Design of DC septum magnets based on measurements and 3D calculation of an R&D septum magnet for Rapid Cycle Synchrotron of J-PARC

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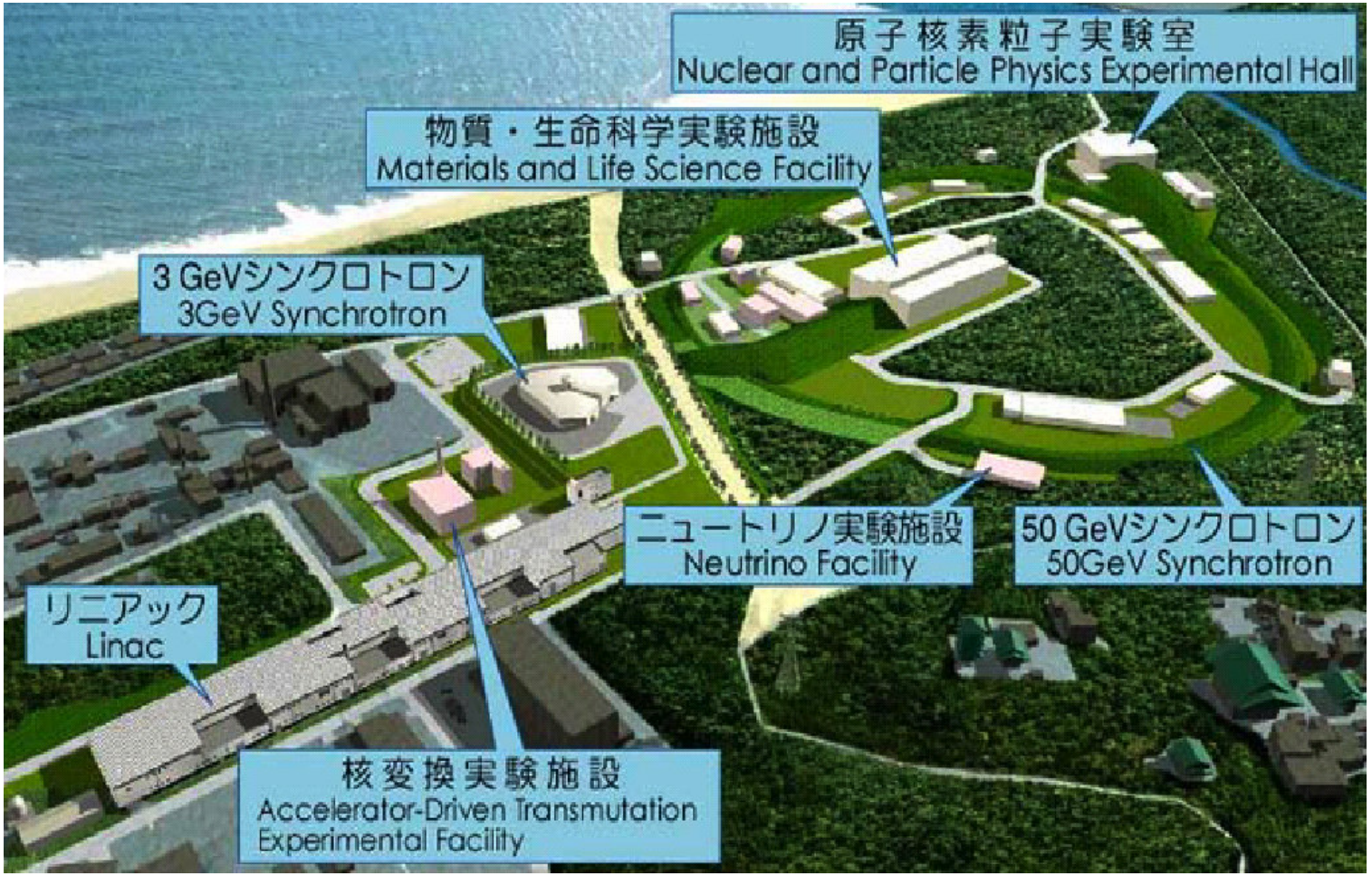
Outline

- J-PARC overview
- RCS and the septum magnets overview
- Comparison of measurements and 3D calculation of an R&D septum magnet
- 3D calculation of RCS septum magnets

Overview of J-PARC



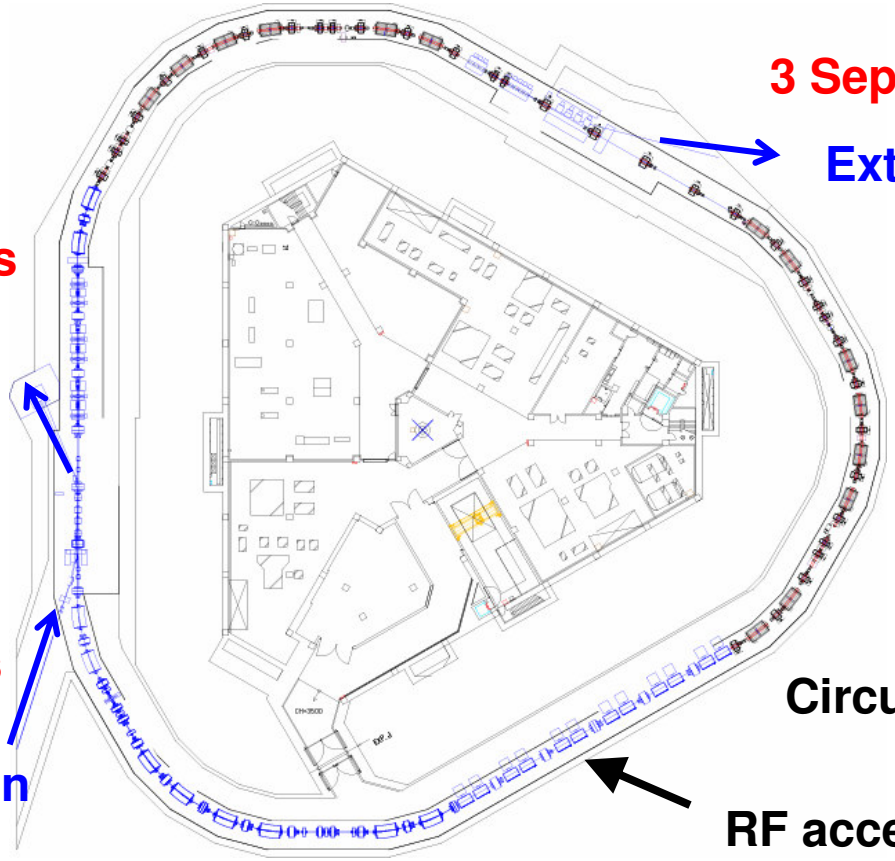
Main Parameters

J-PARC RCS

Circumference	348.333 m
Injection Energy	**181MeV (400MeV)**
Extraction Energy	3.0 GeV
Beam Power	1MW
Particle Per Pulse	8.3×10^{13}
Repetition Rate	25 Hz
Harmonic Number	2
Average Current	333 μA
Circulating Current at extraction	11.1 A
Super Periodicity	3
Unit Module	3-Cell Straight + 3-Cell FODO x2module arc

Nominal tune (x/y)	6.72 / 6.35
Natural Chromaticity (x/y)	-8.5 / -8.8
Transition Gamma	9.14
Momentum Compaction	0.012
Transverse Emittance **(at injection)**	4 p mm-mrad
Painting Emittance	216 p mm-mrad
Extraction Emittance to MLF	81p mm-mrad
Extraction Emittance to MR	54p mm-mrad
Collimation Emittance	324 p mm-mrad
Physical Aperture	>486 p mm-mrad
Longitudinal Emittance (Inj./Ext.)	3.5 / 5 eV s
Tune Shift at injection	-0.20

RCS and Septum magnets



3 Septum magnets

Extraction

3 GeV
(Bρ=12.8Tm)

2 Septum magnets

Dump

2 Septum magnets

Circumference: 348m

181 MeV
(Bρ=2.03Tm)

Injection

RF acceleration

Septum magnets of RCS are required for

- 7 Septum magnets [2(injetion) 、3(extaction)、2(dump)],
- large aperture for low losses of high intensity beam (1 MW),
- high durability to minimize the maintenance after the high activation.

Design parameters of septum magnets

		Injection		Dump		Extraction			
	Unit	SEPI-1	SEPI-2	SEPD-1	SEPD-2	SEPE-1	SEPE-2	SEPE-3	R&D(SEPE-3)
number of magnets		1	1	1	1	1	1	1	1
max. field	T	0.487	0.439	0.501	1.086	0.695	1.402	1.659	1.13
effective length	mm	1400	800	1000	1000	900	1000	1000	1000
gap width	mm	370	348	368	622	336	521	743	760
gap height	mm	136	136	136	140	223	189	166	142
wave form		DC							
environment		Air (not in vacuum)							
septum thickness	mm	87	45	51	340	34	90	260	185
material of core		Electromagnetic soft iron (JIS SUYP-1; block)							
excitation current	A	6246	5650	6787	5603	11176	12312	11035	12800(MAX)
turn number of coils	turn	8	8	8	24	10	16	20	10
max. voltage of coil	V	20	14	19	53	33	28	17	10
cooling of coils		Water							

