

# Technical Frame Conditions and Interfaces

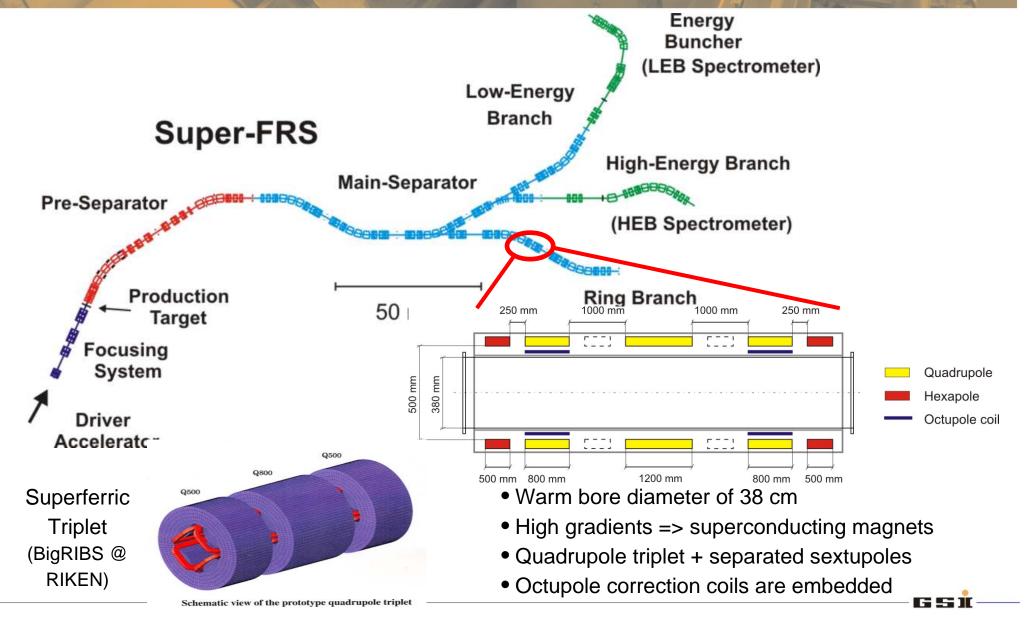
H. Leibrock, GSI Darmstadt

March 11<sup>th</sup>, 2009, GSI, Darmstadt



## Superferric Multiplets for the Super-FRS





#### Configurations of standard Multiplets



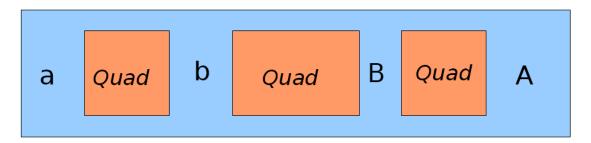
Definition of a standard multiplet: 2 short quadrupoles, 1 long quadrupole, up to 3 sextupoles, 1 m distance between short and long quadrupoles.

17 standard multiplets installed in the Preand 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

