Technical Frame Conditions and Interfaces

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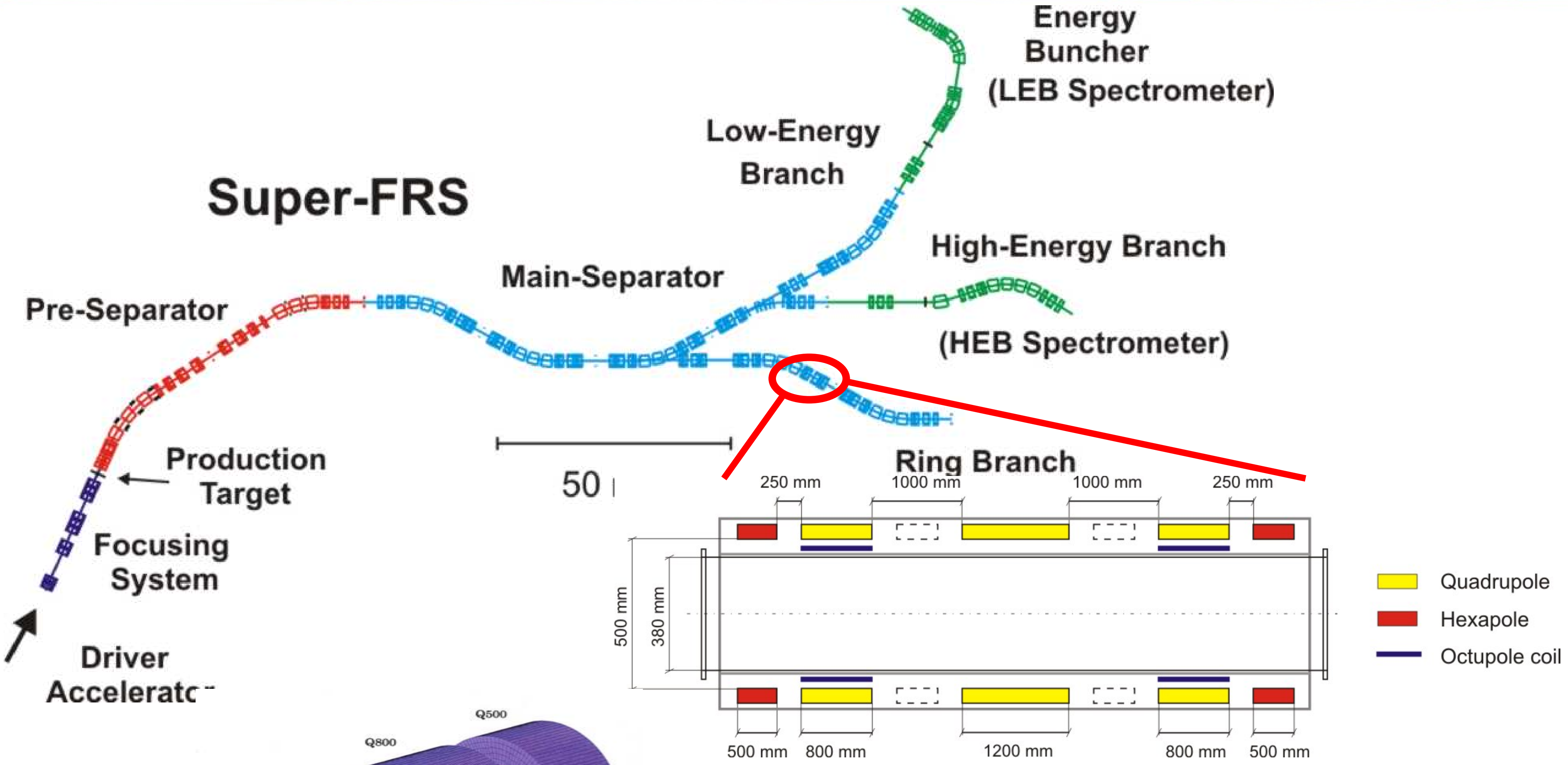
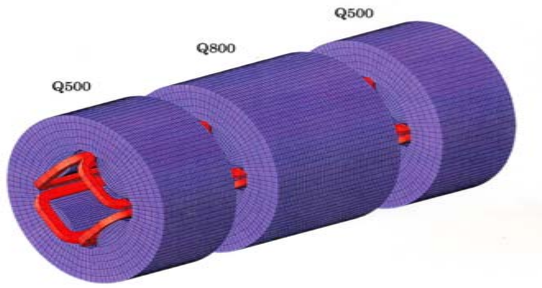
Superferric Multiplets for the Super-FRS



Superferric Triplet (BigRIBS @ RIKEN)



Schematic view of the prototype quadrupole triplet

- Warm bore diameter of 38 cm
- High gradients => superconducting magnets
- Quadrupole triplet + separated sextupoles
- Octupole correction coils are embedded

Configurations of standard Multiplets

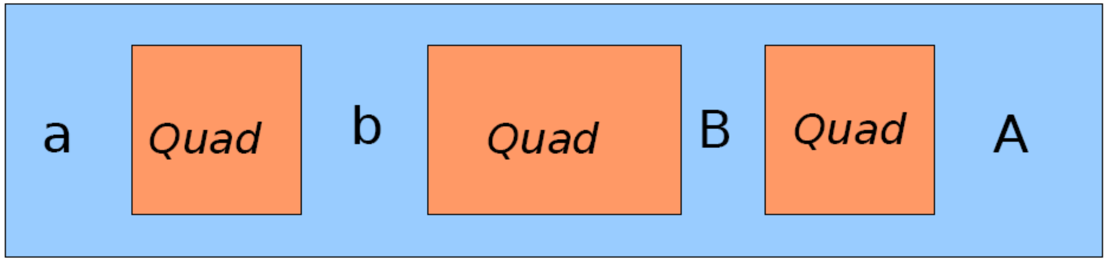
Definition of a standard multiplet: 2 short quadrupoles, 1 long quadrupole, up to 3 sextupoles, 1 m distance between short and long quadrupoles.

