Status of magnets R&D for CLIC BDS

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Acknowledgments:
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International Workshop on Future Linear Colliders
LCWS13
11-15 November 2013, The University of Tokyo

Outline:

1) CLIC QD0 status

2) Anti-solenoid studies

3) CLIC SD0 status

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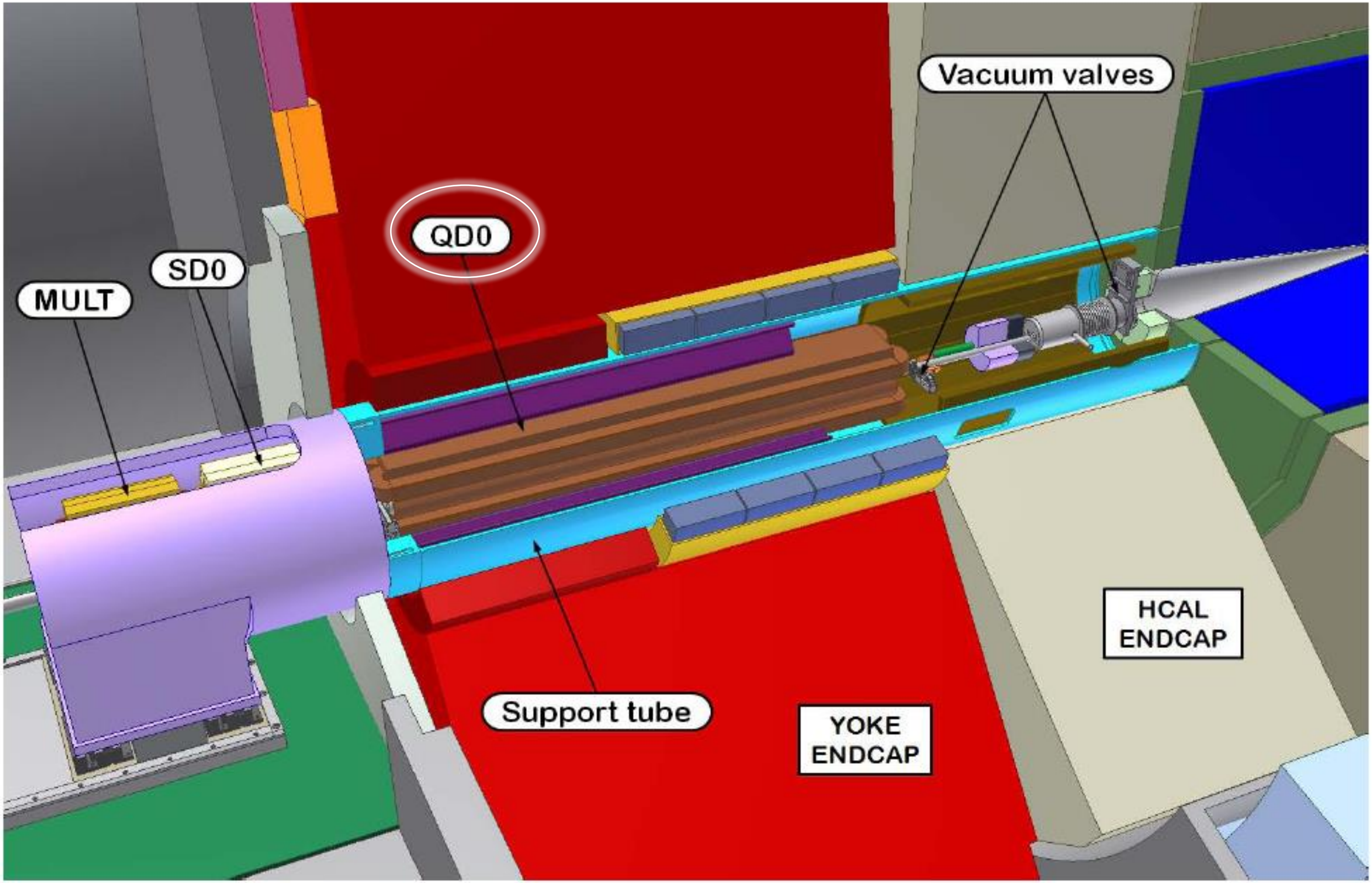
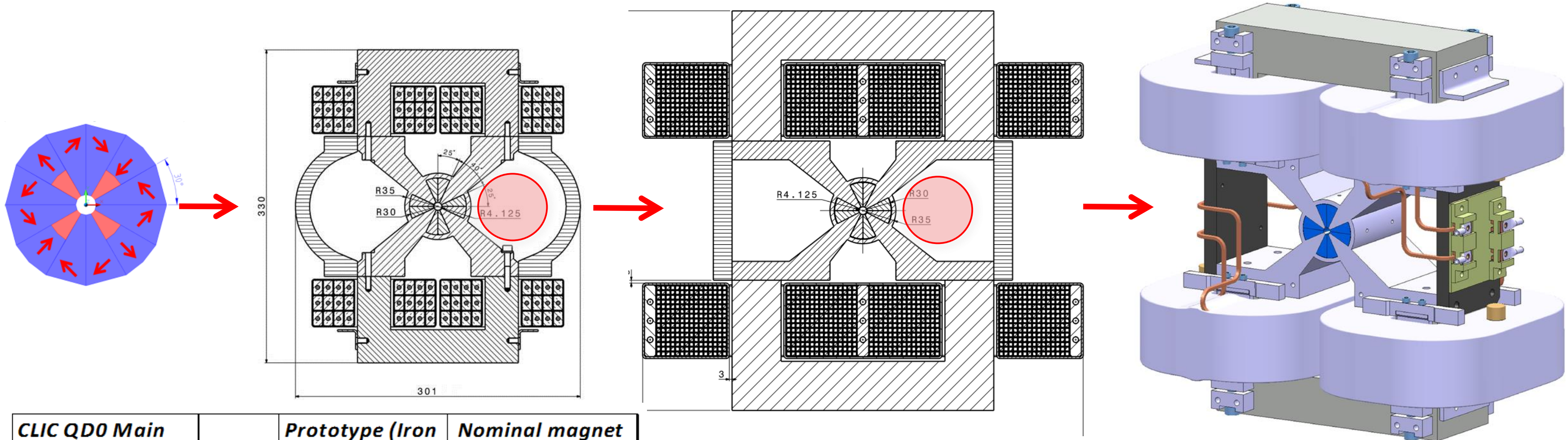
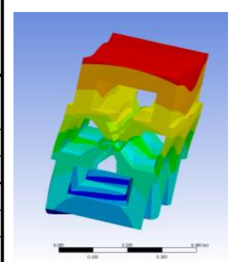