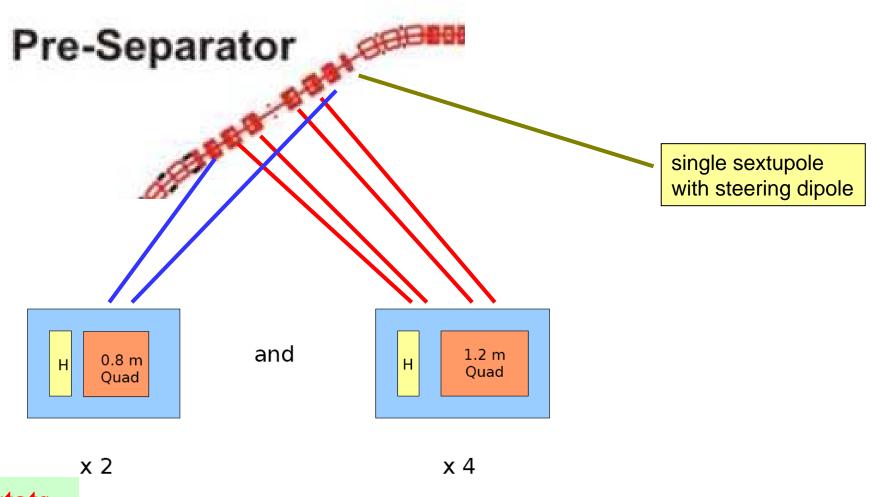


#### Sextupole positioning

Туре	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		

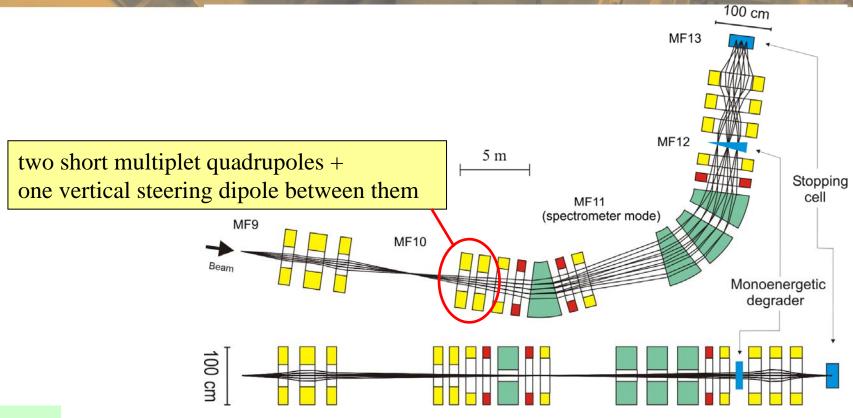
# Other quadrupole-sextupole configurations in the pre-separator





# Special multiplet in the Energy Buncher





# 1 Cryostats

N	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 (ΔΒ/Β)
Qı	uadrupole 7	3	Superferric	0.05 T/m	4.7 T/m	0.8	_	600 x 400	±8E-4
Qι	uadrupole 8	3	Superferric	0.1 T/m	5.2 T/m	1.2	_	600 x 500	±8E-4

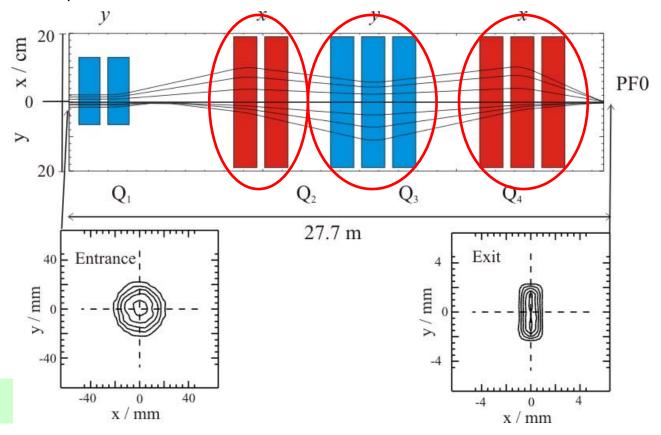
#### Fine Focusing System



GSI

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):

 $36 \times PSP$  2.4.2.2.3,  $4 \times PSP$  2.4.2.2.5,  $2 \times PSP$  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**

 $39 \times PSP 2.4.2.3.2 \Rightarrow 39$ 

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

identical in construction:  $36 \times PSP 2.4.2.3.5, 4 \times PSP 2.4.2.3.6 \Rightarrow 40$ 