17 standard multiplets installed in the Pre- and Main Separator

1 standard multiplet installed in the Energy Buncher

1 standard multiplet installed in R3B

1 standard multiplet installed in the HEBT after the Ring Branch

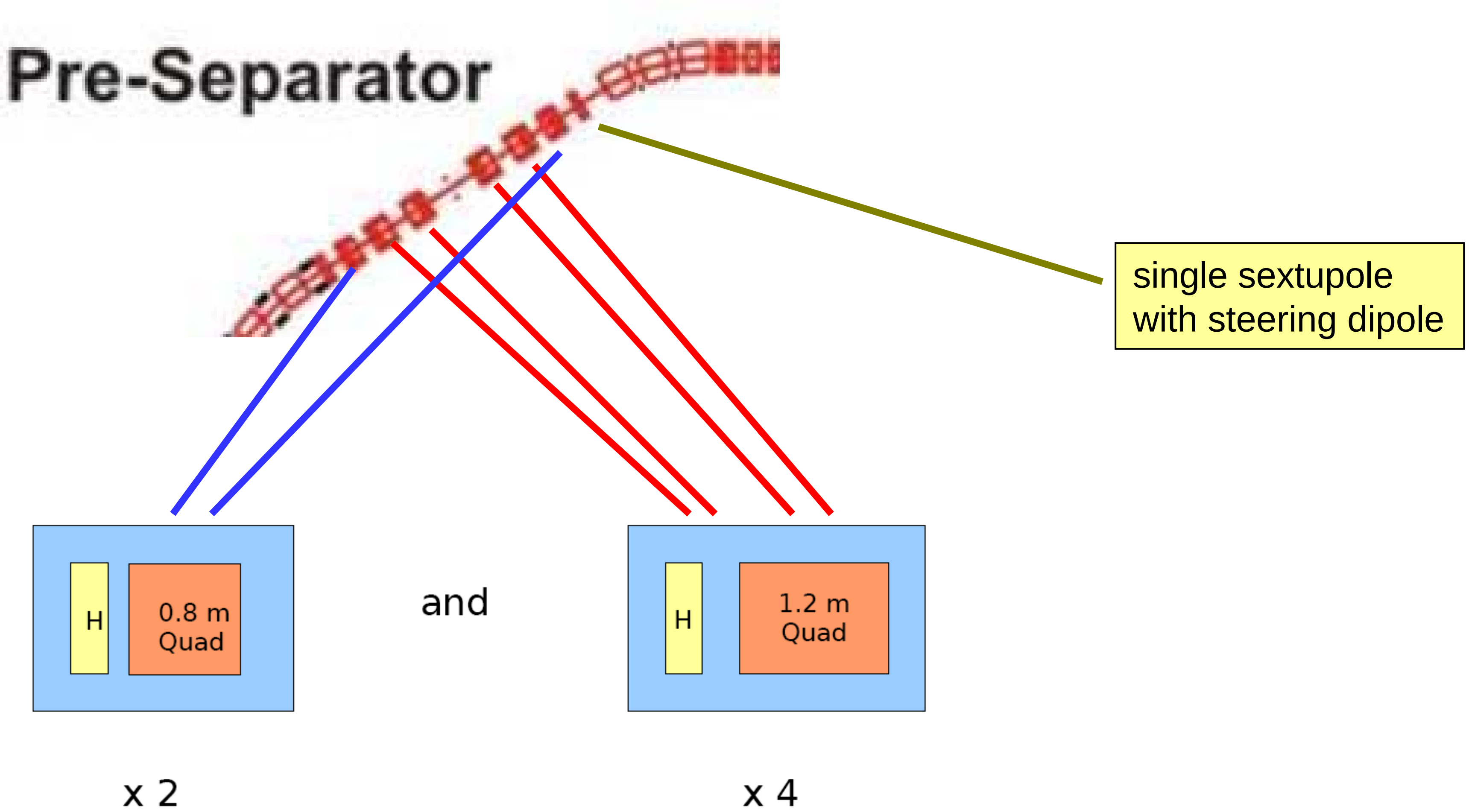


Sextupole positioning

Type	Number of sextupoles in multiplet	Number of Multiplets of the same type
a or A	1	6
bA or aB	2	7
aBA or abA	3	4
null	0	3

20 Cryostats

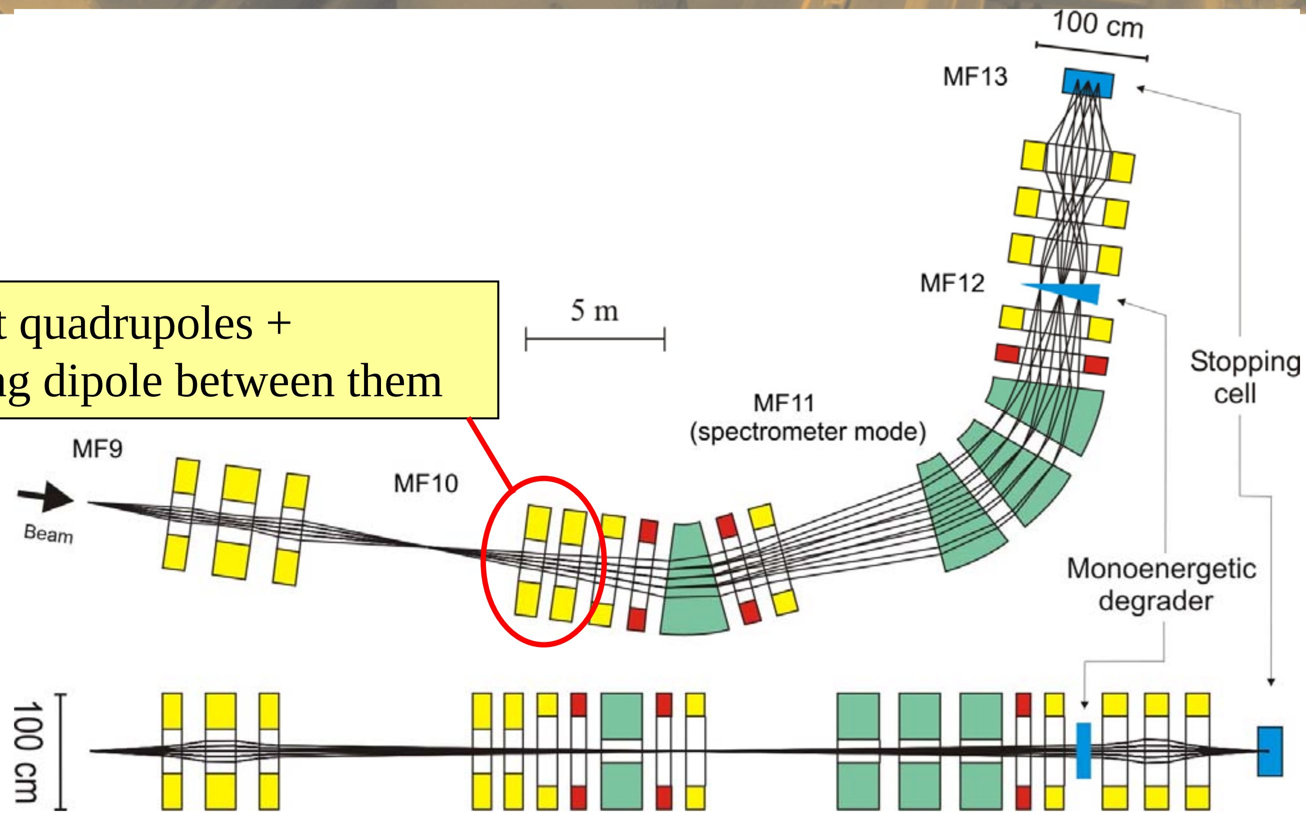
Other quadrupole-sextupole configurations in the pre-separator



