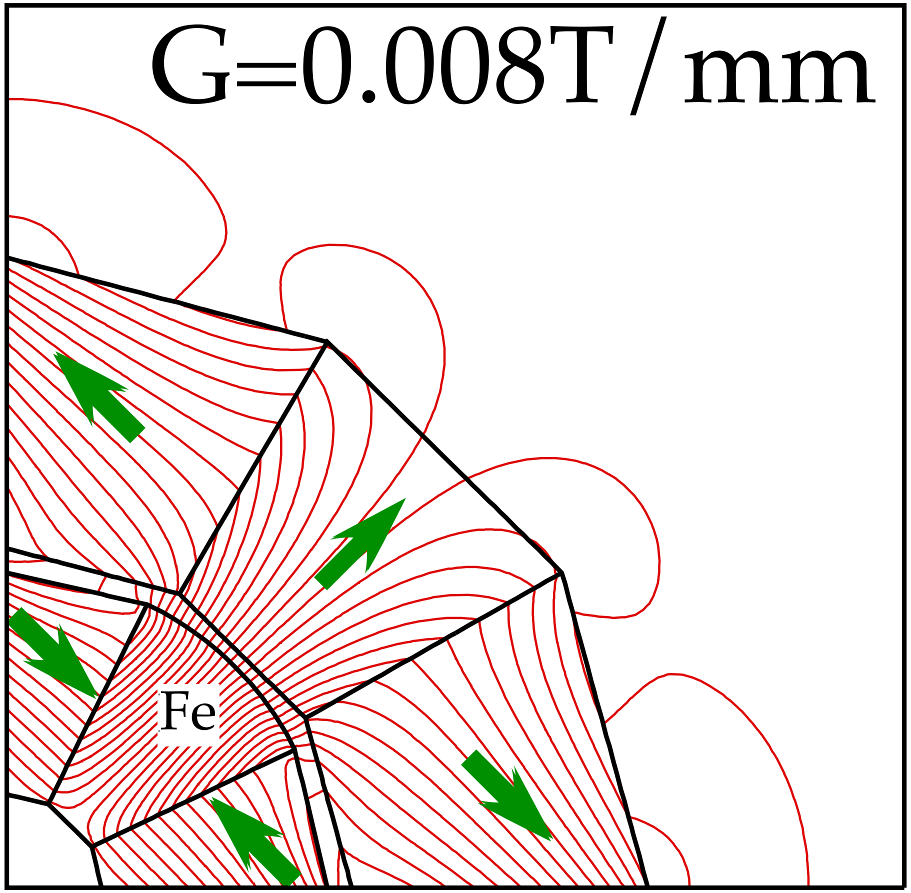
Effect of External Field





Integrated strength is reduced by Solenoid field because PMQ has pole (Vanadium Permendur). Back coil and/or some shield is needed.


G=0.3T / mm
Fe


G=0.008T / mm
Fe