Status of the magnets for ELENA

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AD-User/ELENA Meeting

20th November 2012 – 16:40 - 17:10

Room 37-R-022

Overview

A

I. Introduction, scope of work package & workflow
II. Main acceptance criteria for ELENA magnets
III. Design & manufacturing of the dipole prototype

B

I. Procurement of ELENA magnets
II. Cost estimate

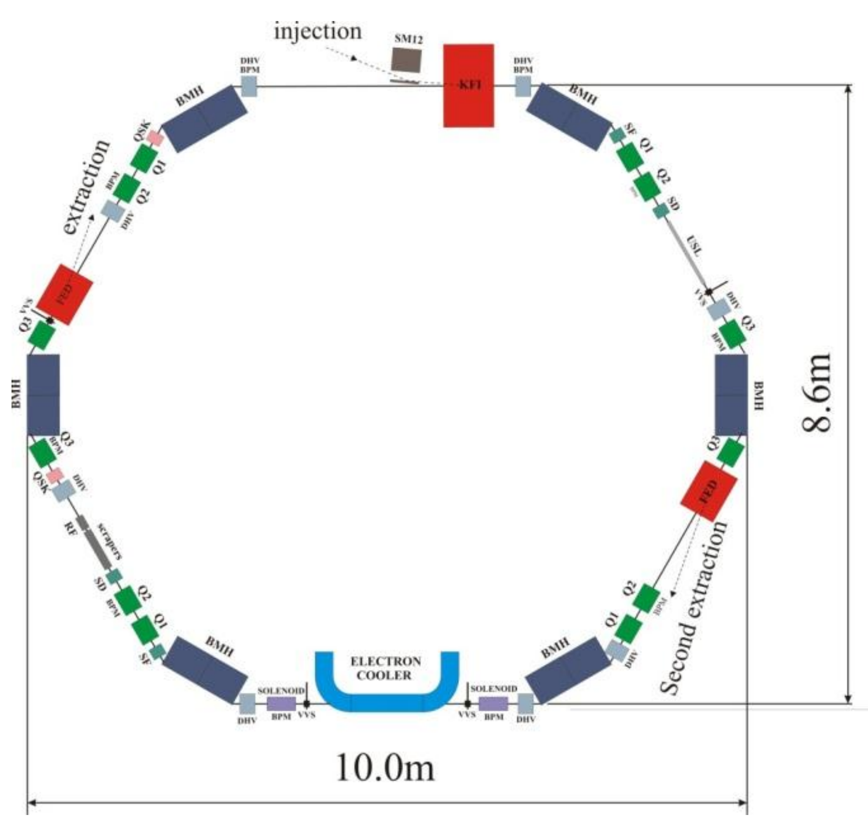
C

I. Summary

A.I Introduction: History

2006	**First contact** of TE-MSC-MNC with ELENA project
2007	**Preliminary magnet design** by T. Zickler; summarized in EDMS: 823968
2010-2011	**Updated conceptual magnet design** by A. Vorozhtsov; summarized in EDMS: 1164537
12/2011 – to date	**Further refinements & design:** Refinement of magnetic design and field quality requirements, design of prototype magnet, discussion on procurement of material, prototype and magnets; see EDMS documents: 1178055, 1208752, 1220958, 1225966, 1231755, 1240824, 1240830, 1240832, 1247757; CDD: AD_MBHEK% **Focus** on technically most challenging magnet type: ELENA bending magnet **Design adaptation** will be required after decision on final lattice, aperture and beam instrumentation

A.I Introduction: Magnet System



- 49 magnets (incl. spare) of 8 types
- Normal-conducting magnets
- Water and air (convection) cooled
- Mostly iron-dominated; laminated yokes
- Cooling designed for DC operation at maximum field

A.I Scope of work package: Overview

RING	Number of magnets	Aperture [mm]	GFR [mm]	Field error in GFR	Magnetic length/ Mechanical length(*), [m]	Field strength	Maximal pole field [T] including margin	Remarks
Bending magnet	6+1 B-Train +1 spare	100	66(H)x48 (V)	$\pm 2\cdot 10^{-4}$	0.97/1.19	0.05-0.36 T	0.36 (0.42)	Schottky pick-up
Quadrupole	12+1 spare	∅111	∅54	$\pm 5\cdot 10^{-4}$	0.25/0.34	0.035-1.1 T/m	0.050 (0.066)	BPMs installed
Sextupole	4+1 spare	∅91	∅43	$\pm 2\cdot 10^{-3}$	0.15/0.16	0.12-22 T/m²	0.023 (0.034)	No instrumentation
H/V corrector	8+1 spare	∅111	∅43	<1%	0.31/0.20	6×10^{-3} Tm (integrated)	0.04 (no margin)	BPMs installed
Skew quadrupole	2+1 spare	∅91	∅40	<1%	0.15/0.16	0.2 T/m	0.009 (0.018)	No instrumentation
Solenoid	2+1 spare	TBD	∅38	$\pm 3\cdot 10^{-4}$	0.41/0.46	0.02 T	0.02 (0.04)	BPMs installed