7 Cryostats

Special multiplet in the Energy Buncher

two short multiplet quadrupoles +
one vertical steering dipole between them

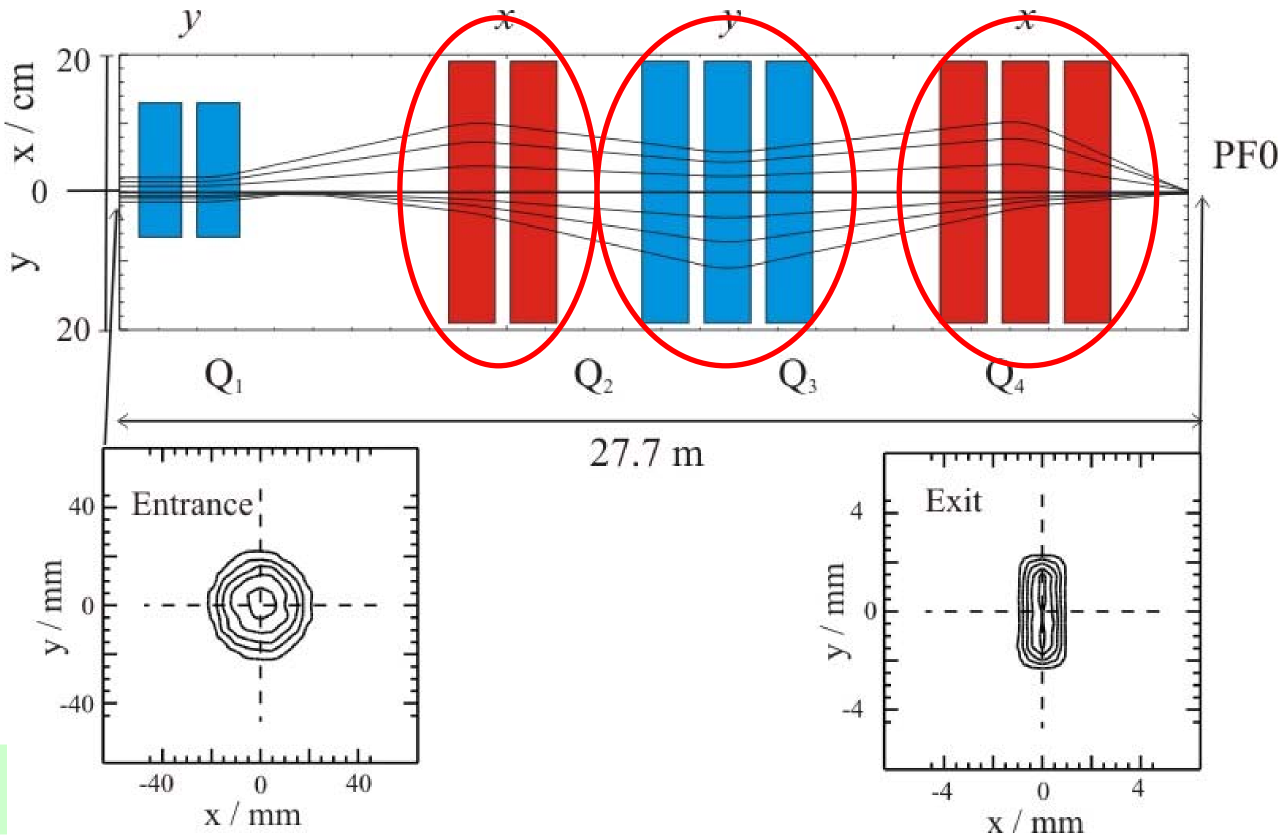


1 Cryostats

Magnet	Number of magnets	Magnet design	Min. field (T), Gradient (T/m),	Max. field (T), Gradient (T/m),	Effective Length/ m	Bending angle /radius (m)	*Usable Aperture/ mm	Field quality (ΔB/B)
Quadrupole 7	3	Superferric	0.05 T/m	4.7 T/m	0.8	—	600 x 400	±8E-4
Quadrupole 8	3	Superferric	0.1 T/m	5.2 T/m	1.2	—	600 x 500	±8E-4

8 long quadrupoles combined in one duplet and two triplets.

Cost book: HEBT! (PSP: 2.3.2.2.8 but identical in construction to PSP 2.4.2.2.4)



3 Cryostats

Ion-optical layout of the split-quadrupole fine-focusing system to be positioned directly in front of the production target. The operating range is determined by the option that projectile beams from SIS18 or SIS100/300 are applied for experiments at the Super-FRS.

Total numbers of multiplet magnets

Quadrupoles

identical in construction (short):

36 × PSP 2.4.2.2.3, 4 × PSP 2.4.2.2.5, 2 × PSP 2.3.2.2.7, 2 in R3B-triplet => 44

identical in construction (long):