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- J-PARC overview
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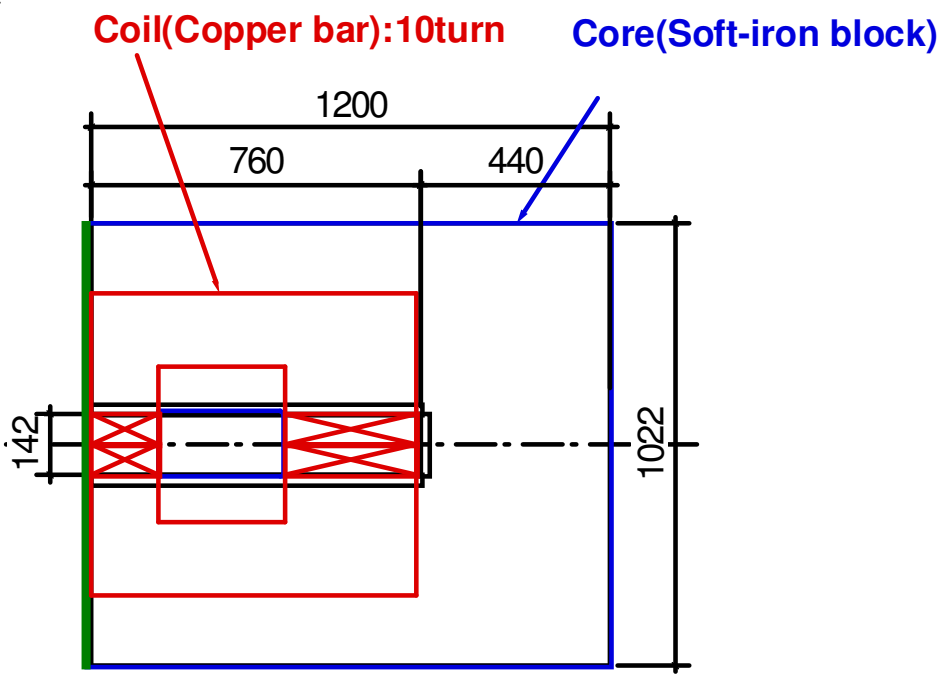
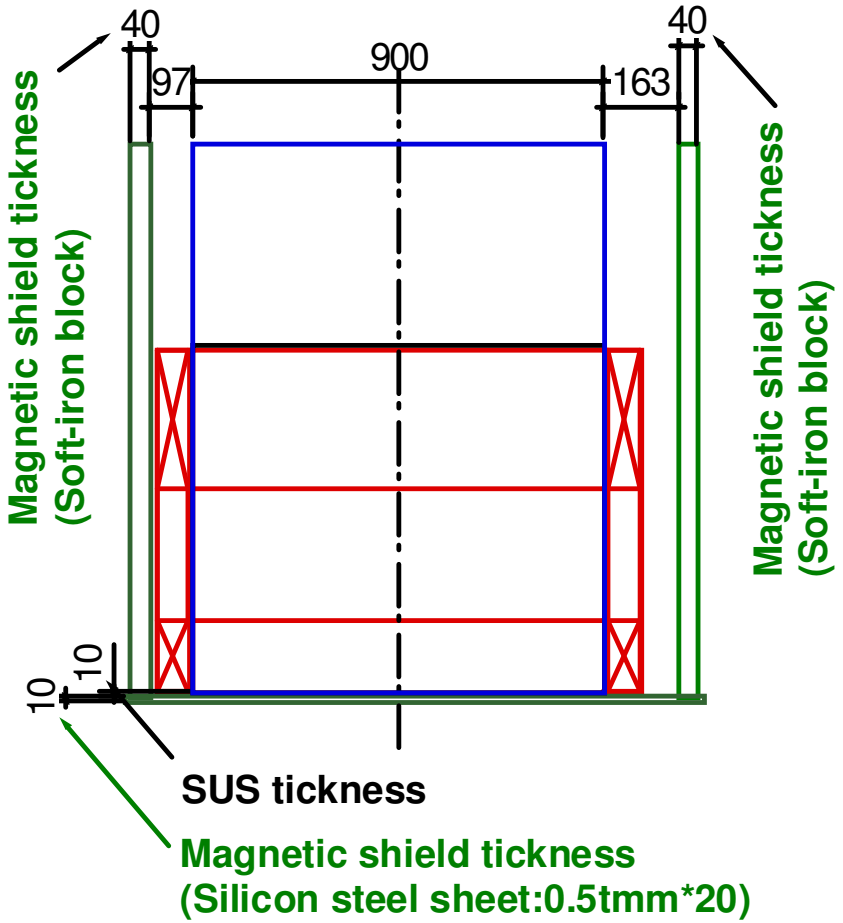
- **Comparison of measurements and 3D calculation of an R&D septum magnet**
- 3D calculation of RCS septum magnets

Schematic diagram of the R&D septum magnet

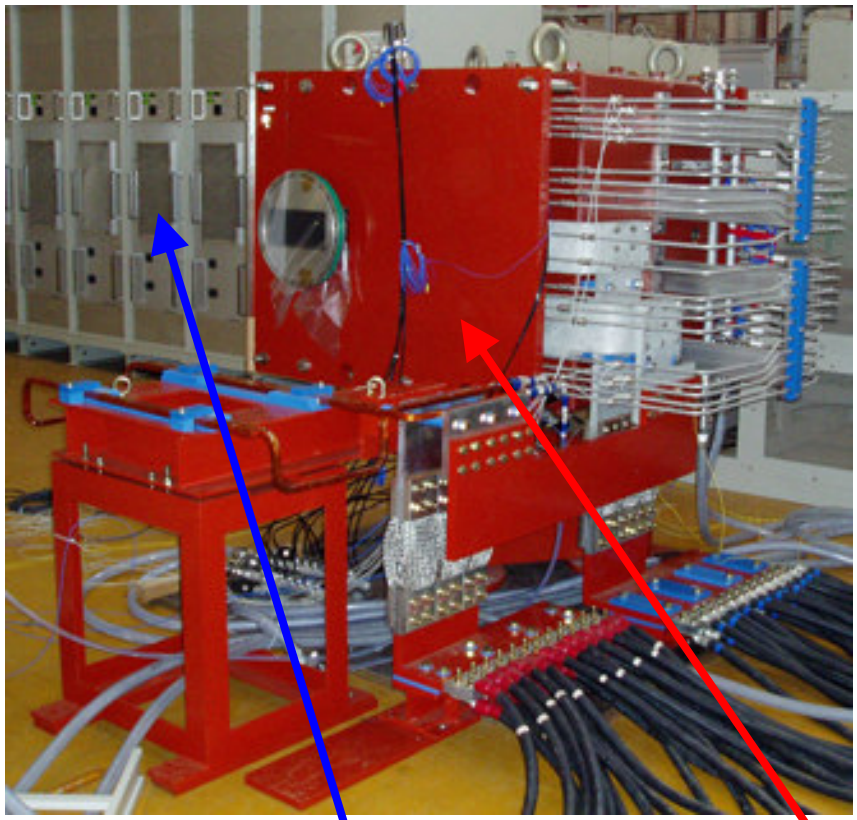


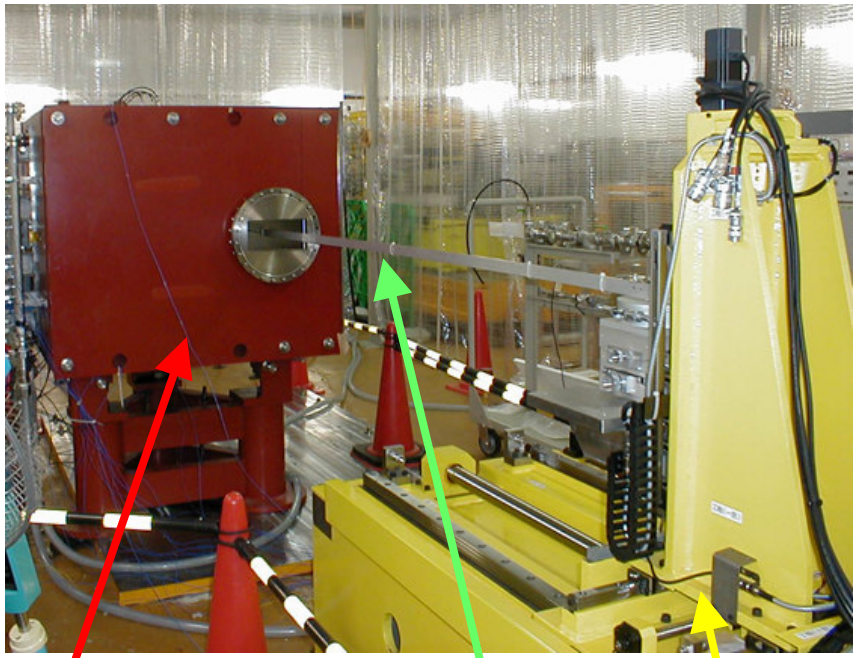
Side view (without edge shield)



