Magnets

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on behalf of WP 2.2 and WP 2.16

ELENA Project Review
14th – 15th October 2013
31-3-004 - IT Amphitheatre

Overview

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I. Introduction, scope of work package & workflow

B

I. Challenges and solutions for all required magnet families

C

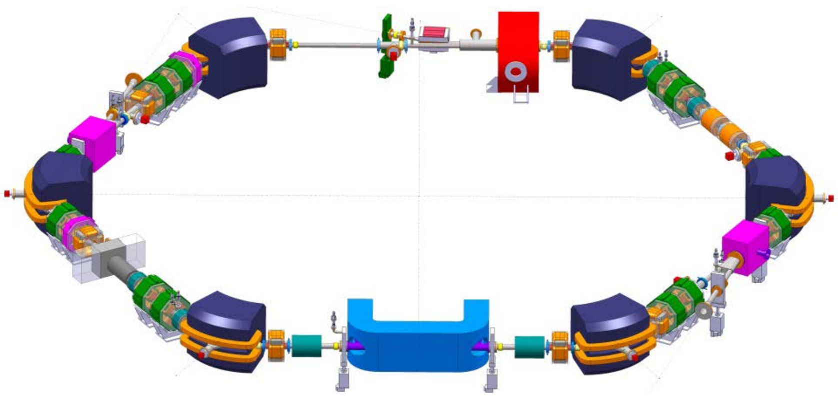
I. Schedule

II. Summary of parameters

III. Procurement strategy

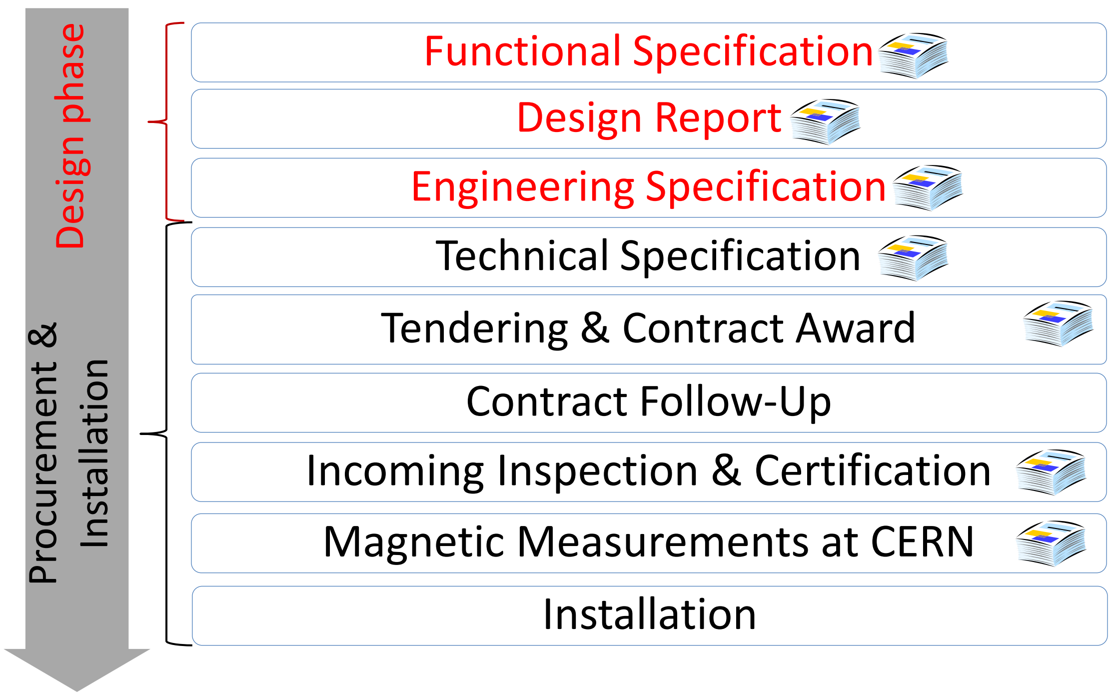
IV. Conclusion

A.I Introduction: Magnet System



- 51 magnets (incl. spare) of 7 types
- Ring magnets + AD-ELENA TL magnets
- Normal-conducting magnets
- Water and air cooled
- Mostly iron-dominated; laminated yokes
- Coil cooling designed for DC operation at maximum field