21 × PSP 2.4.2.2.4, 1 × PSP 2.4.2.2.6, 9 × PSP 2.3.2.2.8, 1 in R3B-triplet => 32

Sextupoles

39 × PSP 2.4.2.3.2 => 39

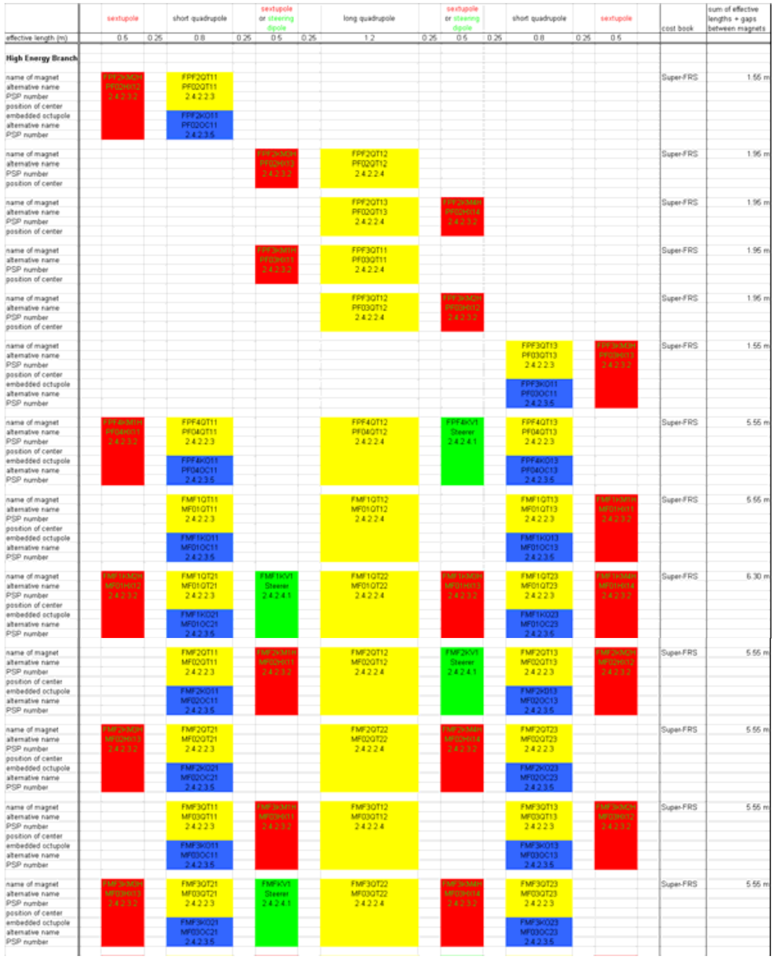
Octupoles (embedded in short quadrupoles PSP 2.4.2.2.3 and PSP 2.4.2.2.5)

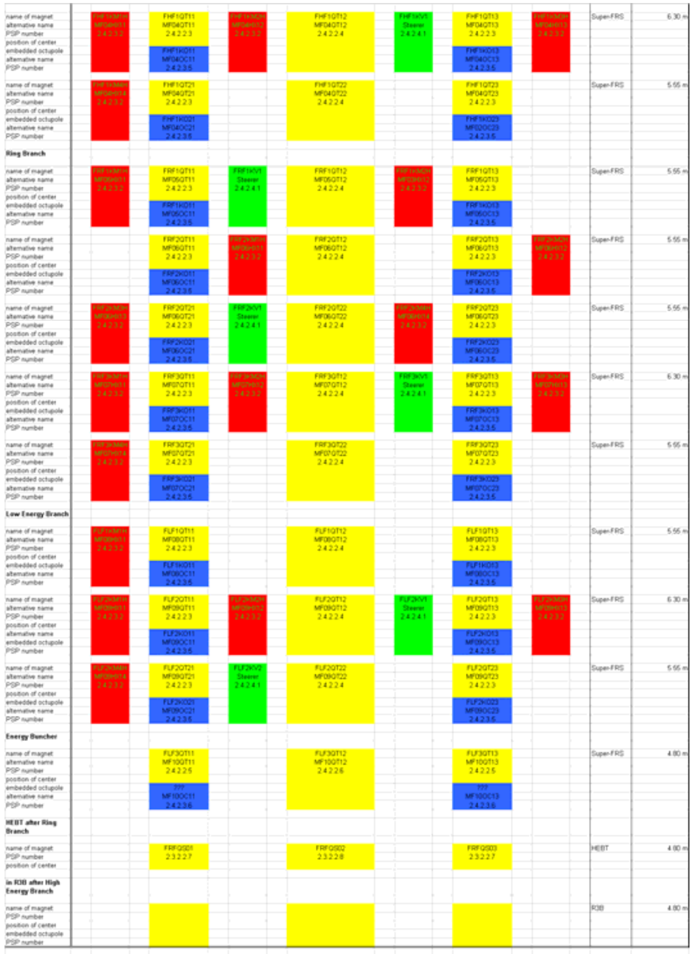
identical in construction: 36 × PSP 2.4.2.3.5, 4 × PSP 2.4.2.3.6 => 40

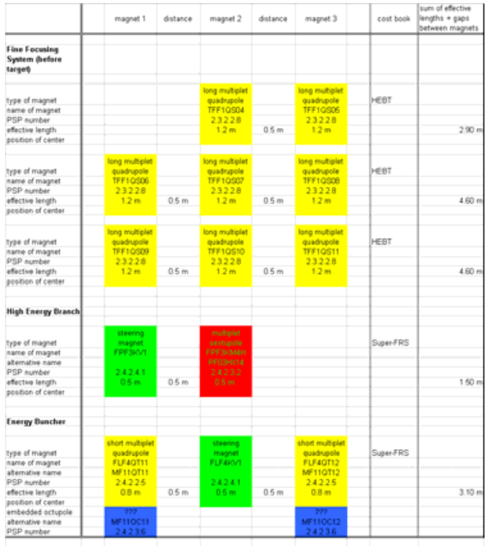
Steering magnets (vertical)