* Preliminary values, final mechanical length can be determined only after detailed mechanical design study

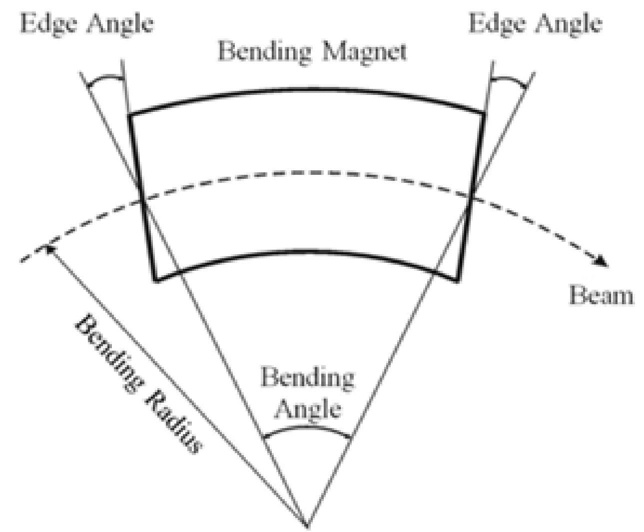
TL	Number of magnets	Aperture [mm]	GFR [mm]	Field error in GFR	Magnetic length [m]	Field strength	Pole field [T]	Remarks
Bending magnet	3+1 spare	71	45x40	$\pm 5\cdot 10^{-4}$	0.55	0.32 T	0.32	No instrumentation
Quadrupole	2+1 spare	∅71	∅50	$\pm 1\cdot 10^{-3}$	0.40	1 T/m	0.036	No instrumentation
H/V corrector	1 (same type as for ring)	∅111	∅43	<1%	0.31	6×10^{-3} Tm (integrated)	0.04	No instrumentation

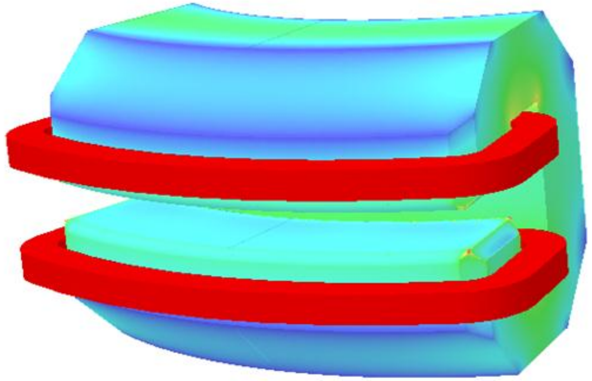
ALL PARAMETERS ARE PRELIMINARY

A.I Scope of work package: Parameter

ELENA Dipole Bending Magnets

Parameter	Value
Number	6 + 1 (Reference) + 1 (Spare)
Field	0.37 T (0.42 T) to 0.05 T
Pole iron gap	100 mm
Bending angle	60°
Radius	927 mm
Magnetic length	970 mm
Edge angle	18°
Ramping speed (up)	0.37 T/s
Ramping speed (down)	0.04 T/s
Good field region	$\pm 2 \cdot 10^{-4}$, 66 mm (H) x 48 mm (V)





A.I Workflow: ELENA Dipole Magnets

Prototype phase

- Electro-magnetic design of prototype
- Choice of materials
- Mechanical design of prototype
- Manufacturing of yoke
- In-house manufacturing of coils
- Assembly & integration of vacuum chamber
- Magnetic measurement of prototype
- Prototype Report

Design phase

- Functional Specification (final parameters)
- Design Report
- Engineering Specification
- Technical Specification

Procurement & Installation

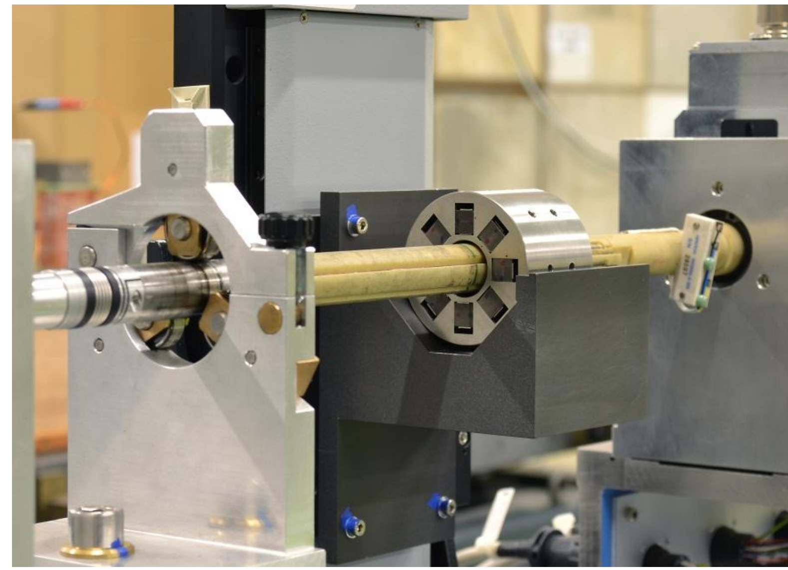
- Tendering & Contract Award (Danish in-kind contribution expected)
- Contract follow-up
- Magnetic measurements at CERN
- Installation