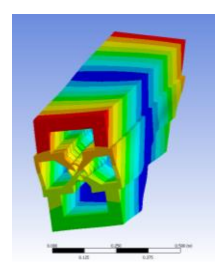
CLIC QDO (3 TeV; L*=3.5 m) typical layout

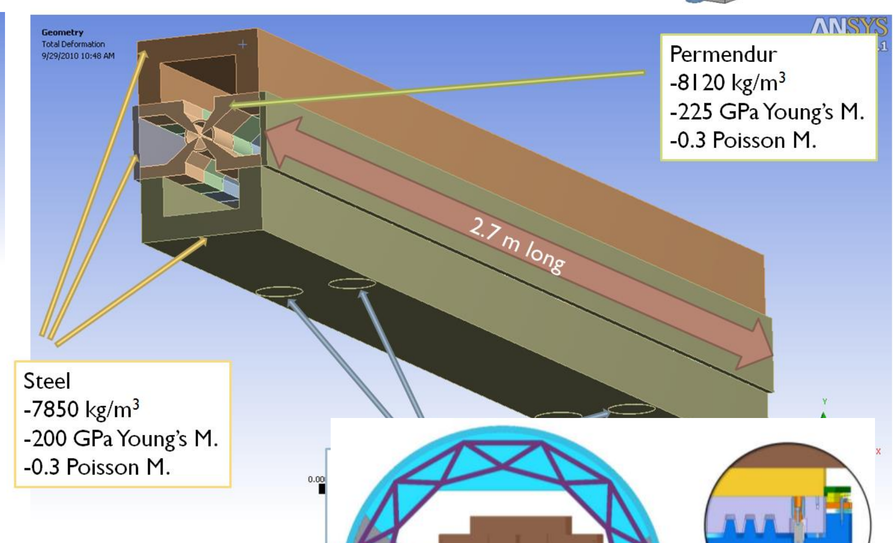
CLIC QD0 Status

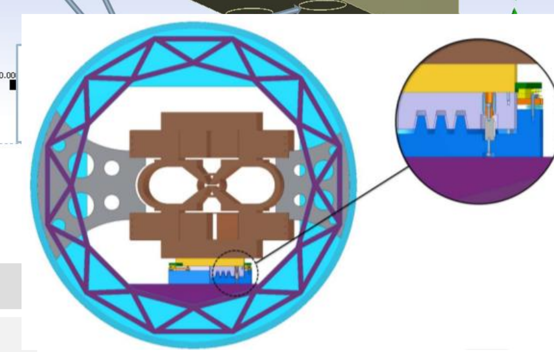


CLIC QD0 Main Parameters		*Prototype (Iron yoke length of 100 mm)*	*Nominal magnet (Iron yoke length of ~ 2500 mm)*
Max. Gradient (computed)	[T/m]	552	615
Magnet aperture	[mm]	8.25	8.25
Tunability		32÷100%	32÷100%
GEOMETRY			
Total length	[mm]	273	2600
Width	[mm]	468	518
Height	[mm]	424	424
Total mass	kg	~ 200	~2700
COILS			
Conductor size	[mm]	4x4	4x4
N. of turns		324 (18x18)	324 (18x18)
Average turn length	[m]	0.586	5.786
Total coils (4) mass	[kg]	107.2	1060.8
ELECT.PARAMETERS			
Ampereturns per pole	[A]	5000	5000
Current	[A]	15.4	15.4
Current density	[A/mm²]	1	1
Total resistance	[mOhm]	896	8838
Total voltage	[V]	13.8	136.4
Total power	[W]	213	2150





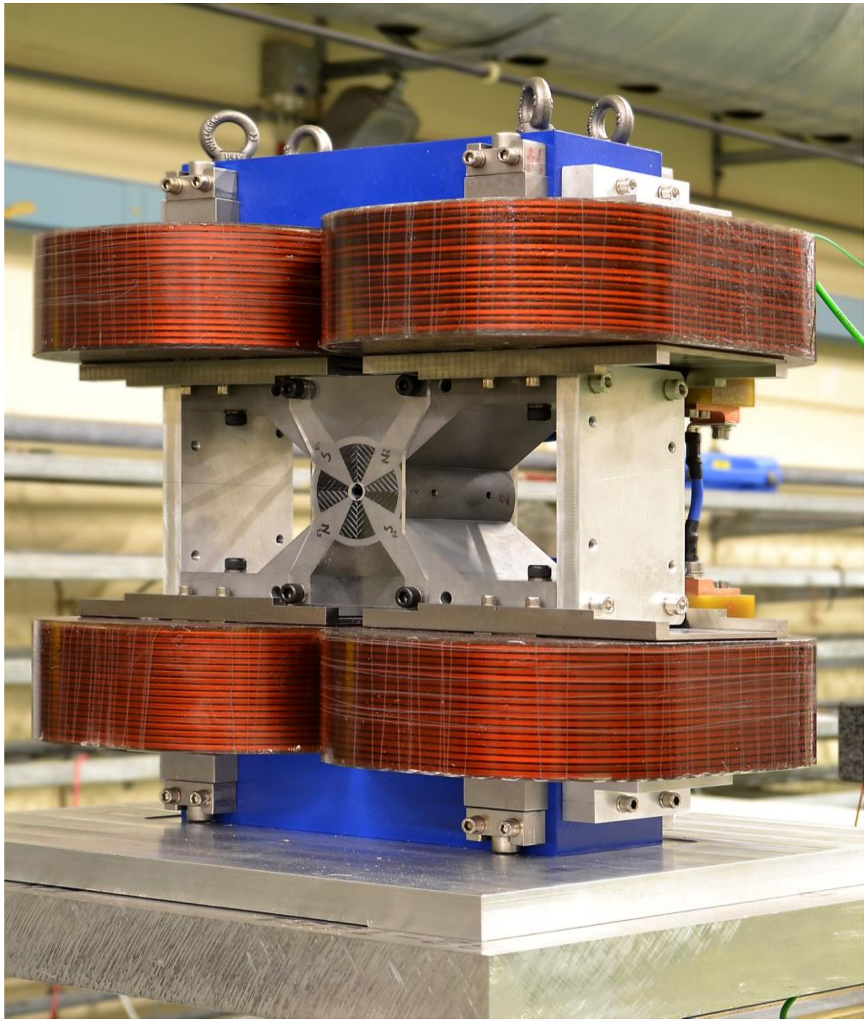




Modal analysis of the central part (full size case, weight: ~ 1500 kg)