#### **Steering magnets** (vertical)

12 × PSP 2.4.2.4.1 => 12

# Configurations with multiplet magnets



				sextus	nole			exhapole						sum of effective						
	sextupo		short quadrupole	or stee	ring	long quadrupole		steering	48	not quadrupole		sextupole		lengths + gaps	name of magnet alternative name	FHE16301H FHE16302H	FHF10712	HF1KV1 FHF1QT13 EBBSD	Super-FRS	6,30
effective length (m)	0.5	0.25	0.8	0.25 0.5	0.26	1.2	0.26	0.5 I	0.26	0.0	0.25	0.5	cost book	between magnets	PSP number position of center	MFG8033 MFG80731 MFG8032 24223 24232	MF040112 24224	Steerer MF040113 MF040 24241 24223 243	2	
High Energy Branch				-											position of center embedded octupole alternative name	FHF1KQ11		FINTSHOUS MEDICALS		-
															PSP number	24235		24235		
name of magnet alternative name	PF02H0	2	FPF2QT11 PF02QT11										Super-FRS	1.55 m	name of magnet	FHETOTOL	FHF10722	FHF1QT23	Super-FRS	5.65 4
PSP number	2.4.2.3		PF020T11 2.4.2.2.3												atemative name PSP number	MF040121 24232 24223	MF040722 2.4.2.2.4	M/040723 2.4.2.2.3		
position of center embedded octupole	_		ERFOUNTS										-		position of center	14111	11111	17117		
alternative name			PF020C11												embedded octupole alternative name	FHP1KI021 MF040021		MF020C23		-
PSP number			24235												PSP number	24235		24235		
name of magnet alternative name				FPF2k	MOH	FPF2QT12 PF02QT12							Super FRS	1.96 m	Ring Branch					
PSP number				2.4.2	3.2	24224									name of magnet alternative name	FRESIONIA FRESCRIST MEDICOLIS MEDICOLIS STANDARDO	FRF10T12 MF050T12	RETRICH FREIGHTS MEDICAL MEDICALS	SuperFRS	5.55
position of center					_								-		PSP number position of center	24232 24223 24241	MF050T12 24224	MF004012 MF050T13 24223		
name of magnet						FPF2QT13		РЕЗУМИН					Super-FRS	1.96 m	embedded octupole	FRF1KOH		FRESKOIS		
alternative name PSP number						PF020T13 2.4.2.2.4	_	902HX14					+		alternative name PSP number	M/060011 24235		MF050C13		_
position of center															name of magnet	FREQUENT TO STATE OF THE STATE	E0E30712	F8F20113 E0003	Super-FRS	5.56 n
name of magnet				FPF3K	MIH	FPF3QT11							Super-FRS	1.96 m	alternative name	MF06GT11 MF06-011 24223	MF060712 2.4.2.2.4	MF060113 MF06H 24223 242	X12	
alternative name PSP number				PF03H 2.4.2		PF030T11 2.4.2.2.4									PSP number position of center	24223	24224	24223 2423		
position of center				242	32	24224							1		embedded octupole	FRF2H011		FRF2H013		
name of magnet						FPF3QT12							Super-FRS	1.96 m	PSP number	24235		24235		
alternative name						PF03QT12	- 1	F03HX12					Super-r KS	1.36 m	name of magnet	ERFORTH FREDRICK	FRF20722	F8F20723	Super-FRS	5.55 4
PSP number						24224		24232							alternative name PSP number	MF0501013 MF050T21 Steener 24223 24241	MF060T22 2.4.2.2.4	MF0501014 MF050123 2.4.2.2.3		
position of center															position of center	14115	11111	14117		
name of magnet										FPF3QT13 PF03QT13	- 1	PF3kM3H	Super-FRS	1.55 m	embedded octupole alternative name	FRF2H021 MF060021		FRF2XXQ3 MF060C23		-
alternative name PSP number										24223	_	24232	-		PSP number	24235		MF060029 2.4.2.3.5		
position of center											_				name of magnet	FRESIGNER FRESIGNER	FRF30112	FREJUNA FREGUTIO	Super FRS	630 4
embedded octupole alternative name									_	PPF3RQ11 PF03QC11	_		+		alternative name PSP number	MF07H31 MF07OT11 MF07H32 24232 24232	MF070712 24224	Steerer 16/07/07/13 M/07/0 24/243 24/223 24/23	5	_
PSP number										2.4.2.3.5					position of center embedded octupole	-		-		
name of magnet	EDE BAN		FPF40T11			FPF40T12		PEASON		FPF4QT13			Super-FRS	5.55 m	alternative name	M/070C11		MF070C13		
alternative name	PF04H0	1	PF04GT11			PF040T12		Steerer		PF04QT13					PSP number	24235		24235	-	1
PSP number position of center	2.4.2.3		24223			24224		24241		24223			+		name of magnet alternative name	FRESCRIP	FRF30722	FRF30723 M/070723	Super-FRS	5 55 4
embedded octupole			FPF4K011							FPF4HQ13					PSP number	MF07-014 MF070121 24223	MF070722 2.4.2.2.4	24223		
alternative name PSP number	_		PF040C11 2.4.2.3.5						_	PF040013			-	-	position of center embedded actupale	F8F3-021		FRENCO		-
															alternative name	M/070021		MFGFOC23		
name of magnet alternative name			FMF1QT11 MF01QT11			FMF1GT12				FMF1QT13 MF01QT13	- 1	METRIMEN	Super-FRS	6.66 m	PSP number	24235		24235		1
PSP number			24223			MF010T12 2.4.2.2.4				24223	_	24232			Low Energy Branch					
position of center embedded octupole			ENGINEER .						_	EMETHODES	_				name of magnet	FLF10711 MEDICOT MEDICOTIS	FLF10T12	FLF10T13 MF08QT13	Super FRS	5,55 n
alternative name			MF010C11							MF010C13	_				alternative name PSP number	24232 24223	FLF10T12 MF080T12 2.4.2.4	24223		
PSP number			24235							24235	_		-		position of center embedded octupole	FEFTHON		FLETKOTA		
name of magnet	FMF1KM	294	FMF1QT21	FINE	C/1	FMF10T22	- 1	METHOWORK		FMF1QT23		MFTKMAH	Super-FRS	6.30 m	atemative name PSP number	M/000011		MF080C13		
alternative name PSP number	MF01H0	2	MF010T21 2.4.2.2.3	Stee 2 4 2		MF010T22 2.4.2.2.4		F01H03		MF01QT23 2.4.2.2.3	_	MF01HX14				24235		24235		
position of center	2423		24223	202		24224		24232		24223	_	24232	1		name of magnet alternative name	FUF2HMIN FUF2HMIN FUF2HMIN MF08H032	FUF20T12 MEDIOT12	PUP2NT	SuperFRS	6 30 =
embedded octupole alternative name			FMF1K021							FMF1K023	_		-		PSP number soution of center	24232 24223 24232	MP080112 24224	24241 24223 242	2	
PSP number			24236							24235					alternative name	FLF2KOTT		FUF2HORS		
name of magnet			FMF2QT11	DATE	50000	FMF2QT12		MENON		EMEDOTES	-	MESONON	Super-FRS	5.55 m	embedded octupole PSP number	M/090C11 24235		MF090C13 2.4.2.3.5		_
alternative name			MF02/0T11	MF02H	0011	MF020T12 2.4.2.2.4		Steerer		MF0QQT13	- 6	wF02H0/12	Superino	9.50,11	name of magnet	0.000	E1 E20000	FU720723	Super-FRS	5.65 =
PSP number			24223	242	3.2	2.4.2.2.4		24241		24223	_	24232			alternative name	MF05H014 MF050T21 Steiner 24232 24223 24241	FUF20722 MF090722 2.4.2.2.4	M/09Q723 2.4.2.2.3	Superrics	500.0
position of center embedded octupole			FMF2K011						_	FMF2HD13					PSP number position of center	24223 24241	24224	24223		-
alternative name PSP number			MF020011						_	MF020C13	_				embedded octupole alternative name	FUF29021		FUF2H023		
		_	2.42.00				_		_	24235	_				PSP number	24235		24235		
name of magnet alternative name	FMF2kN		FMF2QT21 MF02QT21			FMF2QT22 MF02QT22		#F2KM4H		FMF2QT23 MF02QT23			Super-FRS	5.55 m	Energy Buncher					_
PSP number	2.4.2.3		24223			2.4.2.2.4		24232		24223					name of magnet	FUSIONI	FUF30T12	FU30TI3	Super-FRS	4.00 =
position of center															alternative name	MF100T11	MF100712 24226	MF10QT13	Superriss	4.001
embedded octupole alternative name			MF02OC21						_	MF020C23					PSP number position of center	24225	24226	24225		-
PSP number			24235							24235					embedded octupole	777 MF100011		777		
name of magnet			FMF3QT11	EMERY	MIH	FMF30T12				FMF3QT13	-	MESUMON	Super-FRS	5.55 m	alternative name PSP number	24236		MF100C13 2.4.2.3.6		1
alternative name			MF03QT11	MF03H	6011	MF03QT12				MF03QT13	_ [	VF03H9/12	- No.		HEBT after Ring					
PSP number position of center			24223	2.4.2	3.2	24224				24223		24232			Branch					
embedded octupole			FMF3ki011							FMF3k(013					name of magnet	FREQUE	FRFQS02	FRFQ503	HEBT	4.00 =
alternative name PSP number			MF030011							MF030C13					PSP number position of center	23227	23228	23227		
			24235							44235										
name of magnet alternative name	EMESHW METTHO	H	FMF30T21 MF030T21	FMFX	OV1	FMF30T22 MF03QT22	E	#F3kM4H		FMF3QT23 MFG3QT23			Super-FRS	5.55 m	in FOB after High Energy Branch					
PSP number	2.4.2.3		2.4.2.2.3	2.4.2	41	2.4.2.2.4		24232		24223									F38	4.00 =
position of center			CA ACCUMANT							The second second					name of magnet PSP number				KJ0	4.00
embedded octupole alternative name			MF03OC21							MF030C23					position of center embedded octupole					
PSP number			24226							24226					PSP number					