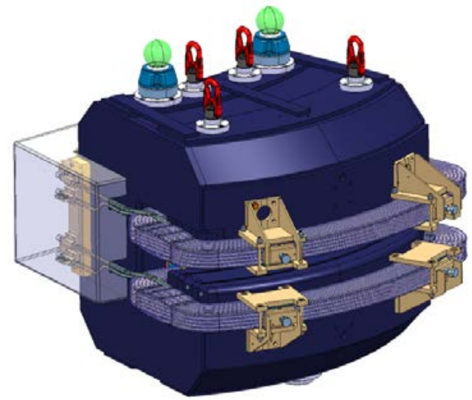
A.I Simplified Workflow: ELENA Magnets

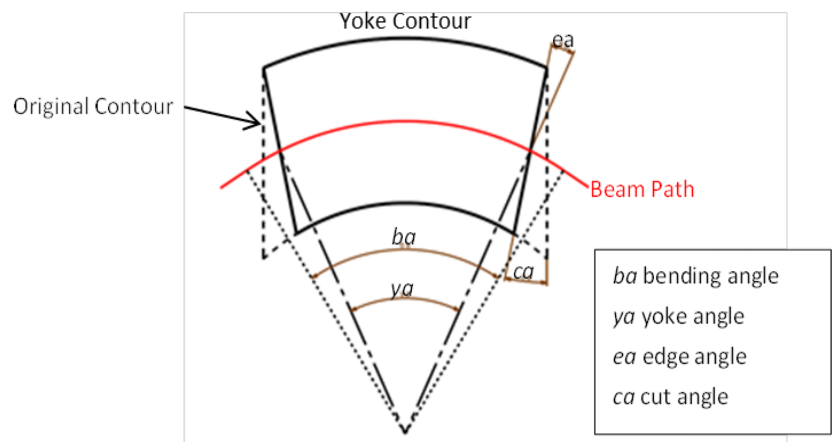


- Functional Specifications define all required information for the design.
- Design Reports document the design process and the taken design decisions.
- Engineering Specifications define the interfaces to other WPs.
- **Further changes of parameters will require to issue an Engineering Change Request.**

B.I Magnets: ELENA Dipole Magnet

Parameter	Value
Number	6 + 1 (Reference) + 1 (Spare)
Field	0.37 T (0.42 T) to 0.05 T
Pole iron gap	76 mm
Bending angle	60°
Radius	927 mm
Magnetic length	970 mm
Cut angle	13°
Ramping speed (up)	0.37 T/s
Ramping speed (down)	0.05 T/s
Good-field-region	$\pm 2 \cdot 10^{-4}$, 66 mm (H) x 48 mm (V)





B.I Magnets: ELENA Dipole Prototype

Challenge

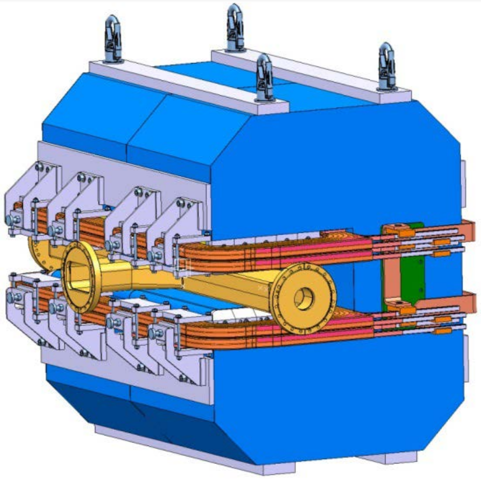
- Excellent and repeatable field quality is requested at very low field.

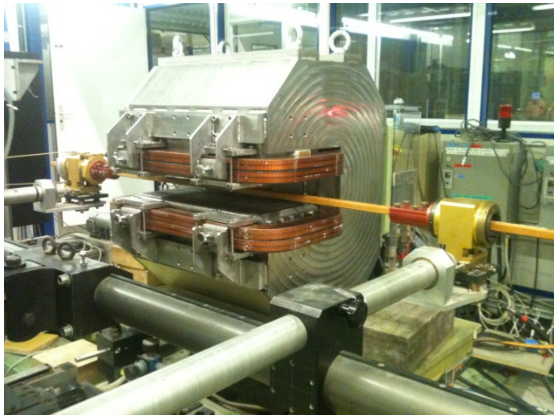
Solution

- Selection of high permeability electrical steel M270-50 A HP.
- Dilution of electrical steel with non-magnetic stainless steel to increase the magnetic induction in the iron and avoid working in the highly nonlinear area of the BH-curve.