Mode	1st	2nd	3rd	4th
Freq [Hz]	190	260	310	366

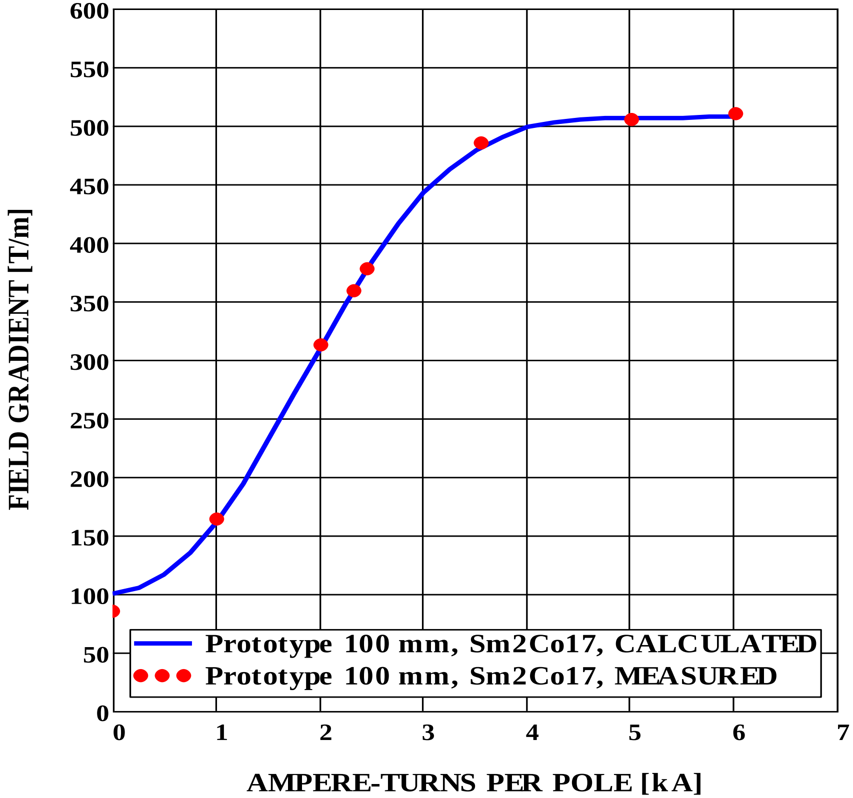
- A **short QD0 prototype** (for CLiC 3TeV layout) **was built** at CERN in 2010-2011.
- **Objective**: validate the Hybrid Magnet design proposed:
  PM blocks - Permendur core structure - coils for tunability (low current density).
- **Two** campaign of measurements were done in 2012 in two different configuration:

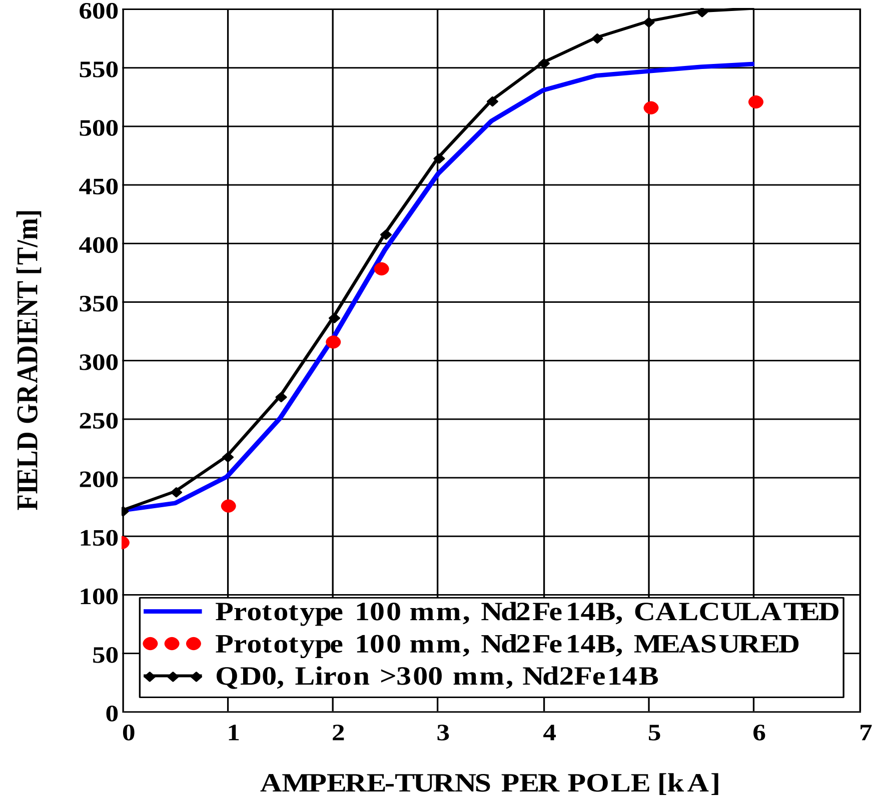


- QD0 equipped with **$Nd_2Fe_{14}B$** blocks (measured in January 2012)
- QD0 equipped with **Sm_2Co_{17}** blocks (measured in August 2012).
- ***"Vibrating Wire"*** MM method was used (the only available due to the small magnet radius).

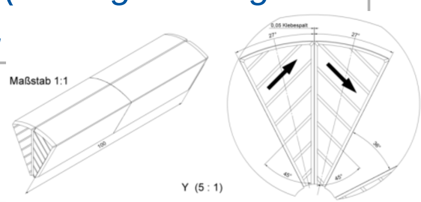
Main Parameter	*Value*
Required field gradient G	575 T/m
Prototype gradient expected	547*(NdFeB)* ; 503*(SmCo)* T/m
Magnetic length (full size QD0)	2.73 m
Magnet aperture *(required for beam)*	7.6 mm
Magnet bore diameter *(assuming a 0.30 mm vacuum pipe thickness)*	8.25 mm
Good field region(GFR) radius	1 mm
Integrated field gradient error inside GFR	< 0.1%
Gradient adjustment required	+0 to -20%

COMPUTED Gradient (blue curves) and MEASURED Gradient (red dots) (extrapolated from the INTEGRATED GRADIENT effectively measured), with **Sm_2Co_{17}** blocks (on the left: 504 T/m) and **$Nd_2Fe_{14}B$** blocks (on the right : 514 T/m).



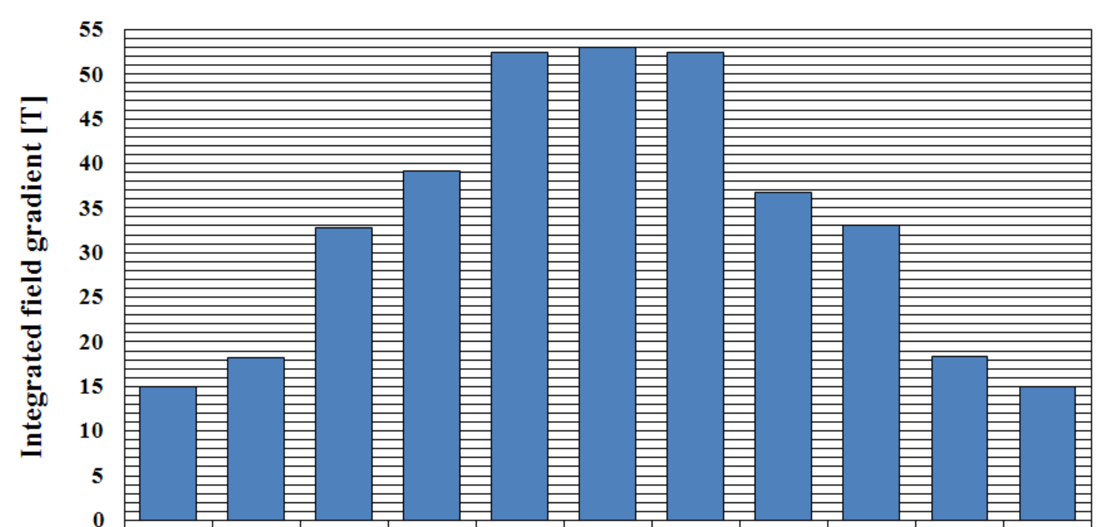


- ***Sm_2Co_{17}*** *blocks: very good agreement with the FEA computation.*
- ***$Nd_2Fe_{14}B$*** *blocks: a difference of ~ -6% is visible.*
  We suspect something not conform in the NdFeB blocks.
  This will be investigate in the next months (waiting a magnetic measurements Helmholtz coils system delivery).