Upper view

Photographs of the septum magnet and the measurement





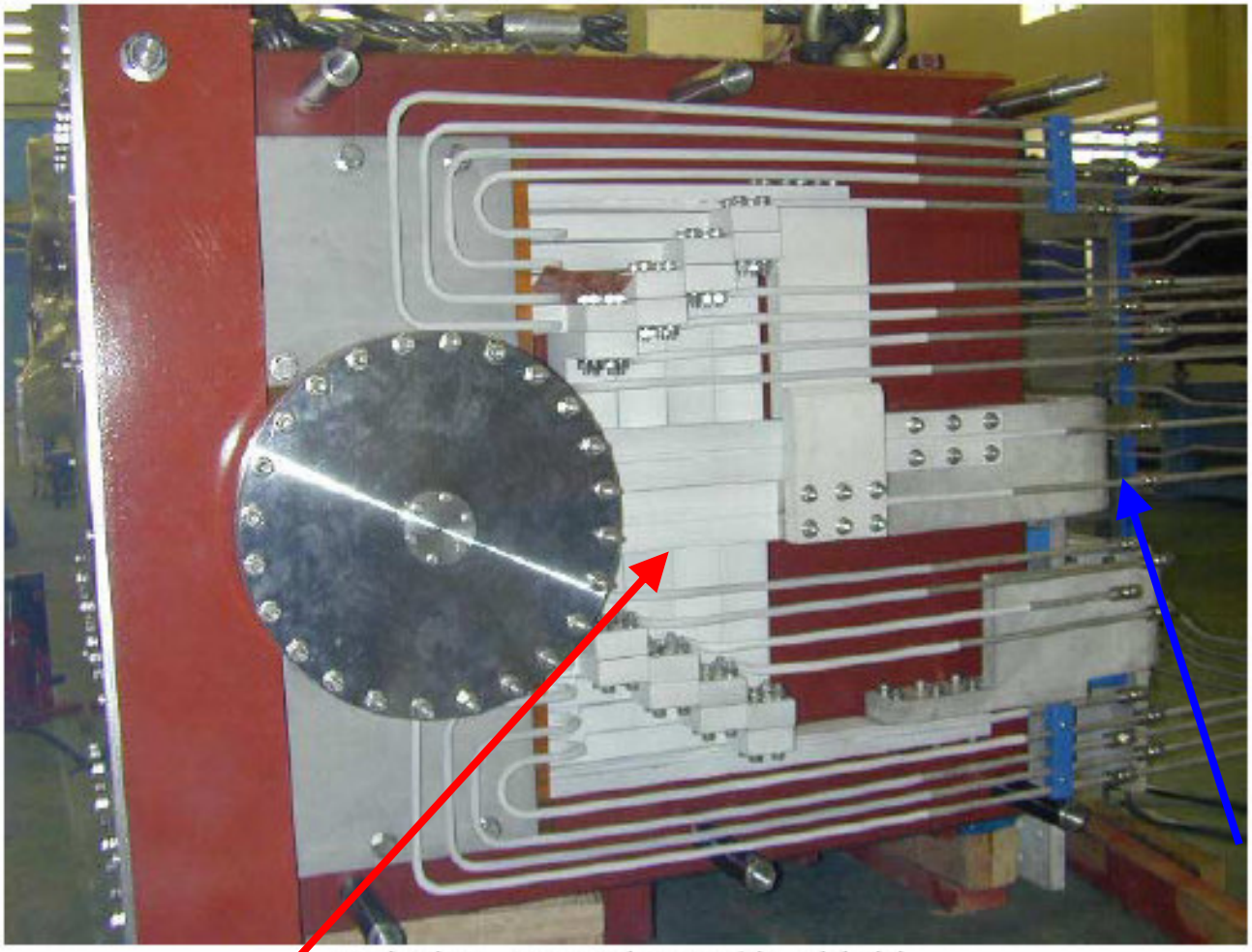
DC power supply

Septum magnet

Hall device probe

3D stage

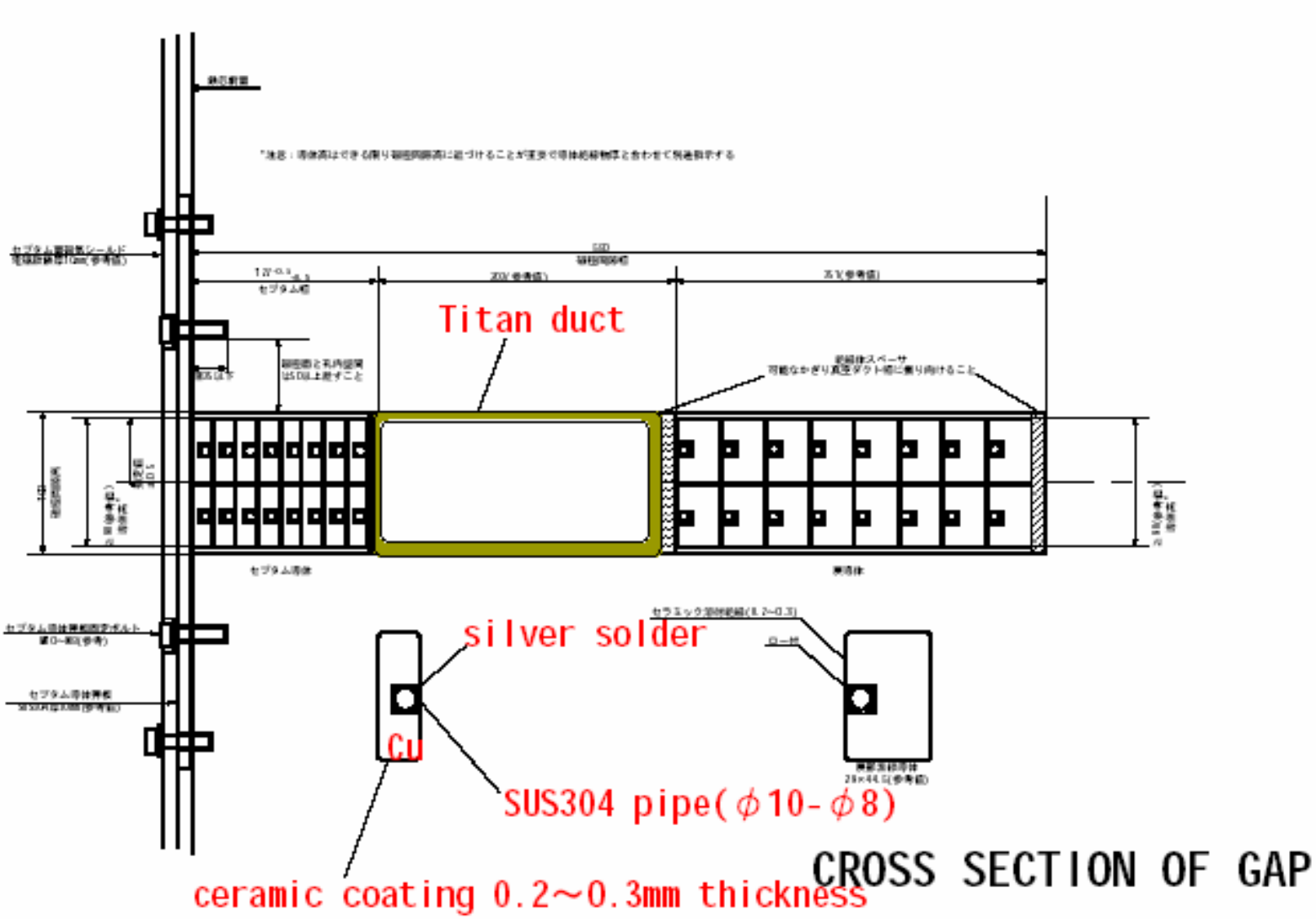
Photograph of the coil inside the shield



end view, removed magnetic shield

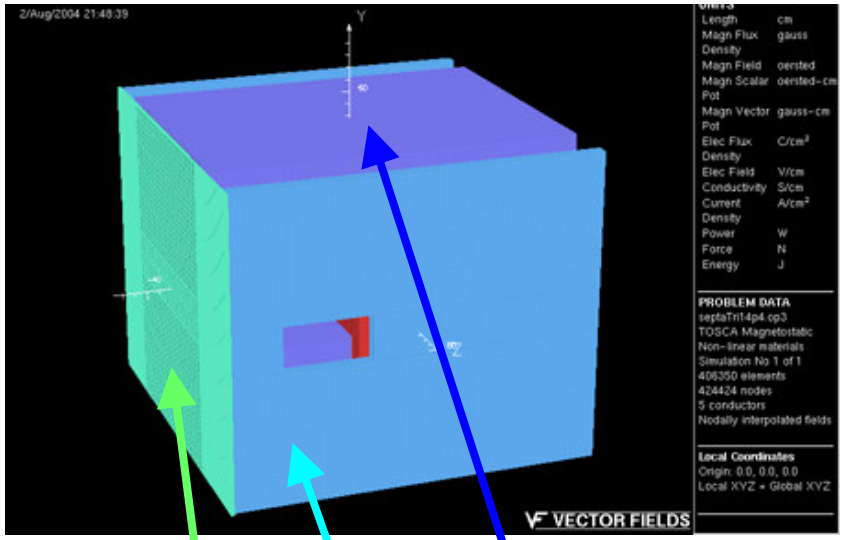
Ceramic is employed against the high radiation for the electronic insulation of the coils.

Schematic diagram of cross section of the gap



OPERA3D model (1/2 model)

Whole view

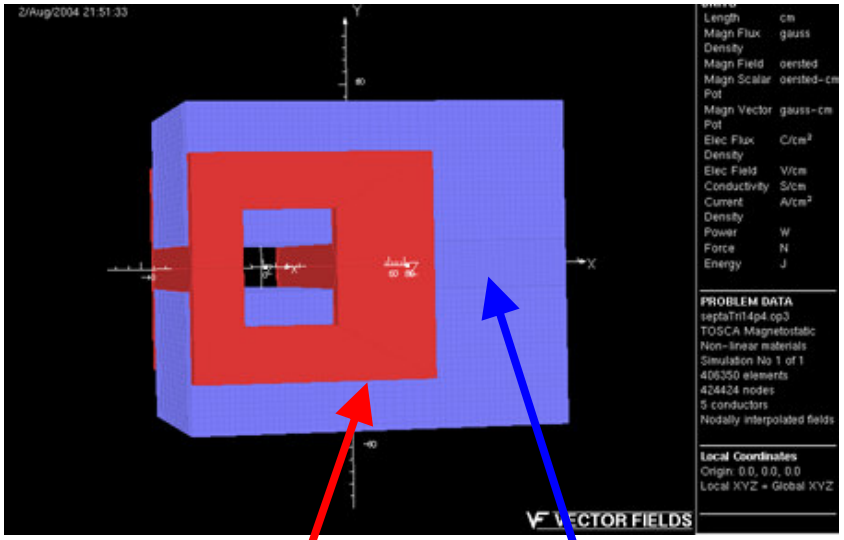


Core (soft-iron)

Magnetic Shield (soft-iron)

Magnetic Shield (Silicon steel)