- Prototype design completed
- Early corrective actions possible
- Final parameters for transfer line and ring are under discussion

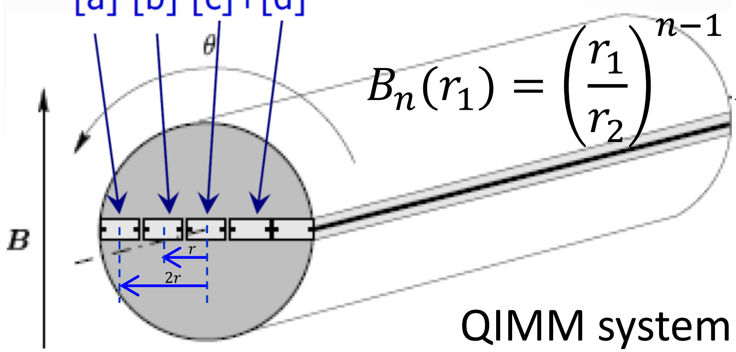
Support from collaborators in all these steps is highly appreciated, so please do not hesitate to contact us if you are interested in joining the ELENA magnet team

A.II Acceptance criteria: Field Quality

Name	Number of available segments	Measurement radius (mm)	Outer diameter shaft + support tube(mm)
LHC dipole	several	17	45
QIMM small	2	17	53
QIMM large	2	27	73
MQXC	1	45	106



Quadrupole scheme
[a]-[b]-[c]+[d]



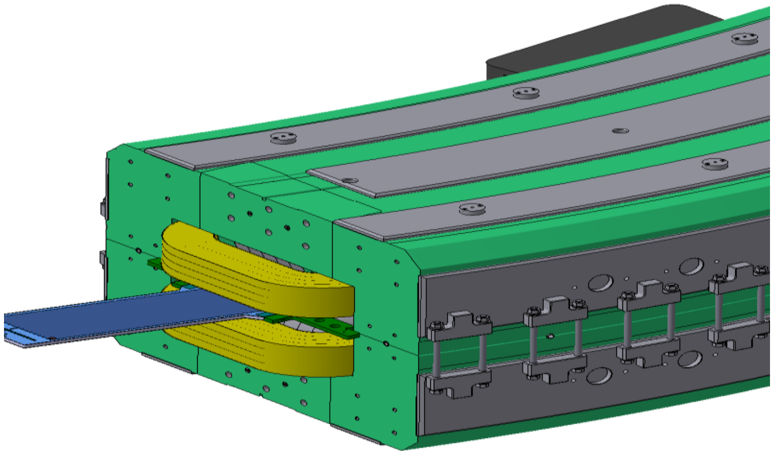
$$B_n(r_1) = \left(\frac{r_1}{r_2}\right)^{n-1} B_n(r_2)$$

QIMM system

- Commonly accepted field quality definition for straight magnets available
- High precision measurement equippment available at CERN

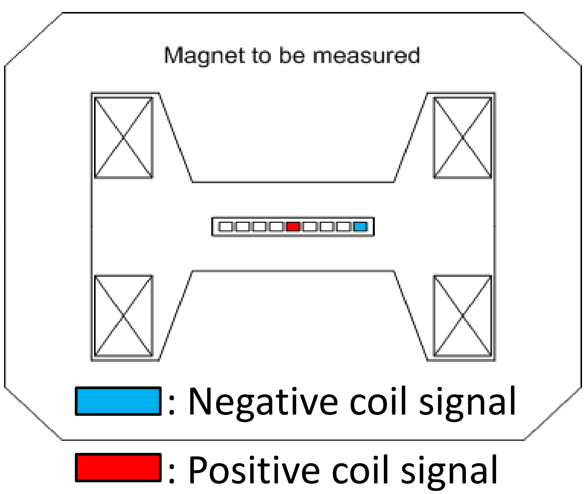
L. Walckiers, in Proceedings of the CAS-CERN Accelerator School: Magnets, Bruges, Belgium, 16-25 June 2009, edited by D. Brandt, CERN-2012-004, pp357-386