Helmholtz coil

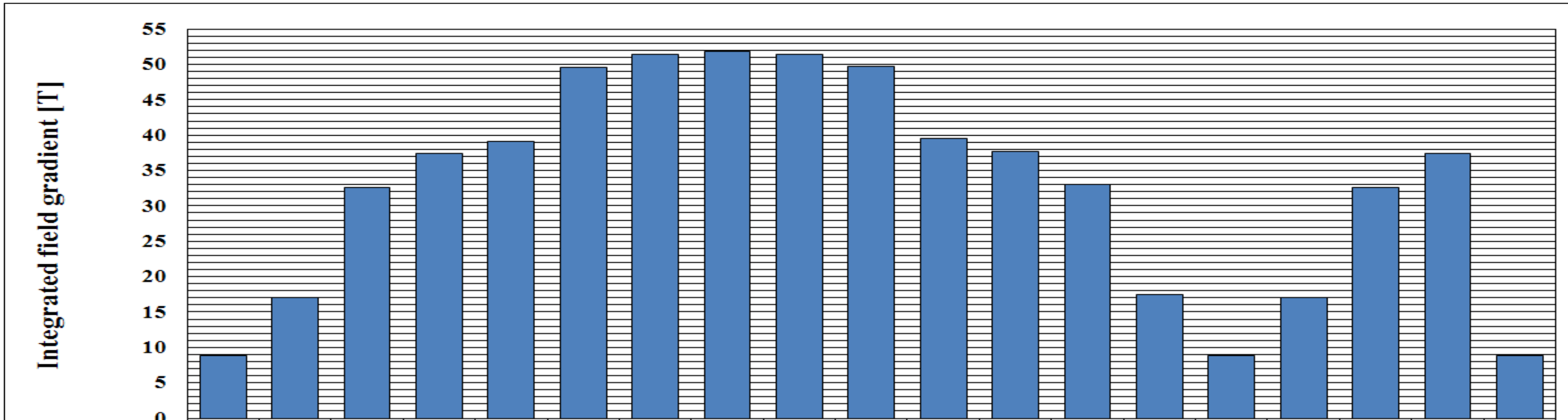
3D Helmholtz coil



N of meas	1	2	3	4	5	6	7	8	9	10	11
GL [T]	14.971	18.283	32.773	39.095	52.494	52.956	52.501	36.790	33.001	18.432	14.913
NI [A]	0.0	1004.4	2008.8	2462.4	5022.0	6026.4	5022.0	2268.0	2008.8	1004.4	0.0

Diagrams show the INTEGRATED Gradient measured versus the magnet powering (NI: total ampere-turns) for both QD0 configurations; upper graph $Nd_2Fe_{14}B$; lower: Sm_2Co_{17}.

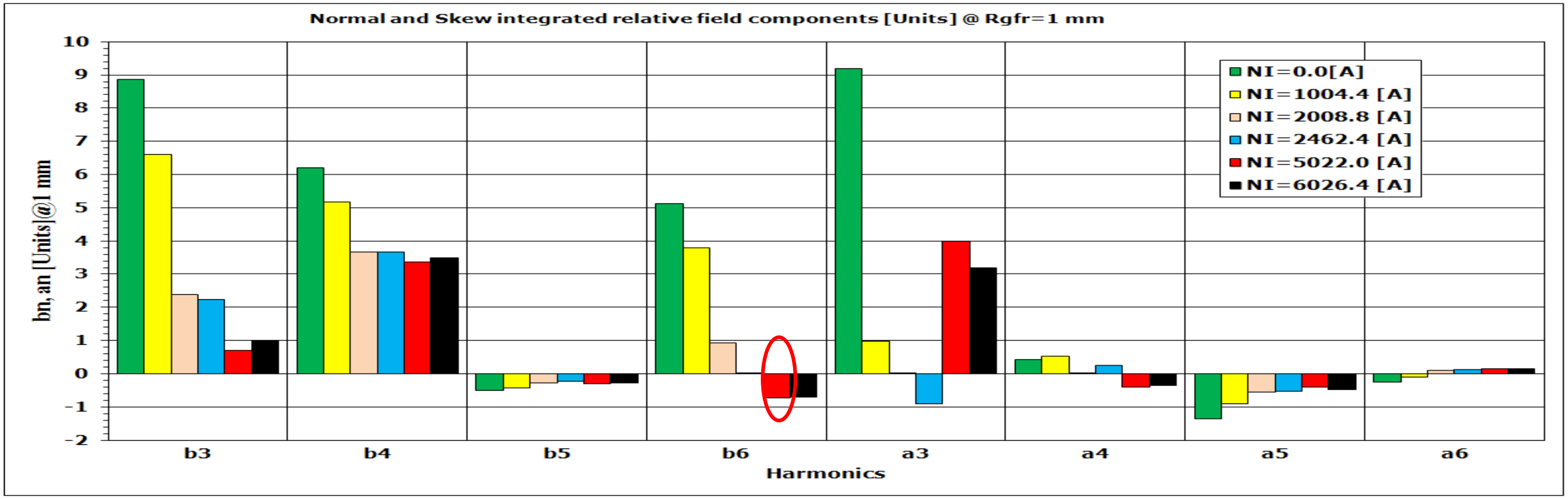
To be noted:
- the absence of PM demagnetization effects,
- no hysteresis effects visible