12 × PSP 2.4.2.4.1 => 12

Configurations with multiplet magnets

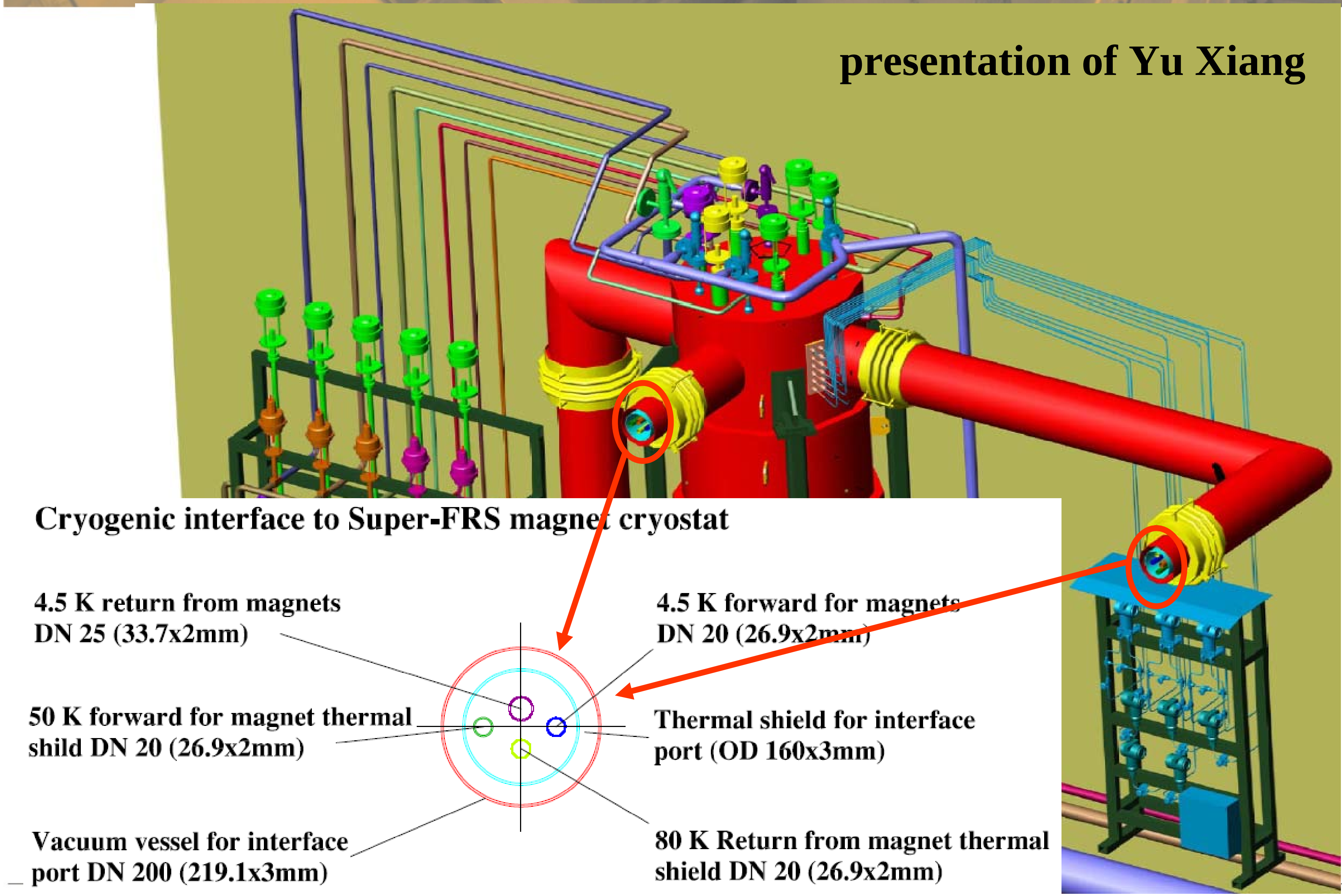




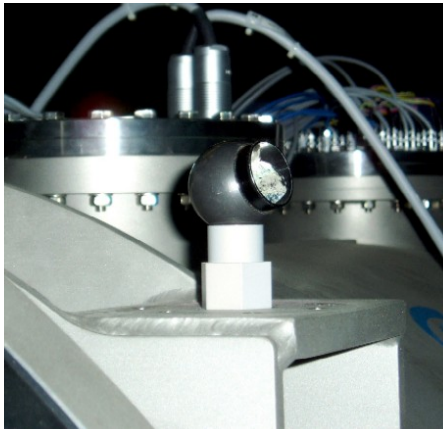


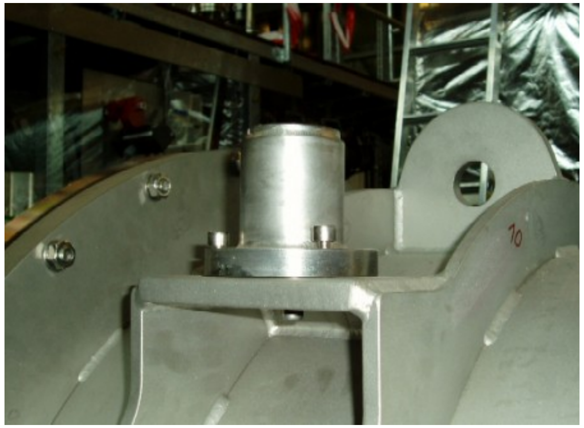
Excel file: Multiplet_configuration_overview

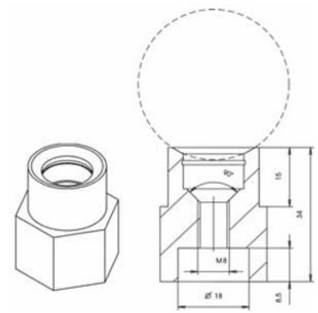
Interface ports to two neighbouring multiplets in the Super-FRS (01-2009)



Fiducialization and Alignment







Examples for cryostat fiducial point (fixed):

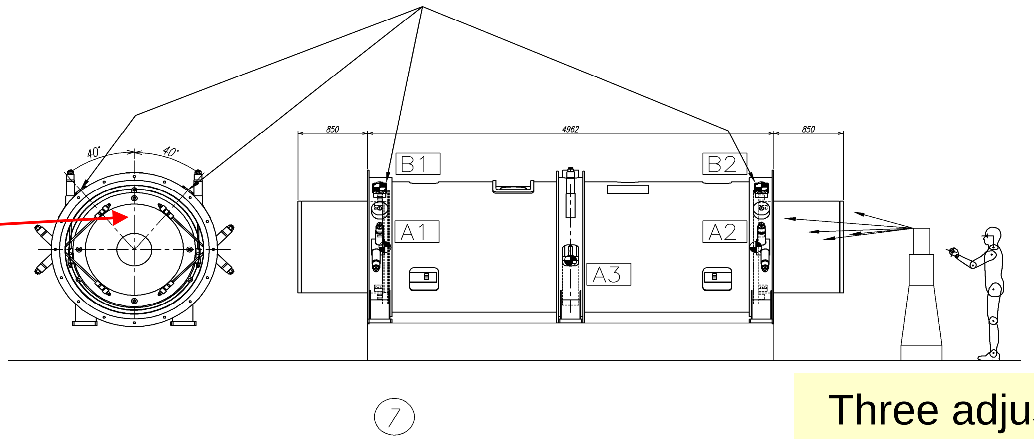
a) Nest with 1,5" corner cube reflector

b) protective cap

Example for magnet fiducial:

Reference drill hole

Vacuum vessel fiducials for alignment to the beam line



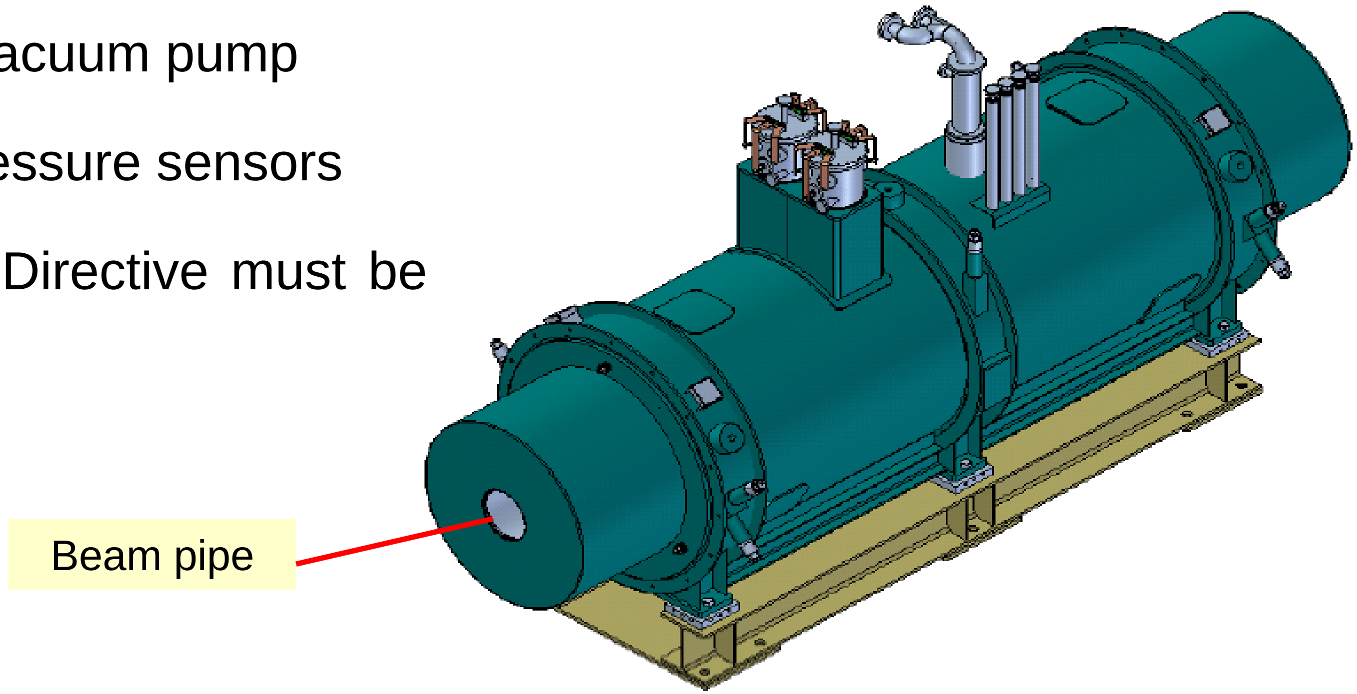
–Trasferring to the fiducials on the vacuum vessel

Three or four fiducials (drill holes, notches, reference planes) on each front side of the cold mass

Three adjustable feet

Vacuum

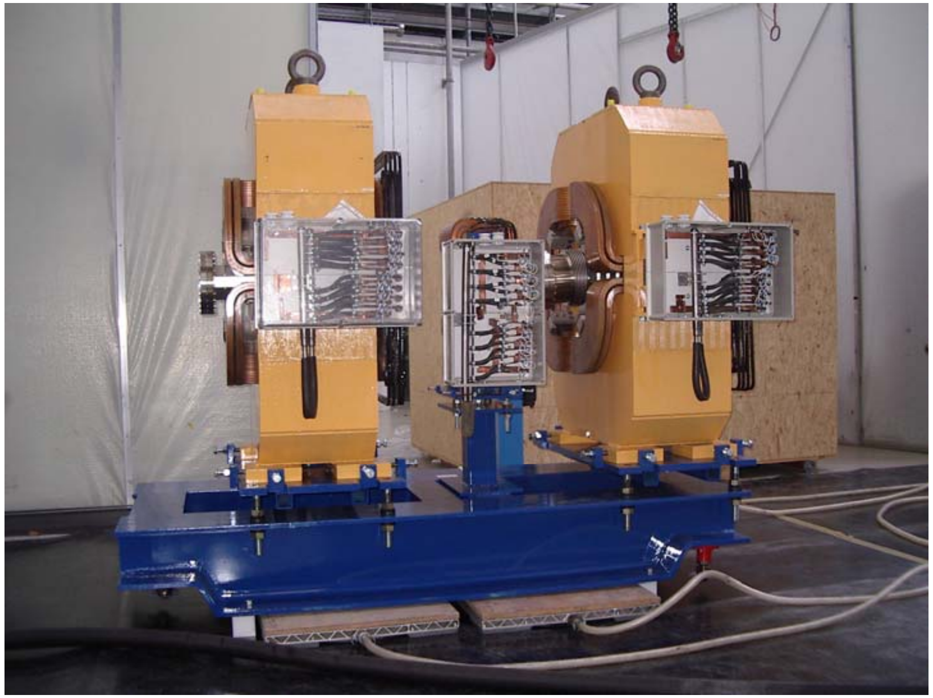
- Beam pipe (stainless steel) is part of the vacuum chamber. Baking is not necessary. Stainless steel: 1.4429 or 1.4435 (316 LN with low magnetizability)
- COF 400 DESY Flansch for the beam pipe on both front sides. (There must be enough space for connection)
- Two DN 160 CF for vacuum pump
- Two DN 40 CF for pressure sensors
- Pressure Equipment Directive must be considered!



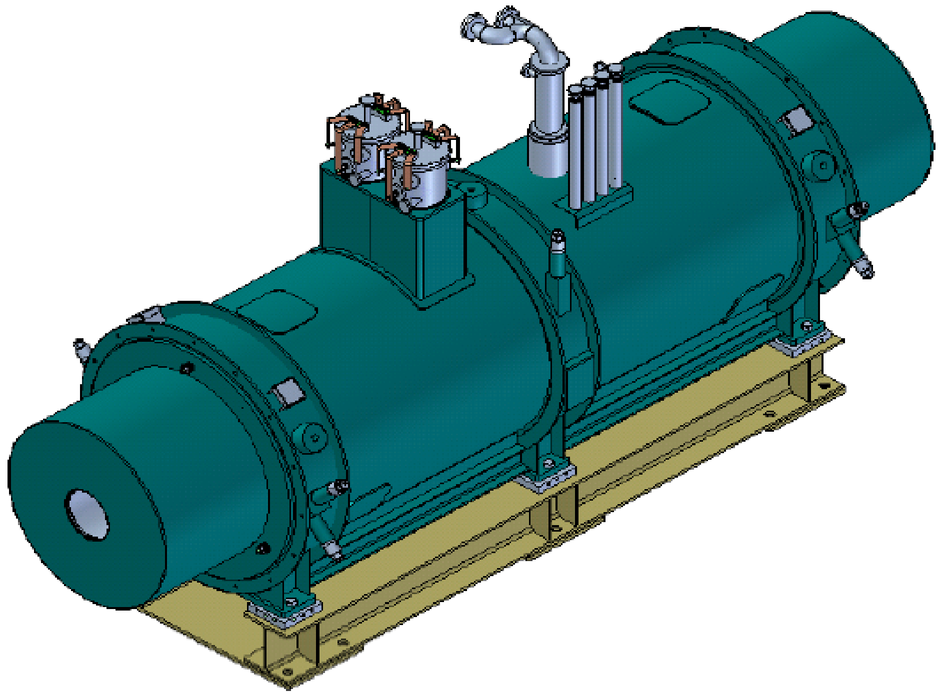
Conceptual multiplet design

Transport

- Lifting unit for crane transportation. The center of mass must be well defined.
- Mountable supports on the girder for air cushion system