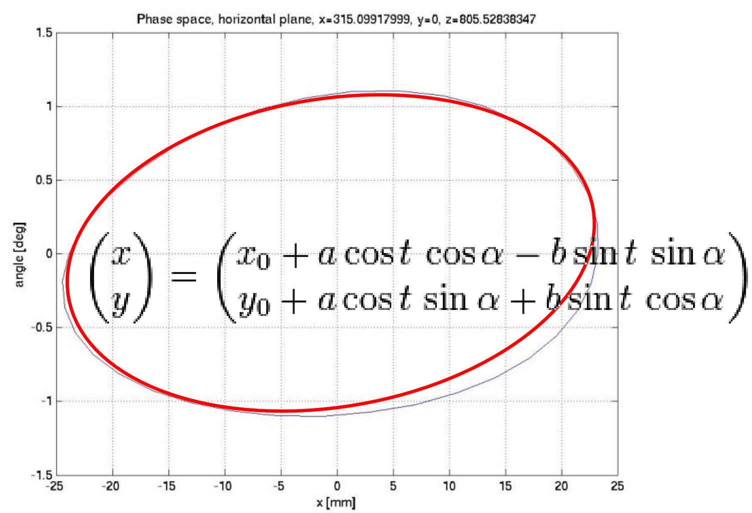
A.II Acceptance criteria: Field Quality



ELENA Dipole Magnet

- Field quality evaluation with tracking code
- Hall probe mapping and flux meter measurements forseen





$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} x_0 + a\cos t\ \cos\alpha - b\sin t\ \sin\alpha \\ y_0 + a\cos t\ \sin\alpha + b\sin t\ \cos\alpha \end{pmatrix}$$

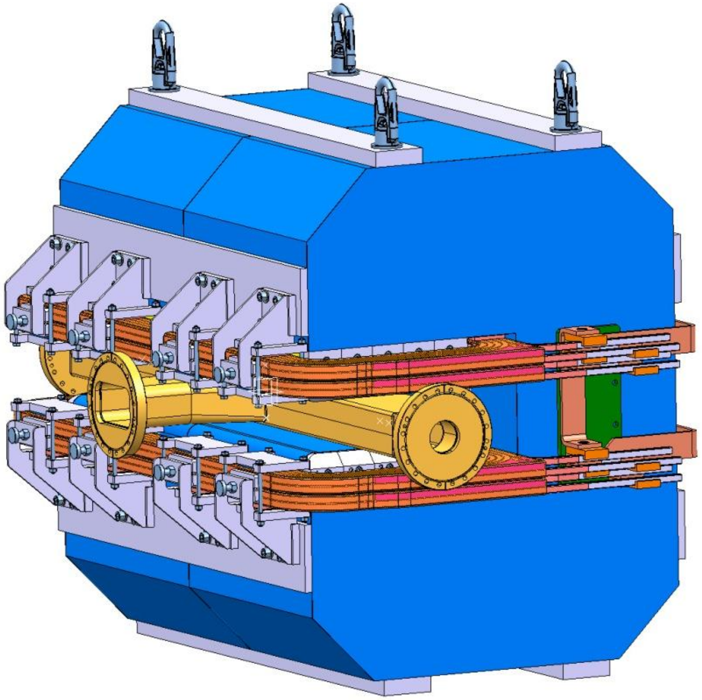
A.III Dipole Prototype: Scope & Purpose

Challenge

- Excellent field quality is requested at very low field

Solution

- 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



Ideas to be tested with prototype

- Production process of a magnetic yoke diluted with stainless steel plates
- Field quality of such a yoke
- Choice of soft magnetic steel
- Hysteresis effects
- Mechanical deformations
- Thermal insulation to intercept heat load from backing for activation of NEG coating in the vacuum chamber (use of 7 mm jackets instead of 20 mm thick jackets)
- Cutting of edge angle and resulting cut laminations
- End shim design & general design issues

A.III Prototype: 3D Packing Factor Analysis

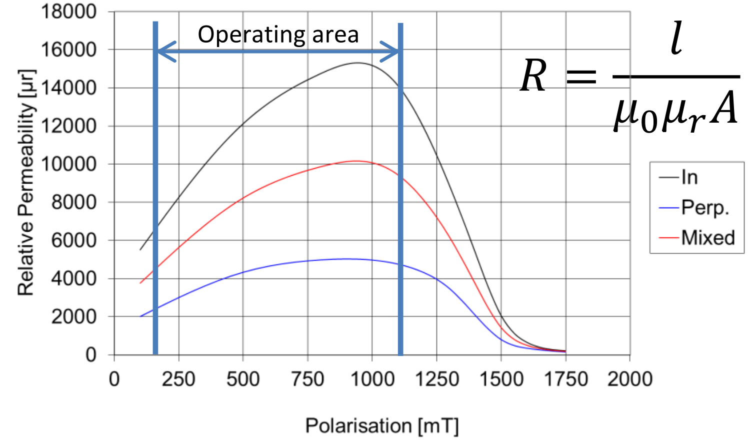
Requirements

- Low field magnet (0.4 T- 0.05 T) with a dynamic range of 8

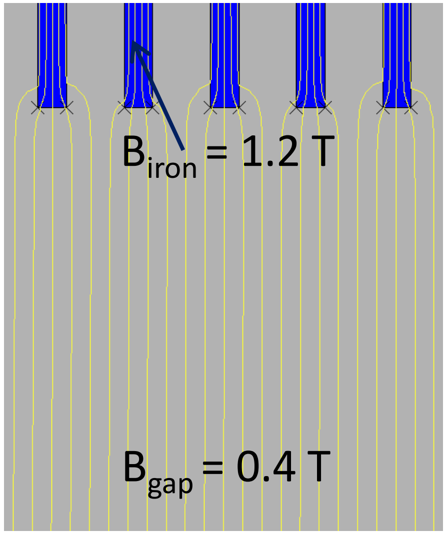
Results

- Intensive simulations have shown that packing is a far-field effect which has no negative impact on the required field quality