Core and coil

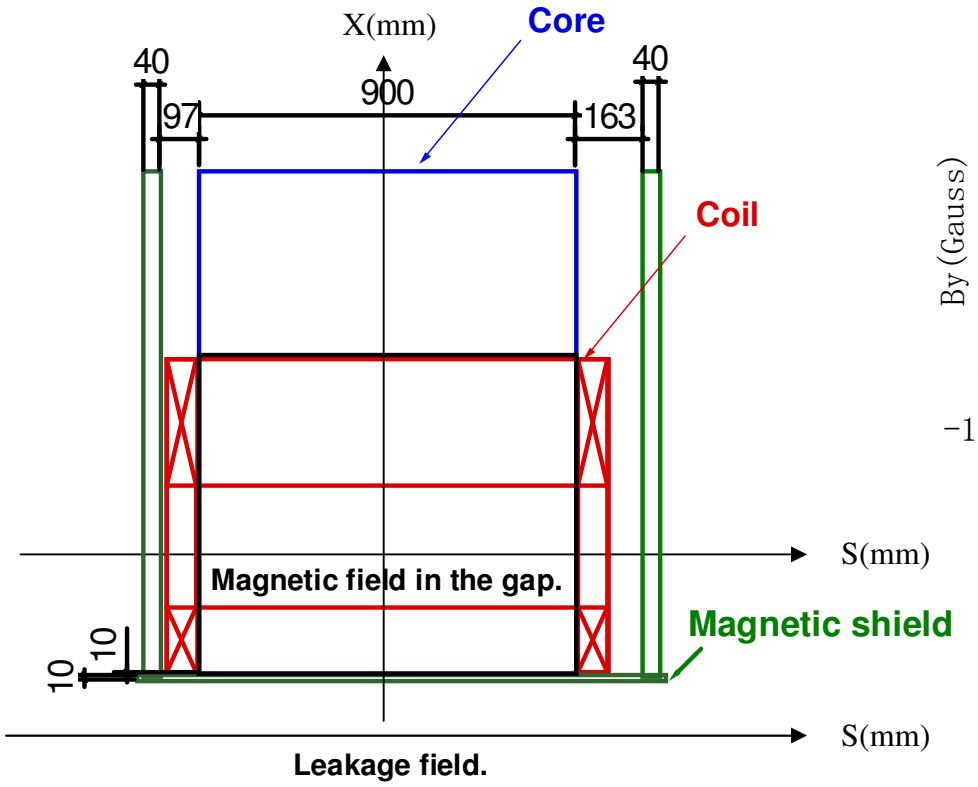


Core (soft-iron)

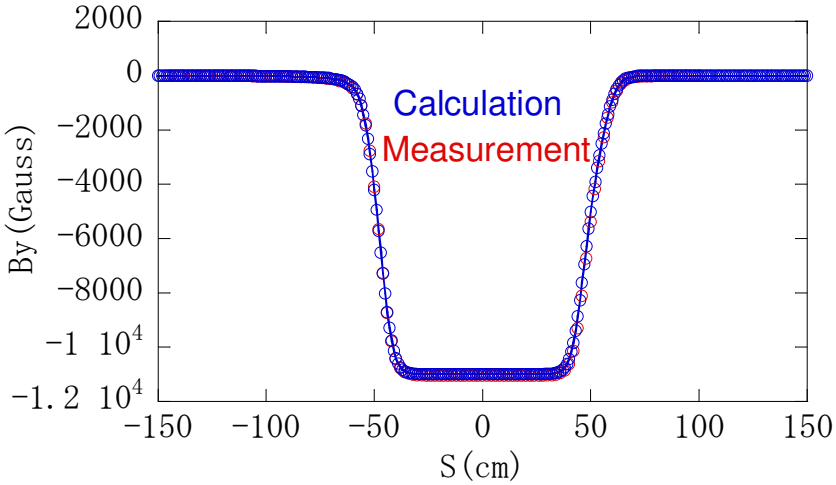
Coil (2 turns)

Comparison of measurements and 3D calculation

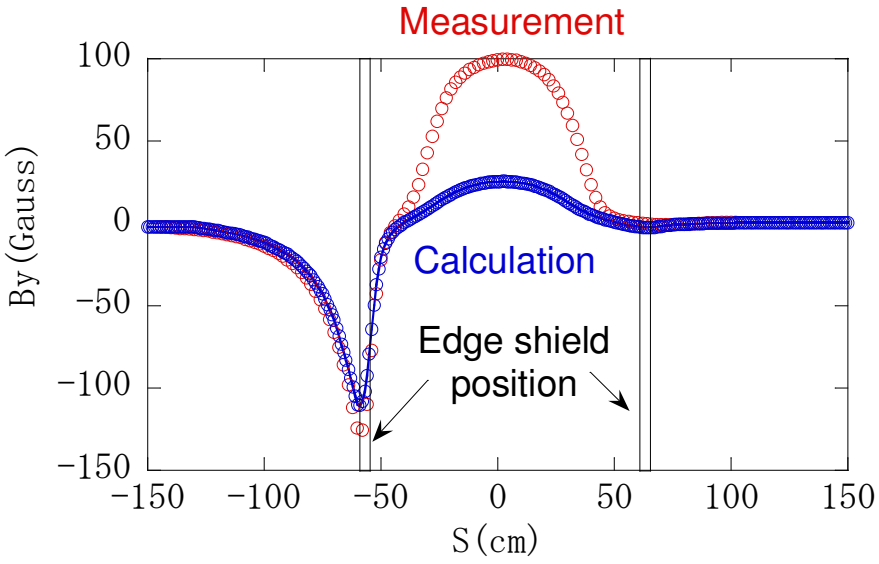
Upper view



Field distribution (By) at X=0



Leakage field distribution (By) at X=-334mm (Distance of 18mm from the septum shield)



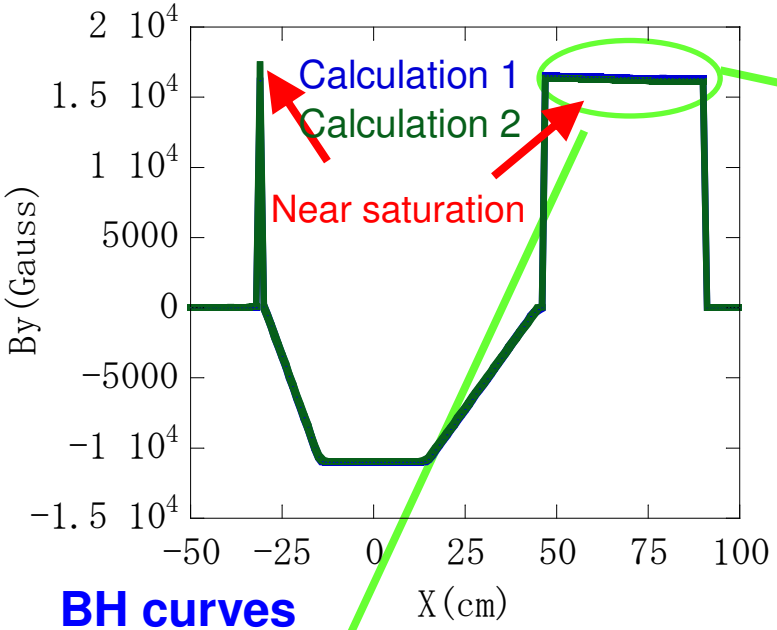
- **Magnetic field in the gap was agreed.**
- **Leakage field was not agreed.**

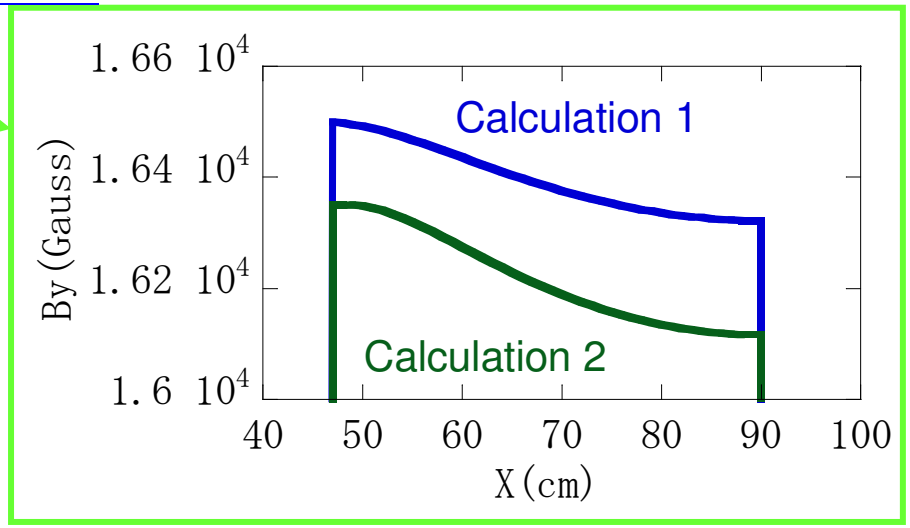
↓

Why?

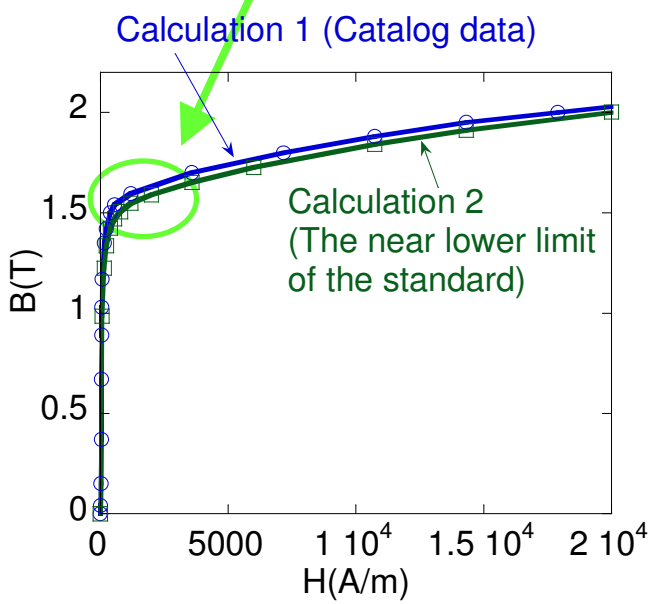
Effects of BH curves near the saturation