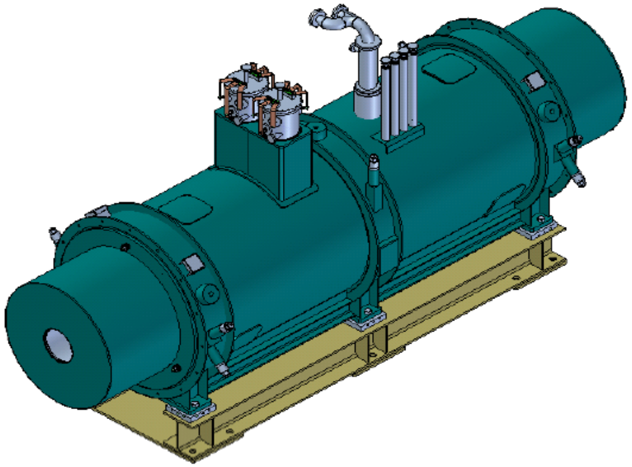
Quadrupol duplet with vertical steering magnet for the Heidelberg Therapy Project (HIT)



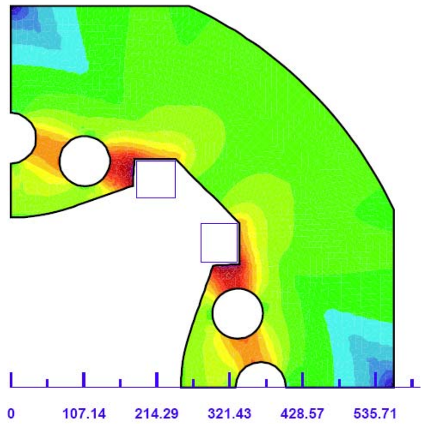
Conceptual multiplet design

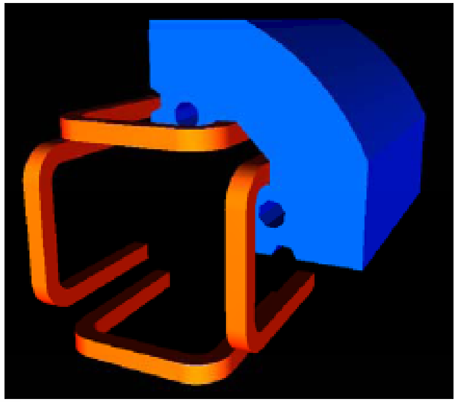
Design ideas of Multiplet

Conceptual design made by Toshiba Corporation

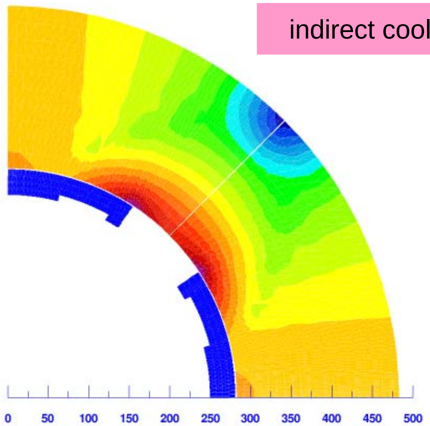


Conceptual design of a made by CIEMAT

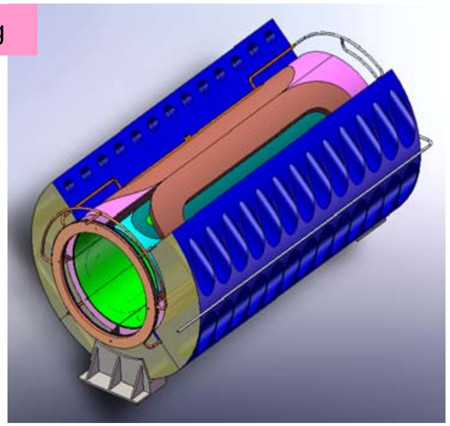




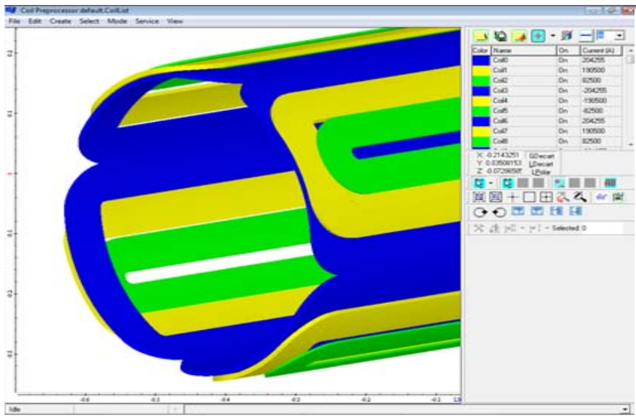
Conceptual design made by CEA

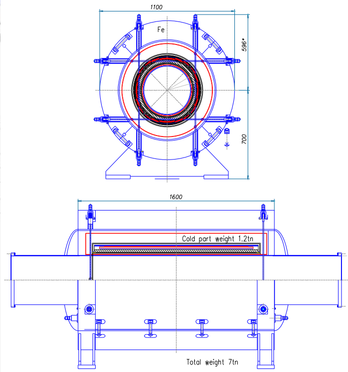


indirect cooling



Conceptual design made by Pavel Vobly



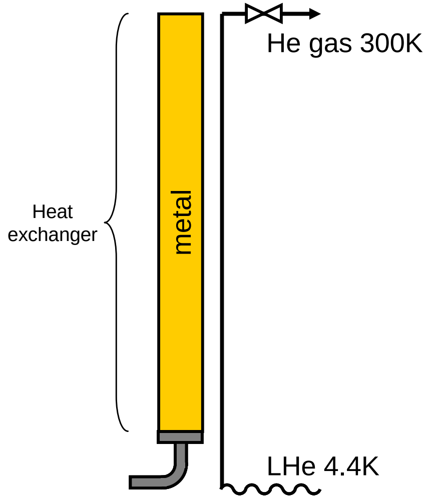


Comparison

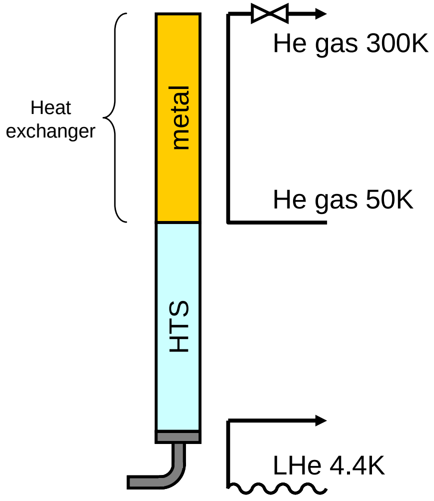
	Superferric			cosine theta	
	Kalimov-Toshiba	CIEMAT	CIEMAT	CEA/Saclay	Pavel Vobly
max. current	292 A	300 A	444 A	834 A	800 A
max. energy / m	754400 J/m	1189400 J/m	1181000 J/m	470000 J/m	475250 J/m
inductance / m	17.696 H/m	26.431 H/m	11.982 H/m	1.351 H/m	1.485 H/m
ramping voltage / m	43.1 V/m	66.1 V/m	44.3 V/m	9.4 V/m	9.9 V/m
ramping VA / m	12573 W/m	19823 W/m	19683 W/m	7833 W/m	7921 W/m
cold mass / m	10.0 t/m	6.1 t/m	5.9 t/m	3.8 t/m	1.2 t/m
iron temperature	cold	cold	cold	cold	warm
field quality (g < 8T/m)	$8 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	$74 \cdot 10^{-4}$	$5 \cdot 10^{-4}$
current leads	cheap standard			HTS	
stray field	short range			long range	
quench heater	probably unnecessary			probably necessary	
postion of coils tolerance sensitivity	low sensitivity			high sensitivity	high sensitivity
Further advantages and disadvantages	similar magnets at MSU and RIKEN			less stored energy, good field quality @ g=10T/m	fast cooling, short coil ends, but supplementary current leads and power converters

Current leads (by courtesy of Birgit Weckenmann)

Resistive design



HTS design



Price (rough estimation)

conventional: ~10 k€ per lead

HTS: ~25 k€ per lead

(Δ ~1140 k€ for 76 Quadrupoles)

	conventional resistive design	hybrid HTS design
100-300 A	0.64-1.93 W	
300-800 A	1.93-5.15 W	0.03-0.09 W
800-1500 A	5.15-9.65 W	0.09-0.17 W
1500-3000 A	9.65-19.31 W	0.17-0.34 W

Comparison of Quadrupole Power Converters for different Magnet Designs

Magnet Design	Rated Current	Effective Apparent Power		Costs Power Converters	Costs Quench Protection	Costs Power Cables and Installation	Cable losses @ 100%	Energy Costs / 1000h of operation	Floor space requirements	Number of Cable Trays	Cable Type per Power Converter
		long quads	short quads								
	[A]	[kVA]	[kVA]	[k€]	[k€]	[k€]	[kW]	[k€]	[m²]		
Toshiba	**292**	**18**	**13**	**1320**	**140**	**165**	**80**	**9**	**250**	**5**	**1 x (4x 95mm²) air**
CIEMAT	**300**	**26**	**19**	**1600**	**140**	**165**	**80**	**9**	**300**	**5**	**1 x (4x 95mm²) air**
CIEMAT	**444**	**28**	**21**	**1670**	**140**	**310**	**125**	**14**	**300**	**9**	**2 x (4x 70mm²) air**