Isovac 270-50A HP



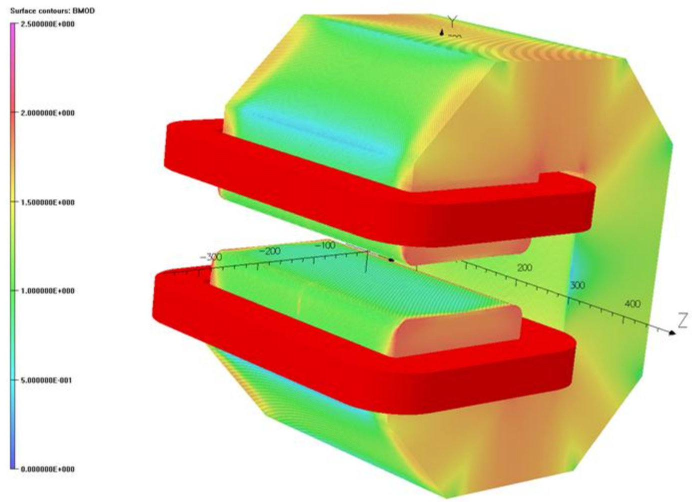
$$R = \frac{l}{\mu_0 \mu_r A}$$



Explaination

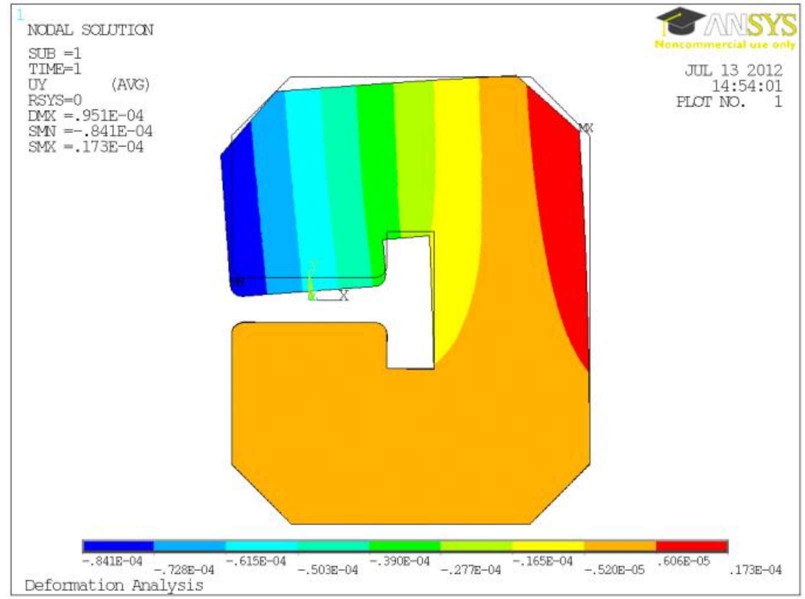
- Maximization of relative permeability
- Ratio 1 (stainless steel) : 2 (iron)