Field distribution (By) on the median plane at S=0

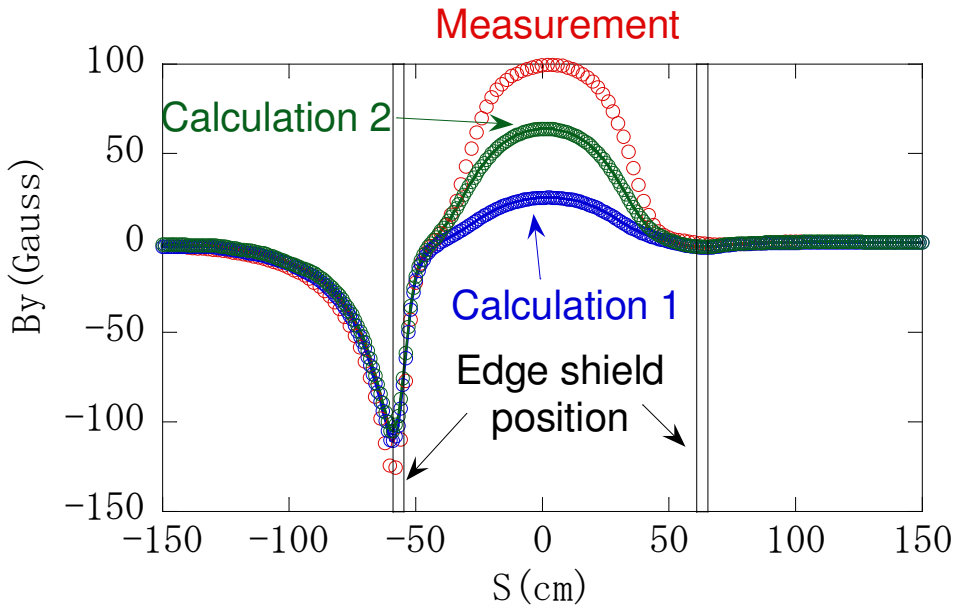




BH curves

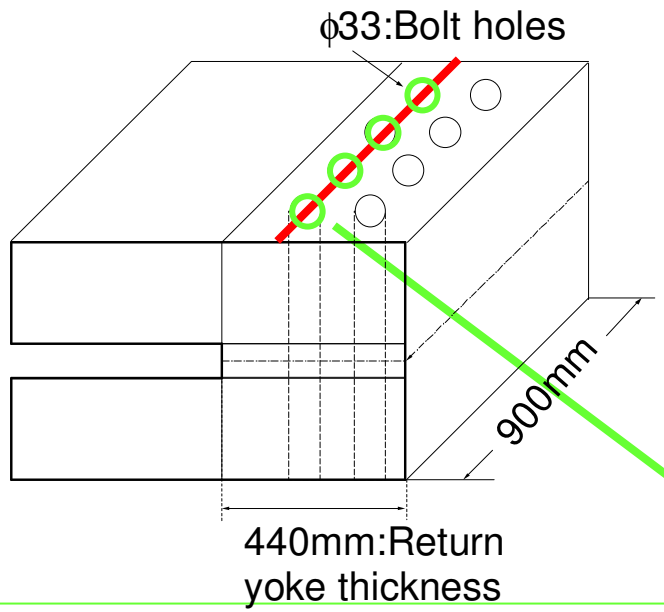


Leakage field distribution (By) at X=-334mm



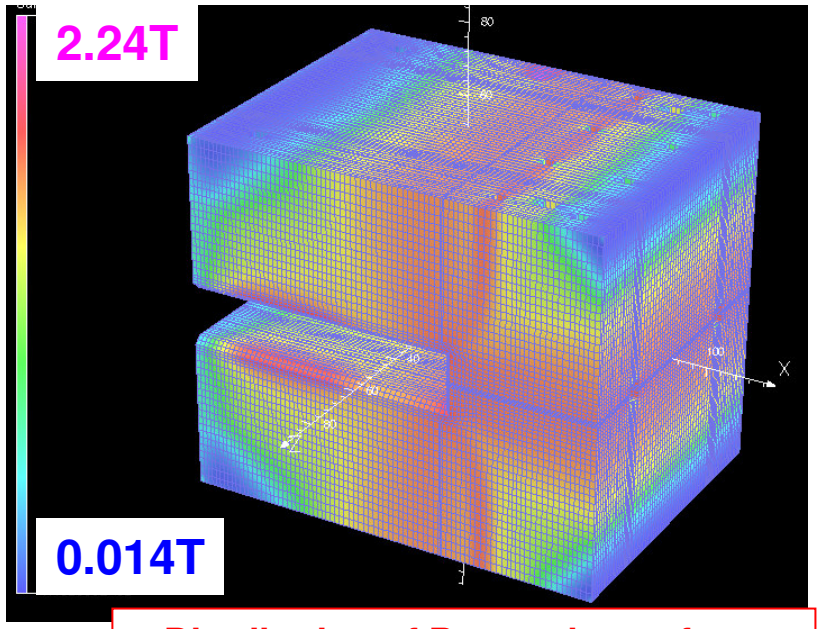
Effects of the bolt holes near the saturation

Schematic diagram of the core

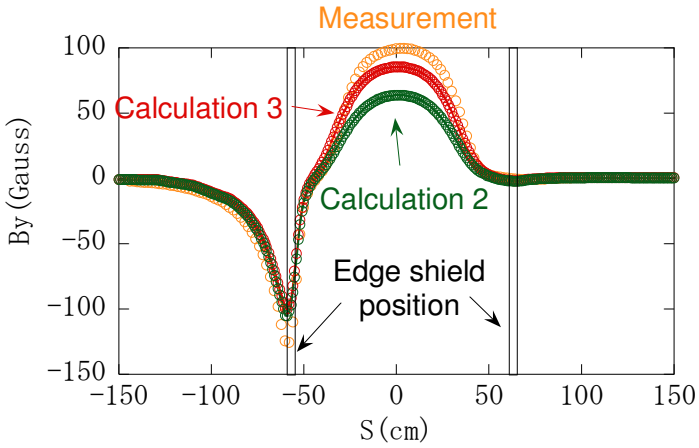


Cross sectional area of the bolt holes are only 0.17% of the one of the return yoke.

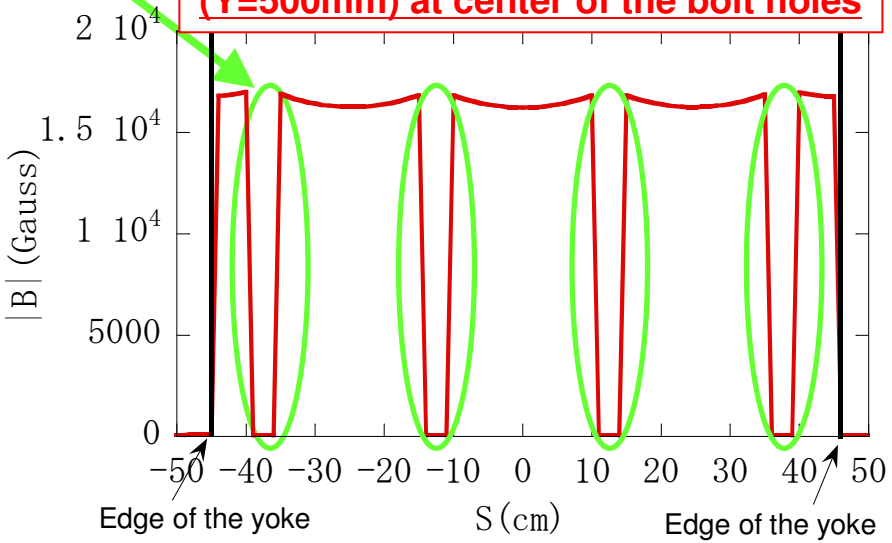
Distribution of B on the surface of the core



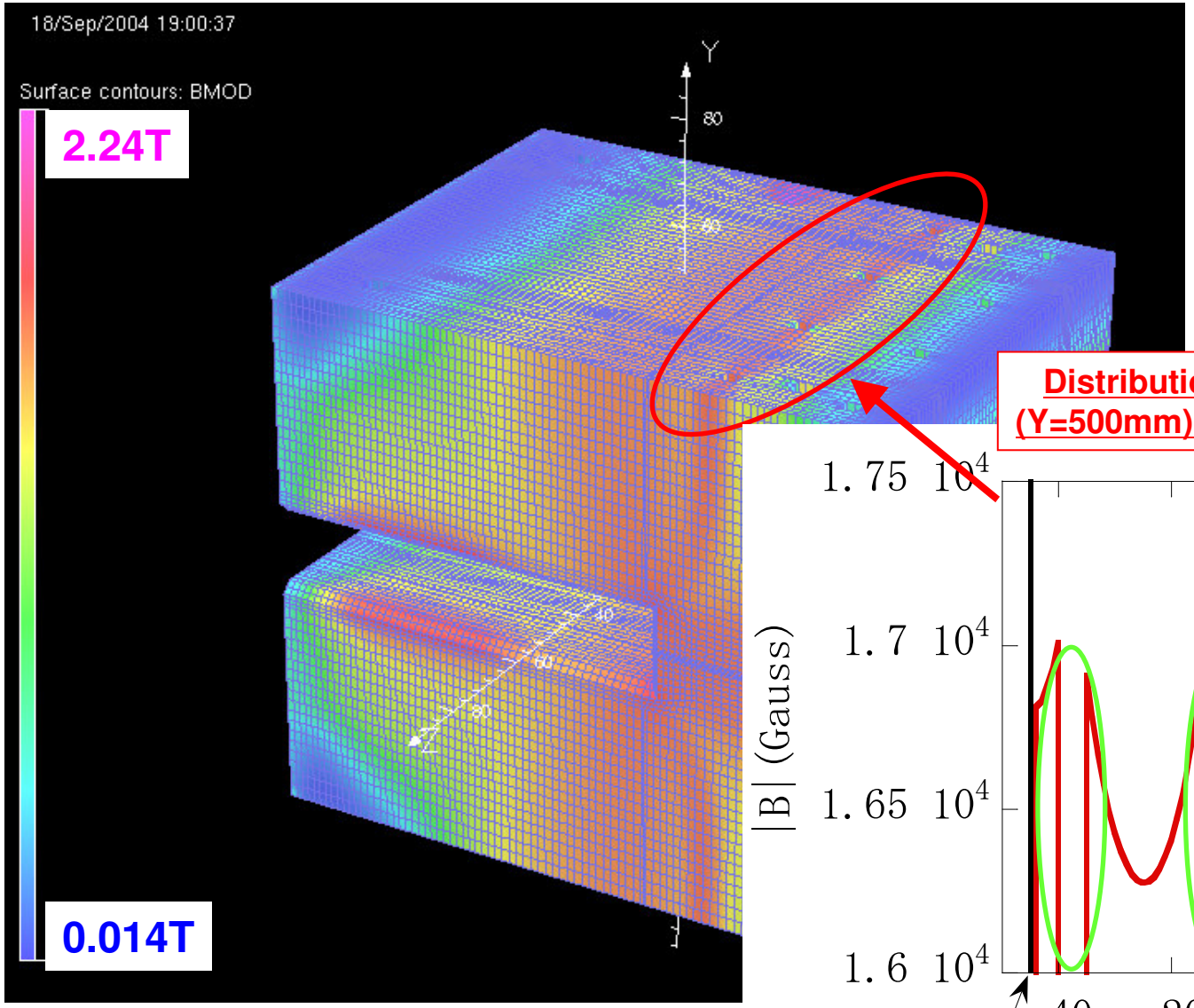
Leakage field distribution (By) at X=-334mm