CEA	**834**	**20**	**17**	**1480**	**140**	**495**	**215**	**23**	**300**	**14**	**3 x (4x 95mm²) air**
CEA	**2191**	**67**	**67**	**2870**	**450**	**2400**	**1140**	**130**	**650**	**11**	**2 x 750mm² water**

Data in table refers to 62 Power Converters (40 x short magnets / 22 x long magnets)

Assumptions:
- average cable length 80 m
- cable loading 60%
- energy costs 0,1€/kWh
- width of cable trays 600mm

Cost comparison of low and high current option (by courtesy of Horst Welker, January 2009)

Cost Comparison for different Magnet Design

Magnet Design	Rated Current	Costs Power Converters	Costs Quench Protection	Costs Power Cables and Installation	Costs due to Floor space requirements	Costs of Tunnel space due to cable	Additional Investment Cost
Toshiba	292 A	1320 k€	140 k€	165 k€	209 k€	300 k€	0 k€
CIEMAT	300 A	1600 k€	140 k€	165 k€	251 k€	300 k€	322 k€
CIEMAT	444 A	1670 k€	140 k€	310 k€	251 k€	540 k€	777 k€
CEA	834 A	1480 k€	140 k€	495 k€	251 k€	840 k€	1072 k€
CEA	2191 A	2870 k€	450 k€	2400 k€	543 k€	660 k€	4789 k€

The in kind contributor must pay the difference!

Slide of Discussion

	Spanish design	*French design*	*Russian design*
Cold mass (Cool down / warm up / downtime)	Cold iron 😐 , but 5.8 tons/meter instead of 10t/m of the Toshiba design	Cold iron 😐, but 3.8 t/m instead of 10 t/m of the Toshiba design	Whole weight of cold part just 1.0 tons/m ☺
Field quality	Good at low gradients ☺ Saturation effects at high gradients 😐	Very good for high gradients ☺ but bad at low gradients ☹	Good ☺ but supplementary current leads and power converters are necessary
Handling (construction, tests)	😐 Acceptable	😐 Acceptable	☺ Could be easily tested separately
Stray field	Short fringe field. ☺	Long fringe field. The magnet is longer than effective length ☹	Long fringe field. The magnet is longer than effective length but shorter than a conventional cosine 2 theta quadrupole 😐
Quench protection	Can be self protecting. ☺ A false quench detection turns the power supply off.	Quench heater is necessary 😐. If quench detection fails => destruction of coil. A false quench detection brings the magnet down.	Quench heater is necessary. More complicated ☹. If quench detection fails => destruction of coil. A false quench detection brings the magnet down.
Current leads	Cheap standard ☺	HTS or more expensive standard design with high cryogenic load 😐	HTS plus supplementary standard current leads ☹
Power Converter and Cable	Smaller and less expensive ☺	Bigger and more expensive ☹	Bigger and more expensive ☹
Cooling	Bath cooling ☺	Indirect cooling ☹	Bath cooling ☺
Experience	Similar magnets at MSU and RIKEN ☺	New development ☹	New development ☹
Radiation sensitivity of coil (to be checked)	Larger distance to beam 😐	Less distance to beam ☹	Less distance to beam ☹
Sensitivity to tolerances (coil)	Low ☺	High ☹	High ☹