Prototype

- Manufacturing methods were studied.
- Planned magnetic measurements: local and integrated dynamic effects, field homogeneity, hysteresis effects, local effect of dilution.
- Concept of shimming will be tested.





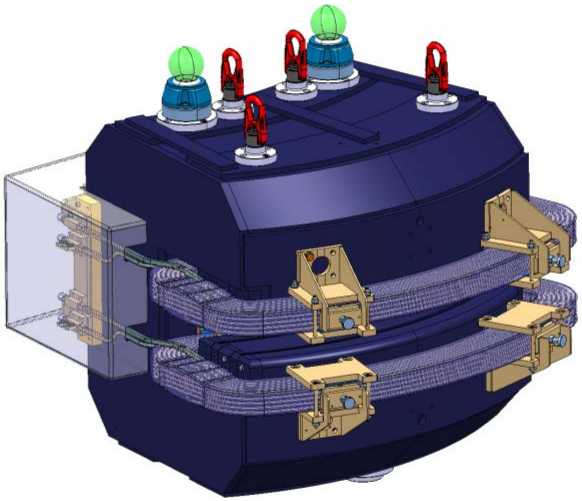
Comprehensive Design Study to be published as ATS report

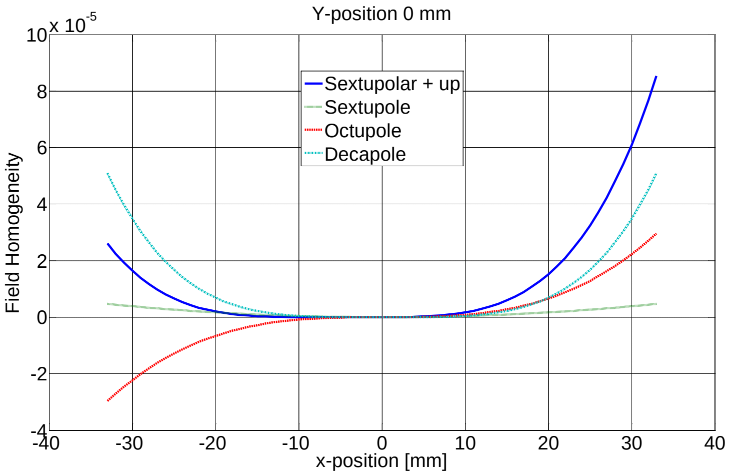
B.I Magnets: ELENA Ring Dipoles

Status
- ELENA dipole prototype measurements are starting.
- Magnetic design finished.
- Engineering and technical specifications are under approval.

Challenges
- Production of the curved yoke is challenging and will require a close follow-up.
- Shimming of final magnet is expected to be time intensive to achieve the requested field homogeneity of $\pm 2\cdot 10^{-4}$ through out the whole working range.
- Eddy currents in vacuum chambers are considered a non-issue and will be measured using the prototype.

Measurement
- Measurement with flux meter is challenging due to small dB_y/dt: long lead item, design and production will start now.





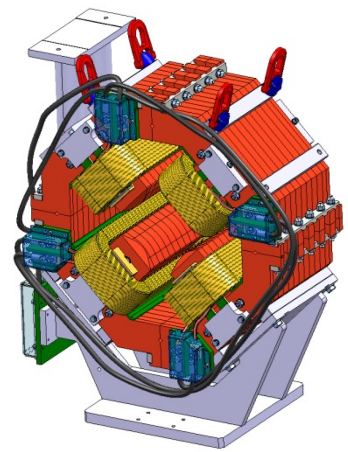
Comprehensive Design Report to be published on EDMS #1311860

B.I Magnets: ELENA Ring & TL Quadrupoles

Status
- Magnetic design finished.
- All documents for call for tender are under approval.
- The design provides stable field quality over the whole required range.

Challenges
- The remanent gradient is only around 2 times smaller than the minimum required gradient: $G_{\mathrm{res}} = -\frac{2\mu_0 H_c l_{\mathrm{iron}}}{r^2} = 9.2 \times 10^{-3}$ T/m.
- Magnets will have to be powered by using the same cycle.
- Prototype is foreseen to validate the above mentioned calculations.