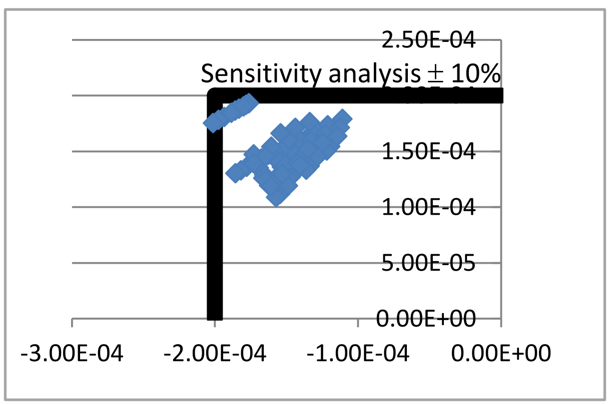
Simulation with diluted yoke

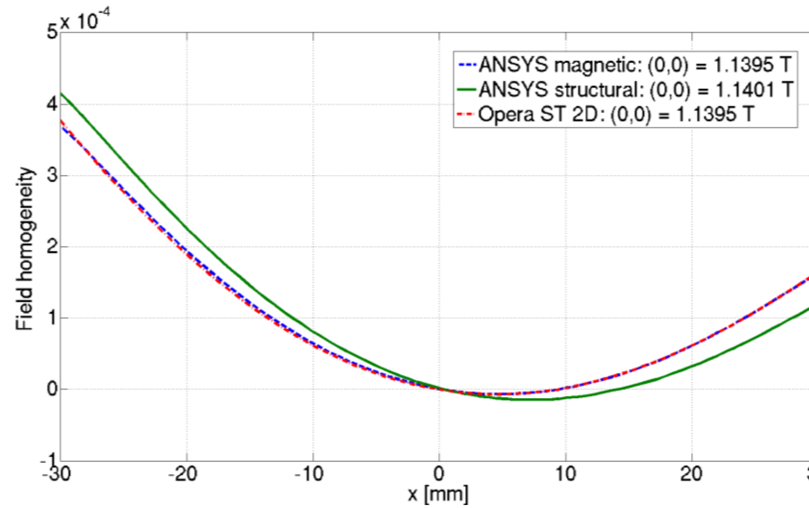


A.III Dipole Prototype: 2D Design

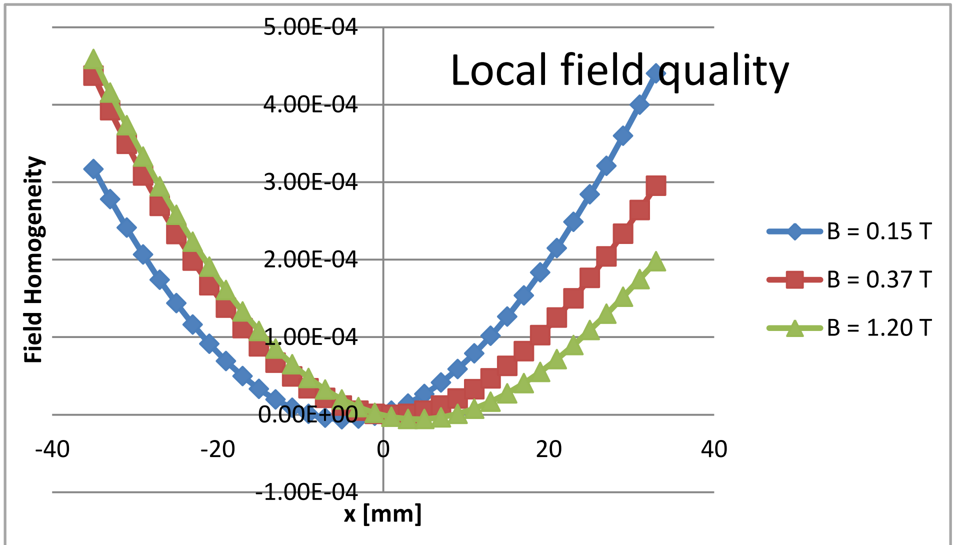
- Different pole profiles were simulated, decision for hyperbolic shape was taken
- Sensitivity analysis shows small influence on field quality of manufacturing errors
- Sextupole component in 2D design was enhanced to reduce effect on integrated field quality
- Due to the small variation of the phase space advance in the bending magnets the integrated field quality is considered much more important than the local field quality
- A quadrupolar component could be easily compensated with the installed quadrupoles