Distribution of B near the surface (Y=500mm) at center of the bolt holes

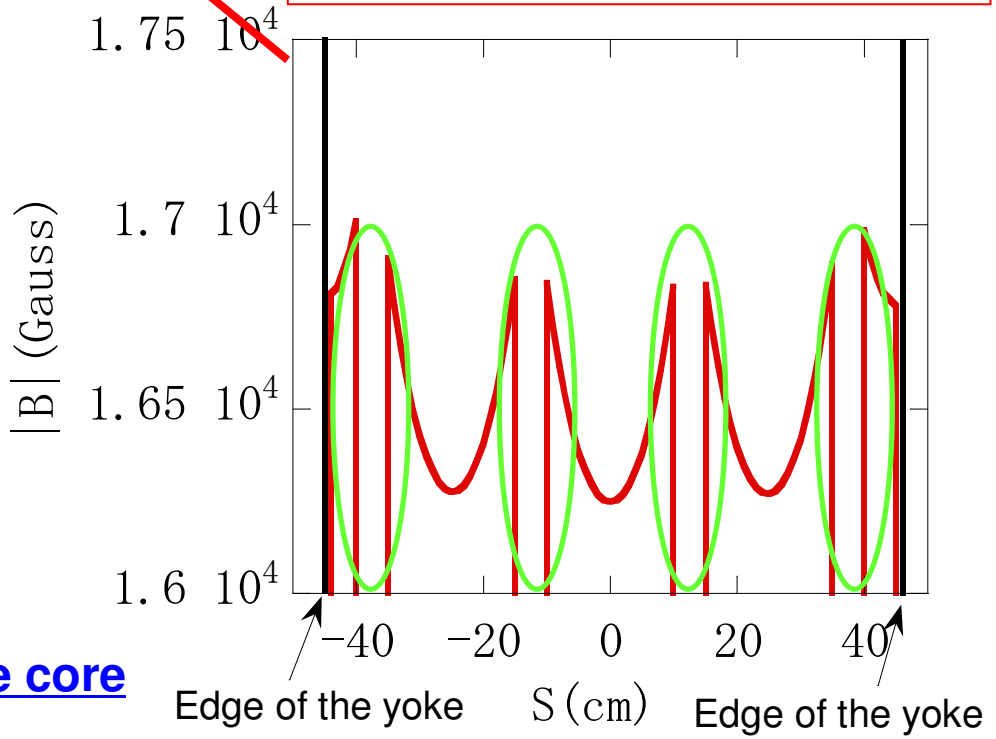


Effects of the bolt holes near the saturation 2



Distribution of B on the surface of the core

Distribution of B near the surface (Y=500mm) at center of the bolt holes



Attention points
in design of RCS septum magnets

When we operate not only the shield but also the return yoke at near saturation region.

1.To suppress the leakage field,

- **we have to operate the core in the low magnetic field region which means the permeability is high enough. Our standard is 1.5 Tesla in maximum to be operated.**

2. When we cannot to obtain the shield or the yoke thickness enough,

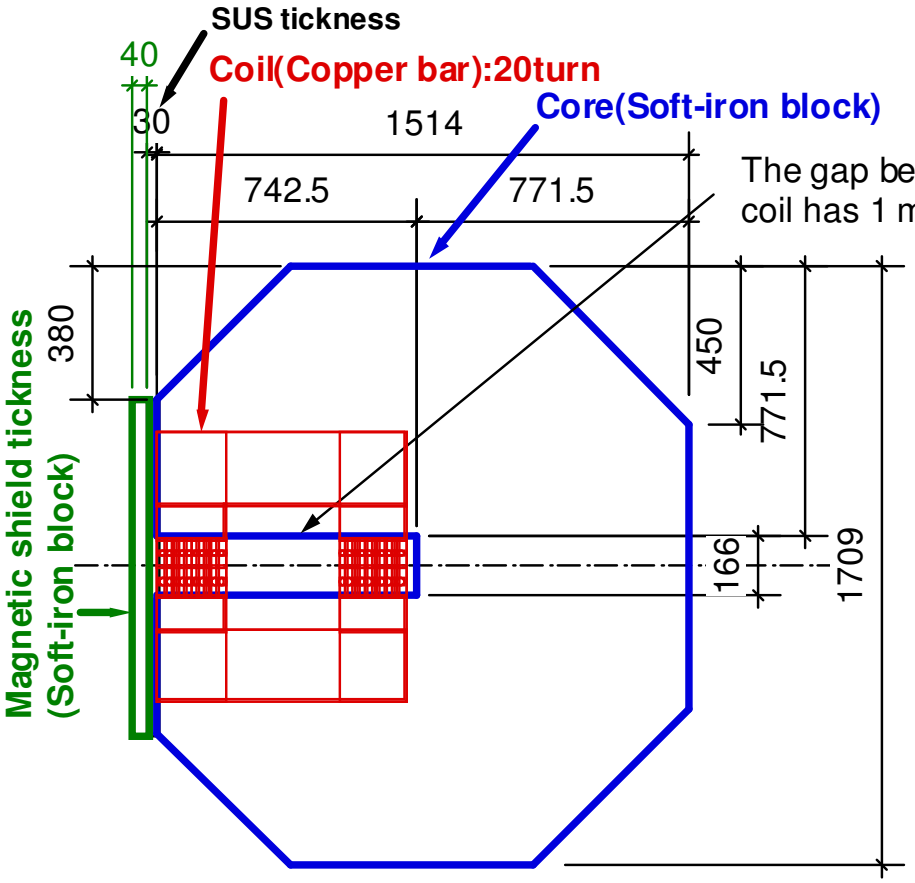
(by weight limit, space limit and so on)

- **we have to take into account effects of dispersion of BH curves and bolt holes.**

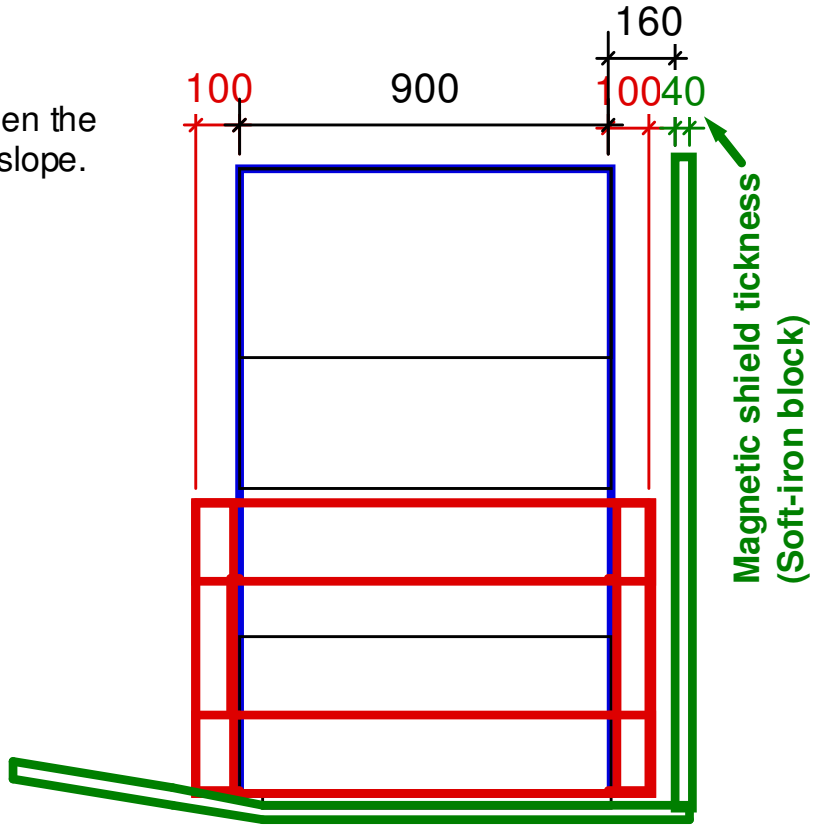
Design parameters of septum magnets

		Injection		Dump		Extraction			
	Unit	SEPI-1	SEPI-2	SEPD-1	SEPD-2	SEPE-1	SEPE-2	SEPE-3	R&D(SEPE-3)
number of magnets		1	1	1	1	1	1	1	1
max. field	T	0.487	0.439	0.501	1.086	0.695	1.402	1.659	1.13
effective length	mm	1400	800	1000	1000	900	1000	1000	1000
gap width	mm	370	348	368	622	336	521	743	760
gap height	mm	136	136	136	140	223	189	166	142
wave form		DC							
environment		Air (not in vacuum)							
septum thickness	mm	87	45	51	340	34	90	260	185
material of core		Electromagnetic soft iron (JIS SUYP-1; block)							
excitation current	A	6246	5650	6787	5603	11176	12312	11035	12800(MAX)
turn number of coils	turn	8	8	8	24	10	16	20	10
max. voltage of coil	V	20	14	19	53	33	28	17	10
cooling of coils		Water							