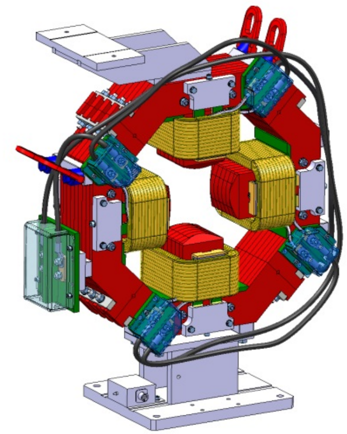
Measurement
- Magnetic measurement of integral field will be performed with existing rotating coil system.



Number of magnet	12 + 3 + 1
Field gradient	0.02-1.45 T/m
Mechanical aperture	124 mm
Magnetic length	250 mm
Good-field-region	$\pm 5 \cdot 10^{-4}$ at ∅54 mm
Designed good-field-region	$1.1 \cdot 10^{-4}$ at ∅54 mm

Design Report published on EDMS #1302869

B.I Magnets: ELENA Ring Skew Quadrupoles



Status

- Magnetic design finished.
- All documents for call for tender are under approval.
- Similar design as for normal quadrupole: Yoke is shorter and coils have less windings.

Challenges

- Same challenges as for normal quadrupole; the prototype will also answer all questions for the skew quadrupole.

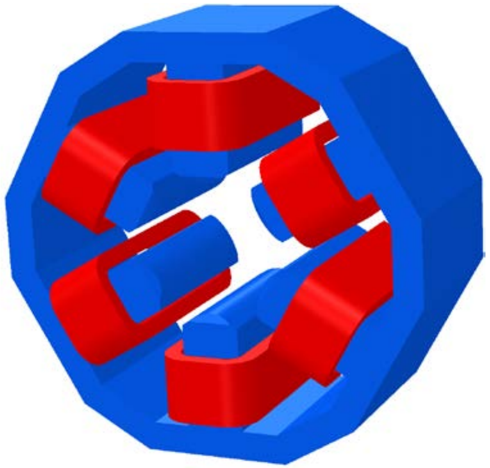
Measurement

- Magnetic measurement of integral field will be performed with existing rotating coil system.

Number of magnet	2 + 1
Field gradient	0.023-0.88 T/m
Mechanical aperture	124 mm
Magnetic length	150 mm
GFR	$\pm 1 \cdot 10^{-2}$ at $\varnothing$46 mm
Designed GFR	$9.2 \cdot 10^{-5}$ at $\varnothing$46 mm

Design Report published on EDMS #1310534

B.I Magnets: ELENA Ring Sextupole



Status

- Magnetic design finished.
- Functional drawings started.
- The design provides stable field quality over the whole required range.

Challenges

- The dynamic range is unusually large: 330!
- The remanent gradient is larger than the minimum required gradient: $B''_{\text{rem}} = -\frac{6H_c l_{\text{mag}}\mu_0}{R^3} = 0.23\,\frac{\text{T}}{\text{m}^2}$. For same cycles, this can be solved by inverting the current direction.

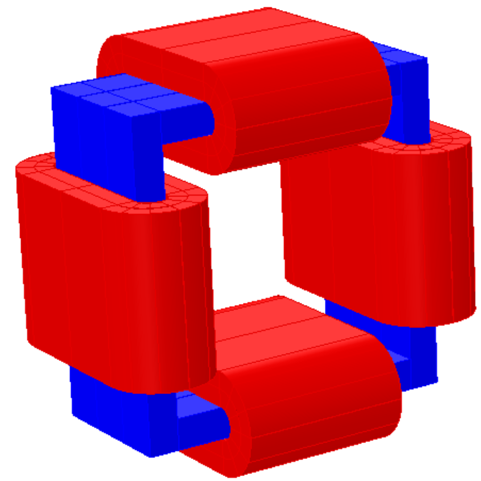
Measurement

- Magnetic measurement of integral field will be performed with existing rotating coil system.

Number of magnet	4 + 1
Field gradient	0.12 - 40 T/m^2
Mechanical aperture	89 mm
Magnetic length	150 mm
GFR	$\pm 2 \cdot 10^{-3}$ at ∅40 mm
Designed GFR	$1 \cdot 10^{-5}$ at ∅40 mm

Design Report published on EDMS #1308783

B.I Magnets: ELENA Ring & TL H/V Correctors



Status
- Magnetic design finished.
- Functional drawings started.