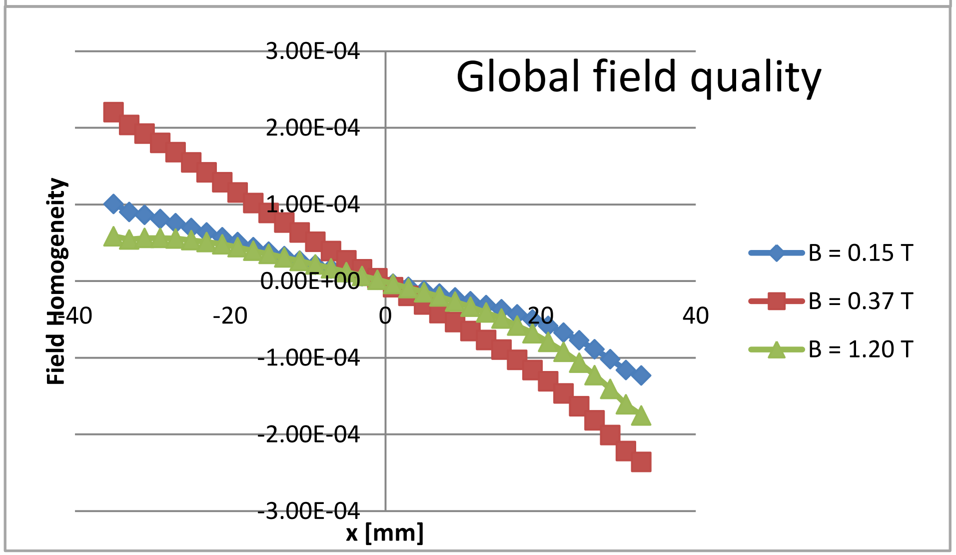


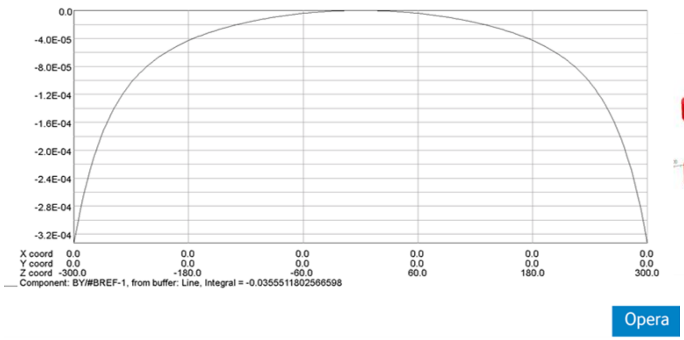


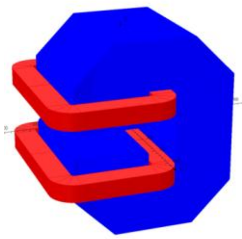


A.III Dipole Prototype: 3D Design



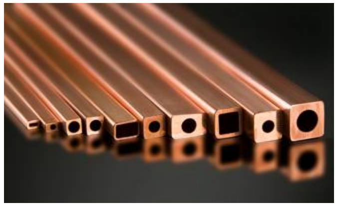


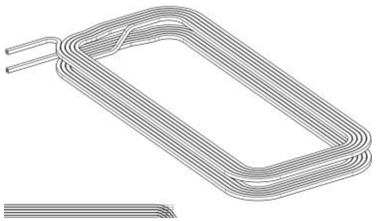


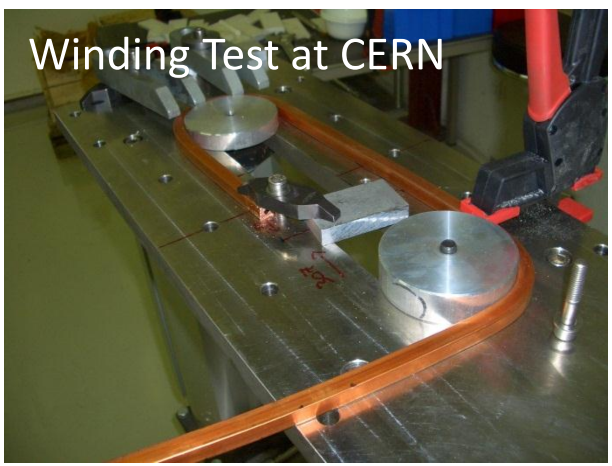


- No edge angles, therefore simple optimization possible
- Sextupolar component in 2D design improves the integrated field quality

A.III Prototype: Coil Manufacturing







1. Define conductor type and material
2. Conductor insulation
3. Winding
4. Ground insulation
5. Epoxy impregnation

Important Considerations

- Water cooling is required for all equipment emitting more than 3 kW in AD hall
- Copper coil to reduce size compared to Aluminum

Status

- Drawings finalized
- Material insulation delivered manufacturing at CERN or external company (offer requested)

A.III Prototype: Yoke Material Selection

- Electrical steels were investigated
  - Fully finished grades: NO30, M270-50A (HP), M330-50A, M330-50A HP, M400-65A, M530-65A, M600-65A, M700-65A, M800-50A, M800-65A
  - Semi-finished electrical steel to minimize the influence of cold-work
  - Grain-oriented electrical steel
  - Amorphous metal , High-silicon electrical steel (6.5% silicon content), NiFe steels, Iron powder
  - Thickness of material
    - Damping of higher harmonics from PC
    - Damping of eddy currents after ramping

Electrical Steel	M270-50 A HP
H_c	<40 A/m
μ_r	6500 – 15000 (In), 2500 – 5000 (Perp.)
Thickness	0.5 mm
Surface	Coated with Rembrandtin Backlack Remisol EB 548

To achieve low coercive force, high permeability and high electrical resistivity (low saturation induction not a problem) electrical steel with high silicon content was selected