Schematic diagram of the third extraction septum magnet

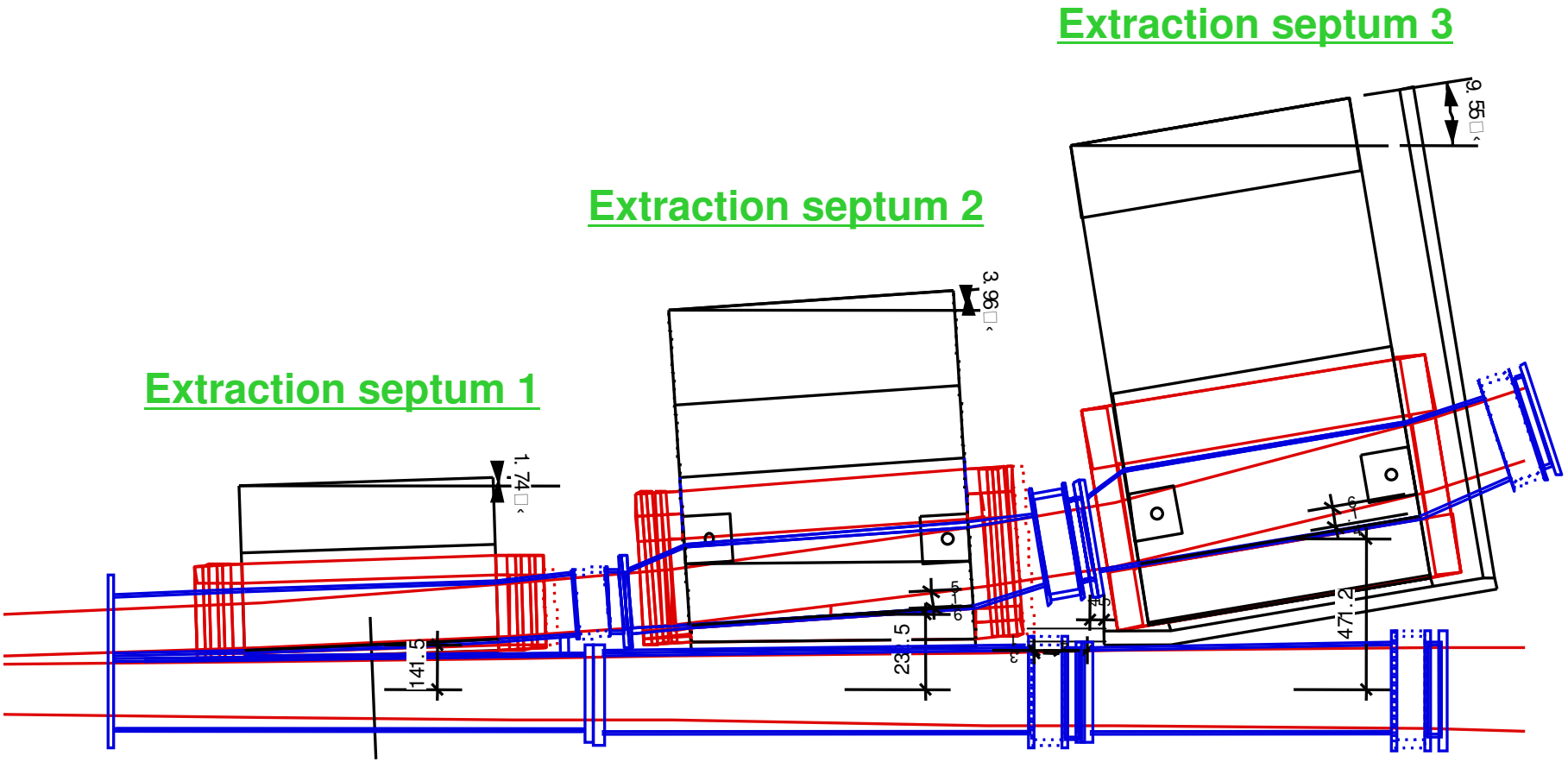


Side view (without edge shield)