Challenges
- No particular challenges, standard design.
- Cross-talk and remanent fields will be measured for typical ELENA cycles with a similar available corrector.

Measurement
- Magnetic measurement of integral field will be performed with existing rotating coil system.

Number of magnet	8 (+ 2) + 3 + 2
Integrated field	$6 \cdot 10^{-3}$ Tm
Mechanical aperture	124 mm
Magnetic length	310 mm
GFR	$\pm 1 \cdot 10^{-2}$ at ∅44 mm
Designed GFR	$1.9 \cdot 10^{-3}$ at ∅44 mm

Design Report published on EDMS #1308780

B.I Magnets: ELENA Compensation Solenoids

Status

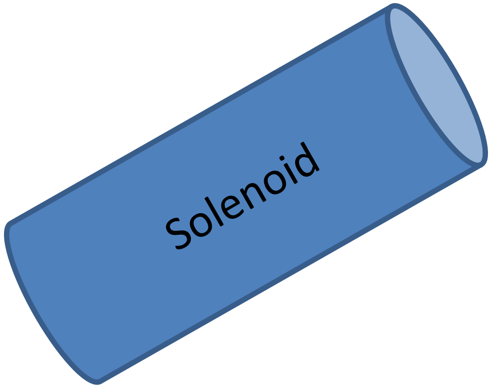
- Compensation solenoids and E-cooler should be considered as a design unit.
- Parameters (length, integrated field) have to be optimized depending on space required for E-cooler.

Challenges

- Standard solenoid with moderate field quality requirements should not provoke challenges.

Measurement

- Measurement will be performed with stretched/vibrating wire measurement system.

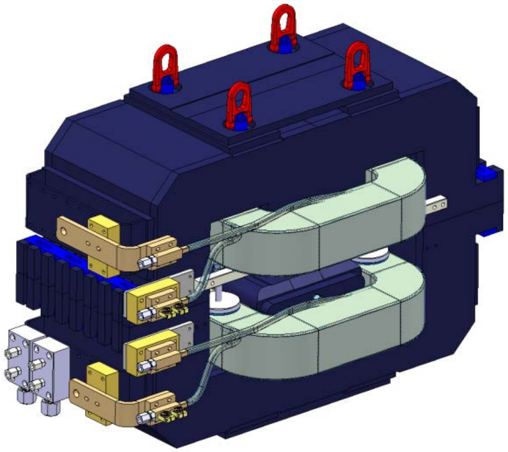


Number of magnet	2 + 1
Field	0.1 T, TBD
Magnetic length	300 mm, TBD
Aperture	89 mm

Possible Design

$NI = 23873\text{ A}$, $I_{\max} = 40\text{ A}$, $N = 600$, $\mathrm{A}_{\text{cable}} = 5 \text{ x } 8\text{ mm}^2$= 39.14 mm^2, 35 Turns, 17 Layers, $U_{\text{DC}} \approx 8\text{ V}$

B.I Magnets: TL Bending Magnets



Status
- Magnetic design finished.
- Functional drawings almost finished.

Challenges
- No particular challenges, standard design.
- Laminated to allow for ramping, but pole profile can be machined to ease the manufacturing process.

Measurement
- Magnetic measurement of integral field will be performed with existing rotating coil system.

Number of magnet	2 + 1
Field	0.67 T
Bending angle	40 degree
Mechanical aperture	65 mm
GFR, straight	$\pm 1 \cdot 10^{-3}$ at 68 x 48 mm^2
Designed GFR, straight	$\pm 3 \cdot 10^{-4}$ at 68 x 48 mm^2