	magnet 1	distance	magnet 2	distance	magnet 3	cost book	sum of effective lengths + gaps between magnets
Fine Focusing System (before target)							
			long multiplet		long multiplet	HEBT	
type of magnet			quadrupole TFF1QS04		quadrupole TFF1QS06	PEDI	
name of magnet						_	
PSP number			23228		23228	_	
effective length			1.2 m	0.5 m	1.2 m	_	2.90
position of center							
	long multiplet		long multiplet		long multiplet		
type of magnet	quadrupole		quadrupole		quadrupole	HEBT	
name of magnet	TFF1GS06		TFF10507		TFF1QS08		
PSP number	23228		23228		23228		
effective length	1.2 m	0.5 m	1.2 m	0.5 m	1.2 m		4.60
position of center							
	long multiplet		long multiplet		long multiplet		
type of magnet	quadrupole		quadrupole		quadrupole	HEBT	
name of magnet	TFF1QS09		TFF1QS10		TFF1QS11		
PSP number	23228		23.228		23228		
effective length	1.2 m	0.5 m	1.2 m	0.5 m	1.2 m		4.60
position of center							
High Energy Branch							
	steering		multiplet sextupole			Super-FRS	
type of magnet name of magnet	magnet EPE36V1		EPESMANN			ouget FRS	
alternative name	FF73KVI		PF03H014			_	
PSP number	24241		2.4.2.3.2				
effective length	24.24.1 05 m	0.5 m	0.6 m				150
position of center	USM	USM	0.5 m				150
Energy Buncher							
	short multiplet		steering		short multiplet		
type of magnet	quadrupole		magnet		quadrupole	Super-FRS	
name of magnet	FLF4QT11		FLF4KV1		FLF40T12		
alternative name	MF11QT11				MF11QT12		
PSP number	24225		2.4.2.4.1		24225		
effective length	0.8 m	0.5 m	0.5 m	0.5 m	0.8 m		3.10
position of center							
embedded actupole	772				277		
alternative name	MF110C11				MF110012		
PSP number	24236				24236		