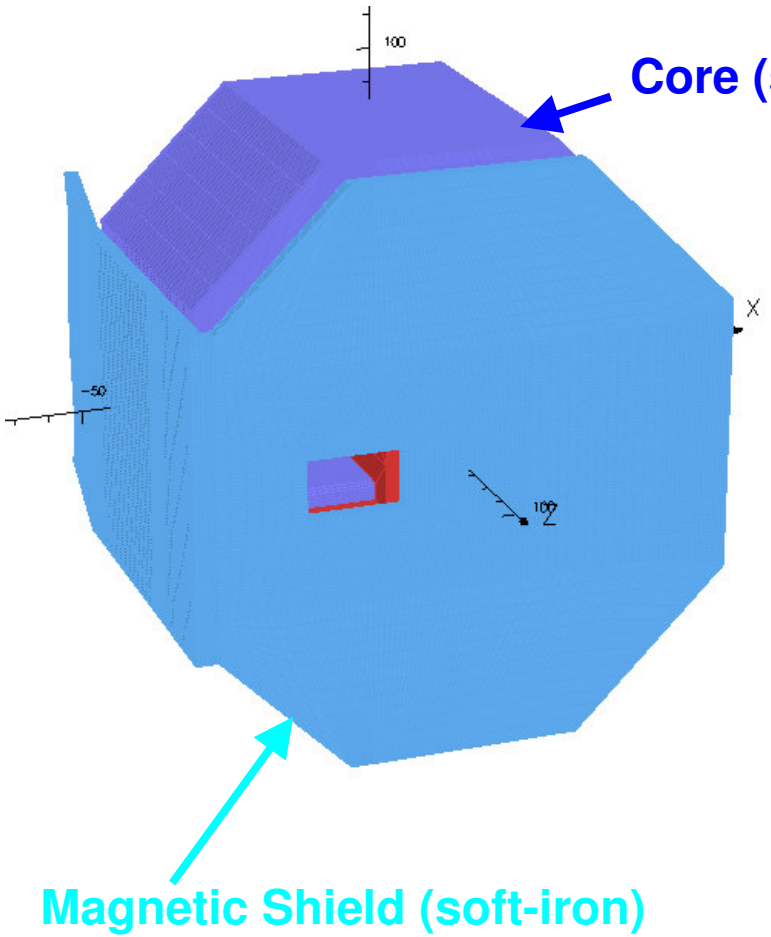
Upper view

Schematic diagram of extraction septum magnets

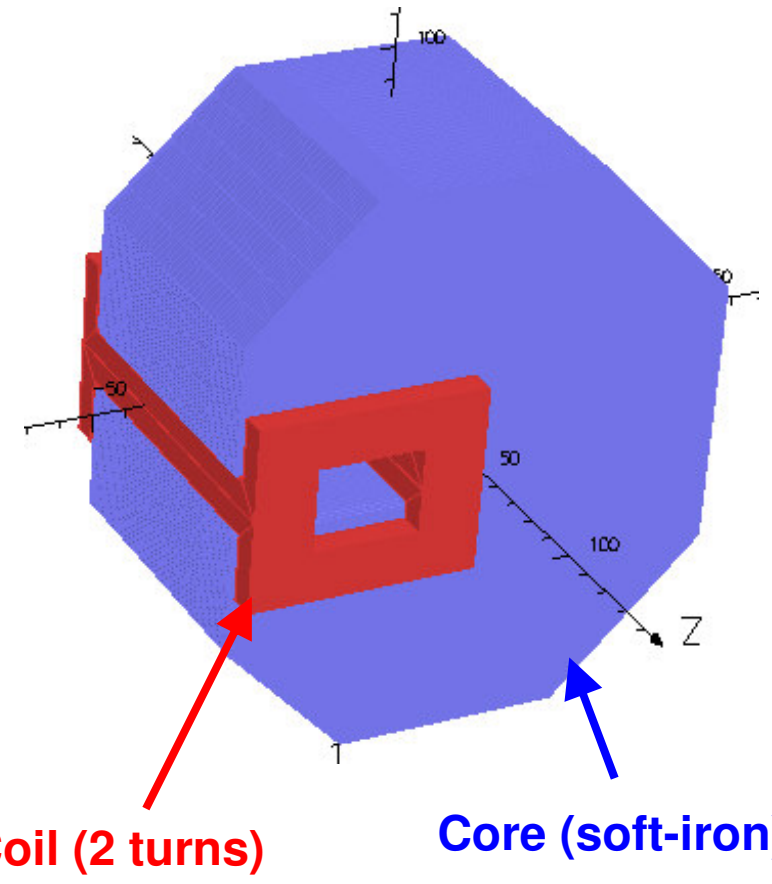


OPERA3D model

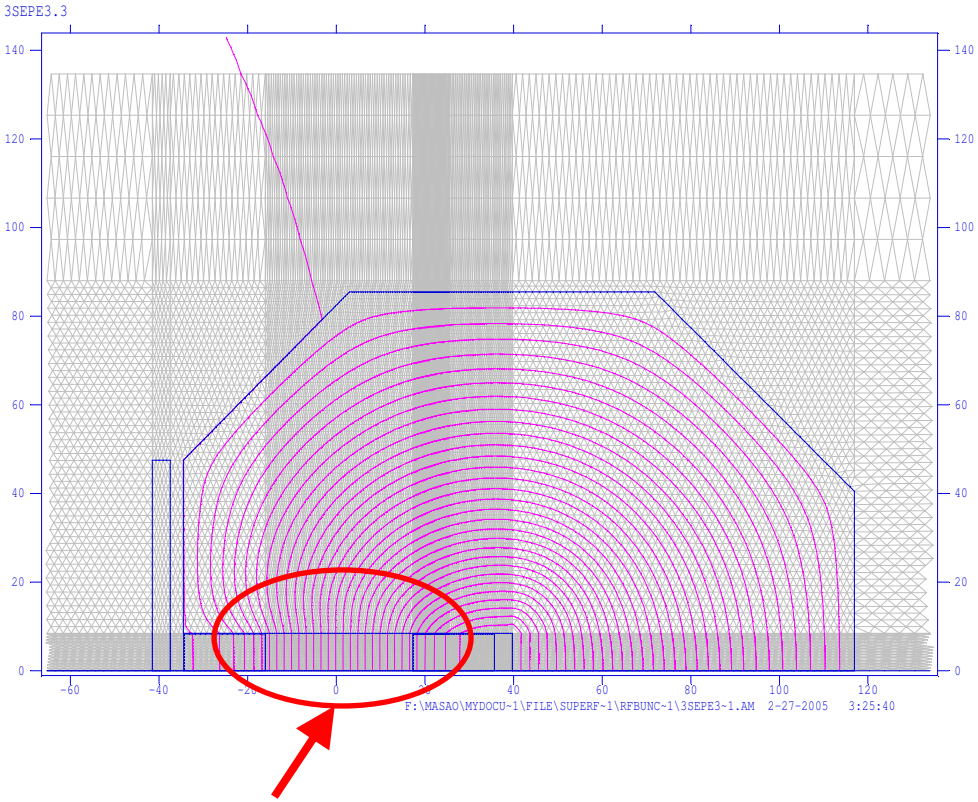
Whole view



Core and coil



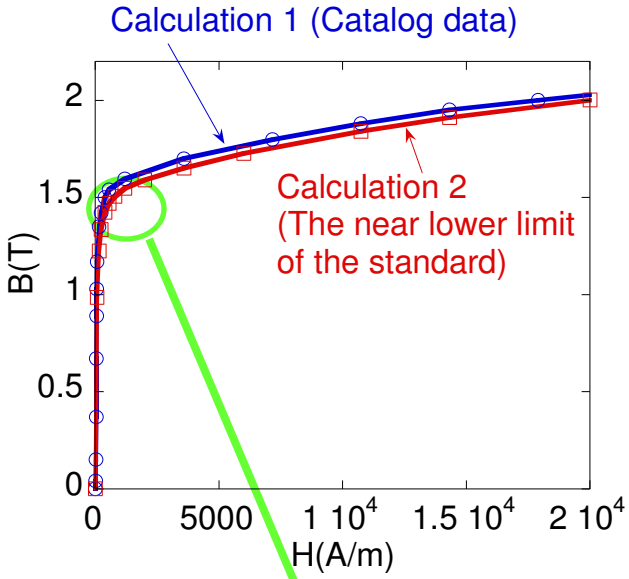
2D calculation and effects of BH curve

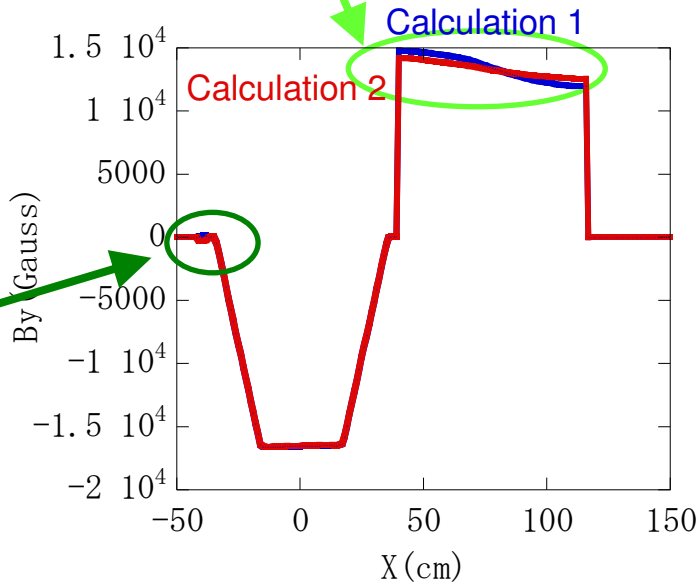


More than 1.5T region.

Not saturated in the shield

BH curves of soft iron

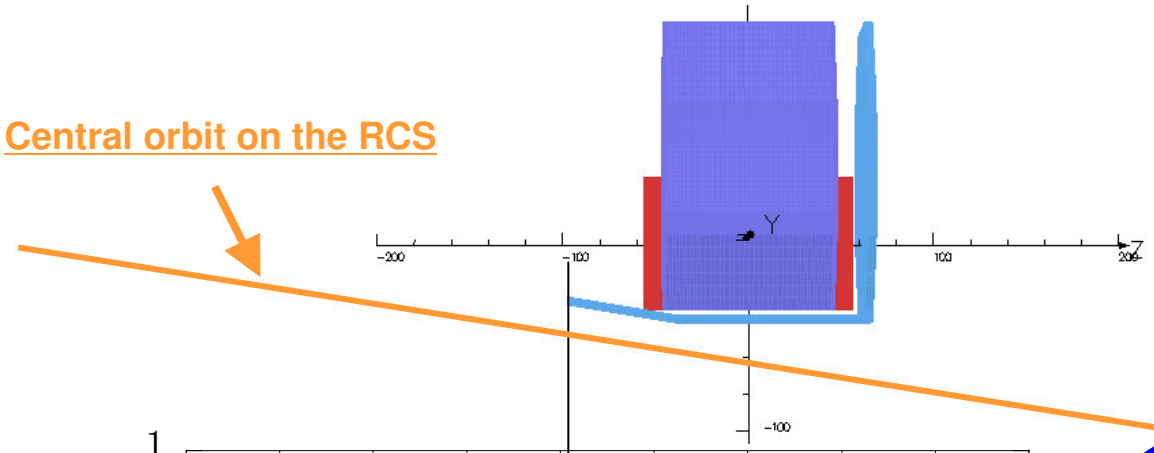




Field distribution (By) on the median plane

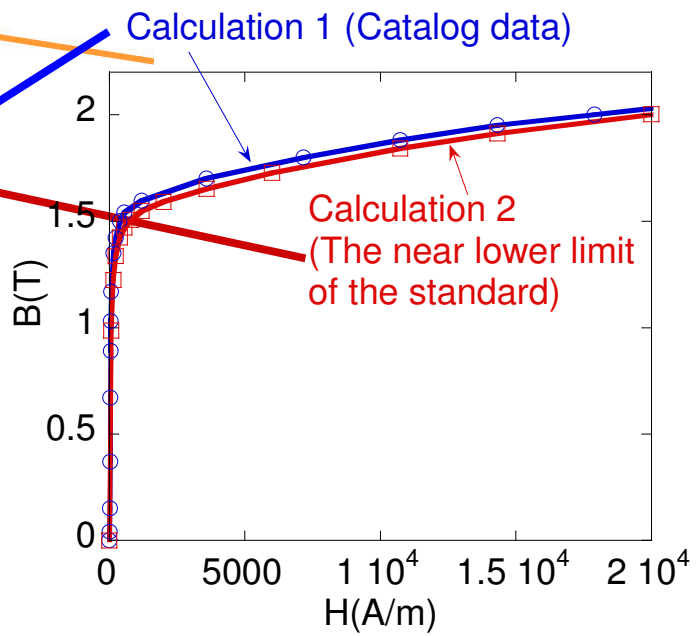
Leakage field of the extraction septum 3

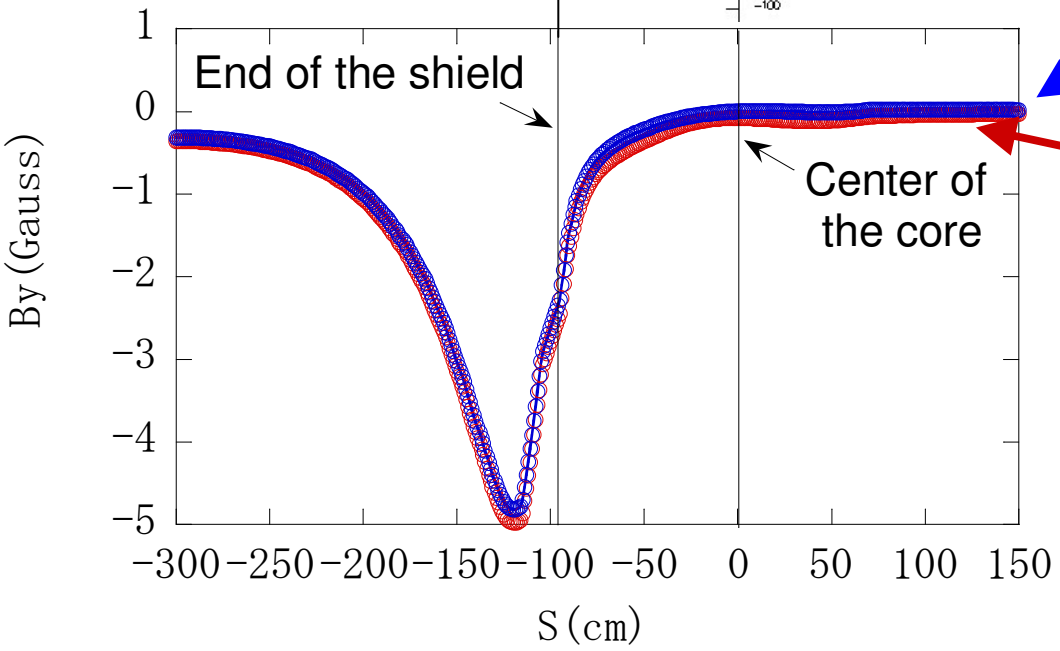
OPERA3D model



Central orbit on the RCS

BH curves of soft iron





Leakage field distribution (By)
at the central orbit on the RCS

Conclusions

- Magnetic fields of an R&D septum magnet were measured and calculated by OPERA3D (TOSCA).
- The core was operate in high magnetic field region. This means the permeability is low. Leakage fields depended on not only the dispersion of BH curves but also bolt holes to fasten the return yoke.
- We obtained a standard ; the core should be excited less than 1.5 Tesla.
- On the basis of the results of the R&D magnet, the third extraction septum magnet was designed. The magnetic field in the core and the leakage field were estimated.