Design Report published on EDMS # 1297334

C.I Summary: Parameters

ELENA RING

Design-Status	Element type	Label	Short label	Total number of magnets	Aperture in mm	Good-field region in mm	Integrated field homogeneity	Magnetic length in m	Mechanical length in m	Maximum field strength	Minimum field strength	Instrumentation
	Bending Magnet, Horizontal	PXMBHEKCWP	MBR	8	76	66 (H) x 48 (V)	$\pm 2\cdot 10^{-4}$	0.97	1.20	0.42 T	0.05 T	None
	Quadrupole, Normal	PXMQNLGNAP	MQR	13	∅124	∅54	$\pm 5\cdot 10^{-4}$	0.25	0.31	1.45 T/m	0.02 T/m	BPMs
	Sextupole, Normal	PXMXNADNAP	MXR	5	∅89	∅40	$\pm 2\cdot 10^{-3}$	0.15	0.16	40 T/m^2	0.12 T/m^2	None
	Quadrupole, Skew	PXMQSABNAP	MQS	3	∅124	∅46	$\pm 1\cdot 10^{-2}$	0.15	0.17	0.88 T/m	0.023 T/m	None
	Corrector H+V	PXMCCAYWAP	MCR	9 (+2)	∅124	∅44	$\pm 1\cdot 10^{-2}$	0.31	0.22	$6\cdot 10^{-3}$ Tm (integrated)	-	BPMs
	Solenoid	PXMLNAFNAC	MLR	3	TBD	TBD	TBD	TBD	TBD	TBD	-	None

TL AD to ELENA

Design-Status	Element type	Label	Short label	Total number of magnets	Aperture in mm	Good-field region in mm	Integrated field homogeneity	Magnetic length in m	Mechanical length in m	Maximum field strength	Instrumentation
	Bending Magnet, Horizontal	PXMBHCBCWP	MBL	3	65	68 (H) x 48 (V)	$\pm 1\cdot 10^{-3}$	0.35	0.49	0.67 T	None
	Quadrupole, Normal	PXMQNLGNAP	MQR	3	∅124	∅54	$\pm 5\cdot 10^{-4}$	0.25	0.31	1.45 T/m	None
	Quadrupole, Normal	PXMQNAFNWP	QPMA	1	∅60	∅20	$\pm 2\cdot 10^{-3}$	0.23	0.30	11.2 T/m	None
	Corrector H+V	PXMCCAYWAP	MCR	4	∅124	∅44	$\pm 1\cdot 10^{-2}$	0.31	0.22	$6\cdot 10^{-3}$ Tm (integrated)	None

Fixed parameters, further changes require a formal Engineering Change Request (ECR) for green and yellow items!

C. II Schedule

- Re-optimization of the schedule was necessary to cope with the late delivery of the magnet parameters.
- An optimization of the schedule makes a magnet delivery until 15/12/2015 possible.
- We will try our best to catch up the remaining delay by trying to accelerate the approval process inside CERN and by performing close follow-up after contract placement.

Dipole Schedule:

ID	*Task Name*	*Start*	*Finish*	*Duration*	*Q4 13 Q1 14 Q2 14 Q3 14 Q4 14 Q1 15 Q2 15 Q3 15*
1	Prototype Measurement	15/10/2013	13/12/2013	8w 4d	
2	Contract Preparation & Placement	15/10/2013	17/02/2014	18w	
3	Pre-Series Production	08/04/2014	17/02/2015	45w 1d	
4	Series Production & Acceptance	01/01/2015	01/12/2015	47w 4d	
5	Installation Period	04/08/2015	15/12/2015	19w 1d	

C.III Procurement Strategy: ELENA Magnets

- All magnet families will be procured independently of each other (in total 6 contracts) because all manufacturers are small and have currently many contracts to follow.
- Normal and skew quadrupole magnets share the same lamination design and will be therefore procured together.
- Bending magnets and quadrupoles are expected to be in the contract class >200 kCHF and require an Invitation to Tender. A Market Survey was performed and 6 companies were qualified.
- Four contracts are expected to be in the contract class <200 kCHF and will require no pre-qualification. Qualified companies, and depending on experience new suppliers, will be asked to provide offers.
- Electrical steel and stainless steel will be procured by CERN and delivered to the companies to reduce the delay and facilitate the procurement.

C. IV Conclusion

The following specifications/activities are finished:

- Functional Specifications
- Design Reports for all magnets (except solenoids)
- Dipole prototype; measurements are starting
- Engineering Specification: MQR, MQS, MBR; for other magnets information available
- Functional drawings: MQR, MQS, MBR, MBL under approval; MXR & MCR under preparation
- Technical Specification: MBR, MQR & MQS approval process started

We see the following challenges:

- Technical challenges can be addressed with prototypes for the bending magnet and the quadrupole.
- Measuring the ELENA dipole magnet requires a dedicated flux meter.
- Parameters of the compensation solenoid are required before starting with the design.
- To meet the schedule and avoid technical complications design changes should be avoided in the future.
- Further changes on the magnet’s parameter will require a formal Engineering Change Request.