Excel file: Multiplet\_configuration\_overview

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





Cryogenic interface to Super-FRS magnet cryostat

4.5 K return from magnets DN 25 (33.7x2mm)

50 K forward for magnet thermal shild DN 20 (26.9x2mm)

Vacuum vessel for interface port DN 200 (219.1x3mm)

4.5 K forward for magnets DN 20 (26.9x2mm)

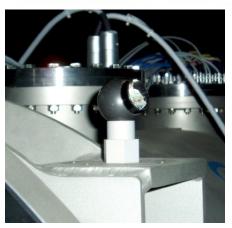
Thermal shield for interface port (OD 160x3mm)

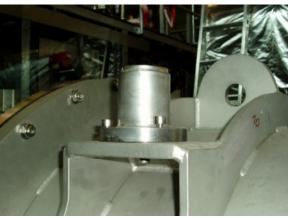
80 K Return from magnet thermal shield DN 20 (26.9x2mm)

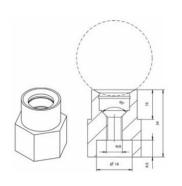


#### Fiducialization and Alignment









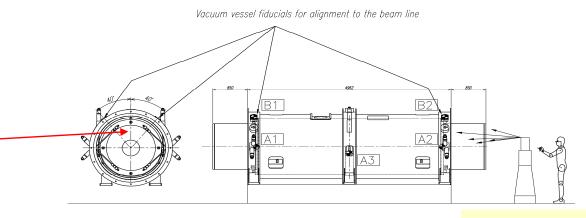


Examples for cryostat fiducial point (fixed):

- a) Nest with 1,5" corner cube reflector
- b) protective cap

Example for magnet fiducial: Reference drill hole

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



7

-Trasferring to the fiducials on the vacuum vessel

Three adjustable feet

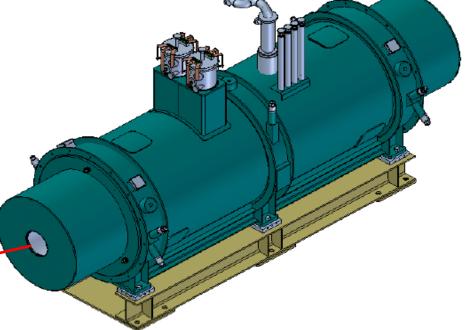


#### Vacuum



- 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!