A.III Prototype: Design & Manufacturing

Laser-cutting of laminations

Stacking laminations into yokes

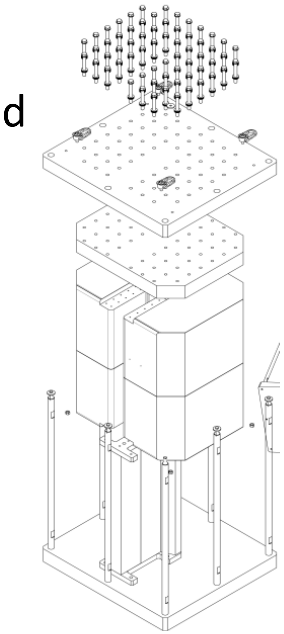
Welding and gluing

Machining

Assembly

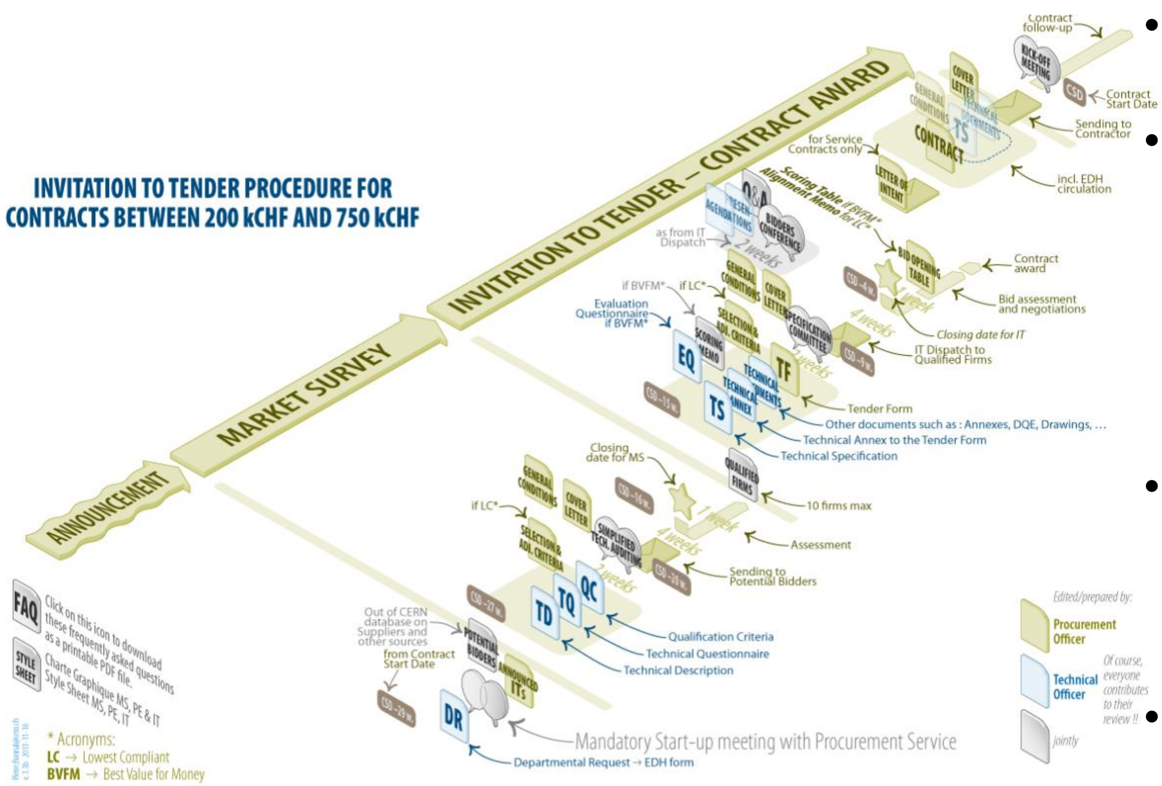
Status

- Drawings are being finalized
- Material ordered and delivered
- Offers received
- Final bonding tests are on-going
- Delivery time after signature: 8 weeks



- Laser-cutting tolerances around 40 µm compared to 20 µm for fine blanking
- Electrical steel is available with bonding varnish on both sides
- Stainless steel is uncoated, best surface is under study
- To activate the bond a pressure of 10 bar and a temperature of 130°C to 180 °C for 2-24 h is required
- Weld 141 is used to weld non-magnetic stripes on the yoke

B.I Procurement of ELENA magnets



- Departmental requests are issued and approved
- Market Survey documents (Technical Description, Technical Questionnaire, Qualification Criteria) are prepared and the simplified technical auditing was performed
- Positive replies of around 9 companies were received for the market survey and are right now evaluated
- These procurement regulations do not apply for in-kind collaborations!

In-kind collaborations are still possible and highly appreciated!

B.II Cost Estimate & Spending Profile

	ELENA Bending Magnet	ELENA Quadrupole	ELENA Sextupole	ELENA + TL H/V Correctors	ELENA Skew Quadrupole	ELENA Solenoid	TL Bending Magnet	TL Quadrupole	Unit
	Potentially Danish in-kind contribution		CERN budget						
Fixed cost	170.9	86.6	66.0	68.1	57.7	40.0	89.9	61.7	kCHF
Material cost	220.6	9.1	1.6	12.8	1.1	4.2	41.3	2.4	kCHF
Manufacturing cost	282.5	165.7	40.0	96.1	26.5	28.0	88.8	39.7	kCHF
Total cost	**674**	**261**	**108**	**177**	**85**	**72**	**220**	**104**	**kCHF**
Percentage of total cost	39.6	15.4	6.3	10.4	5.0	4.2	12.9	6.1	%

Year	2012	2013	2014	2015
Budget	**100**	**550**	**750**	**300**

TOTAL ESTIMATED COST: 1700 kCHF

C. I Summary

- Prototype design is finished, final tests before manufacturing are performed
- Magnet design is advanced, but final parameters are still under discussion
- Cost estimate and schedule is available
- For in-kind collaborations the CERN procurement rules do not necessarily apply
- Decision of Danish FNU what will be delivered as in-kind contribution is expected around end of 2012

In-kind collaborations are still possible and highly appreciated!