Beam pipe



Conceptual multiplet design

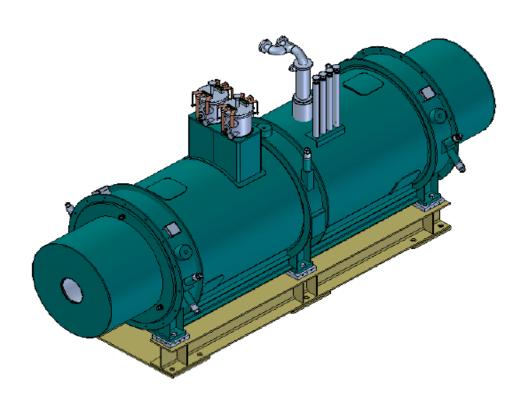
#### Transport



- 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)



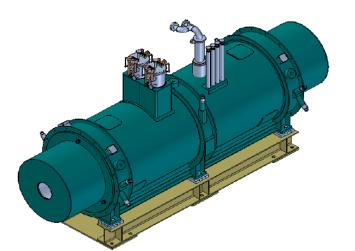
Conceptual multiplet design



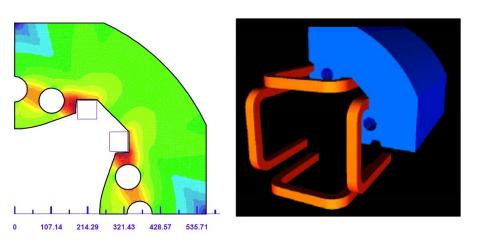
## Design ideas of Multiplet



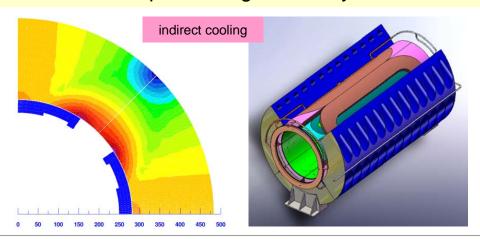
#### Conceptual design made by Toshiba Corporation



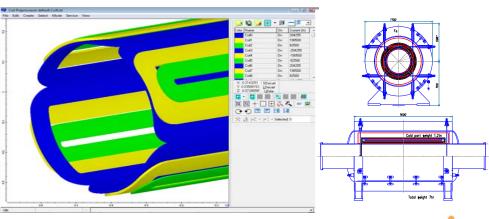
#### Conceptual design of a made by CIEMAT



#### Conceptual design made by CEA



#### 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)	8·10 <sup>-4</sup>	4·10 <sup>-4</sup>	4·10 <sup>-4</sup>	74·10 <sup>-4</sup>	5·10 <sup>-4</sup>	
current leads		cheap standard		HTS		
stray field		short range		long	range	
quench heater	pro	obably unnecessa	ıry	probably necessary		
postion of coils tolerance sensitivity		low sensitivity		high sensitivity	high sensitivity	
Further advantages and disadvantages	similar m	agnets at MSU ar	nd 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 Heat exchanger Heat exchanger Heat exchanger Heat exchanger Heat exchanger He gas 300K He gas 50K

LHe 4.4K

Price (rough estimation)

conventional: ~10 k€ per lead

HTS: ~25 k€ per lead

(∆ ~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



Rated		Effe Apparen	ctive nt Power	Costs Power	Costs Quench	Costs Power	Cable losses	Energy Costs /	Floor space	Number of Cable	Cable Type per
Magnet Design	Current	long quads	short quads	Converters	Protection	Cables and Installation	@ 100%	1000h of operation	requirements	Trays	Power Converter
	[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 (3)	Long fringe field. The magnet is longer than effective length but shorter than a conventional cosine 2 theta quadrupole    Output  Description:		
Quench protection	Can be self protecting. © A false quench detection turns the power supply off.	Quench heater is necessary ①. If quench detection fails => destruction of coil. A false quench detection brings the magnet down.	Quench heater is necessary. More complicated ②. 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 (8)	Bath cooling ©		
Experience	Similar magnets at MSU and RIKEN ©	New development <sup>(S)</sup>	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 <sup>⊗</sup>	High <sup>⊗</sup>		