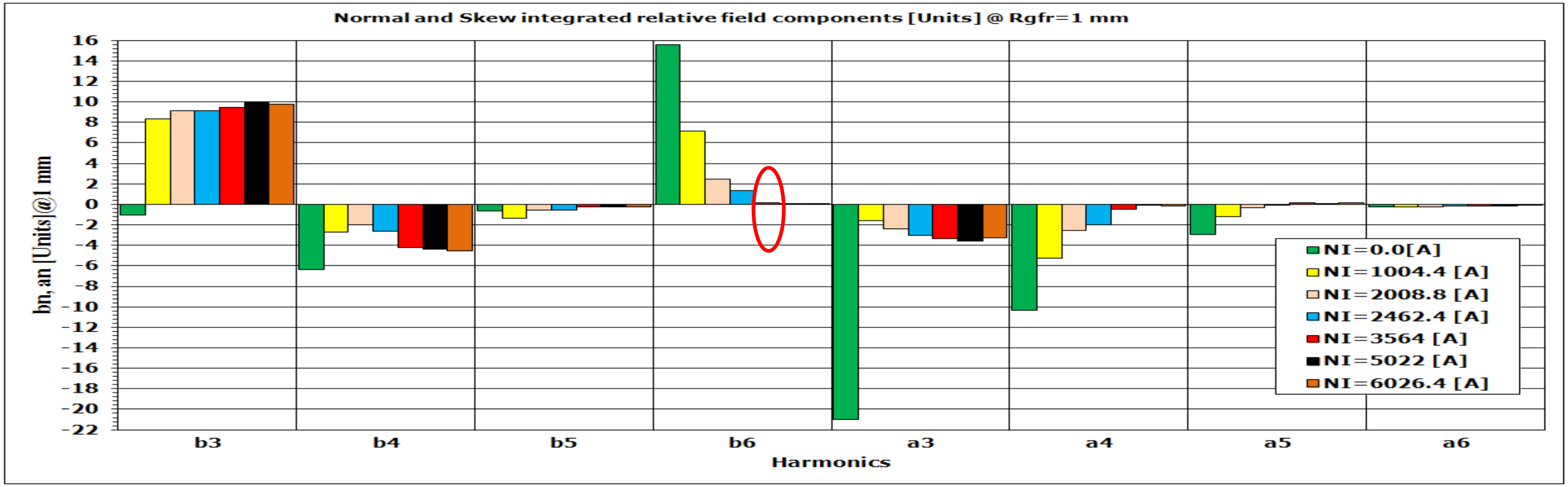


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
GL [T]	8.900	17.050	32.600	37.350	39.150	49.550	51.450	51.900	51.450	49.650	39.500	37.700	33.000	17.400	8.900	17.050	32.600	37.400	8.900
NI [A]	0.0	1004.4	2008.8	2332.8	2462.4	3564.0	5022.0	6026.4	5022.0	3564.0	2462.4	2332.8	2008.8	1004.4	0.0	1004.4	2008.8	2332.8	0.0

Prototype FIELD QUALITY (given as magnetic harmonic content, multipoles) versus the magnet powering: $Nd_2Fe_{14}B$ (upper graph), Sm_2Co_{17} (lover graph).

NOTE: the first "permitted" mutipole is b6: at NI=5000A we compute b6=1.4 units (NdFeB) and b6=0.7 units (SmCo).





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1) CLIC QD0 status

1) Anti-solenoid studies

2) CLIC SD0 status

The anti-solenoid study was finalized in 2012.

*(See **CLIC Note 944** and paper: A. Bartalesi, M. Modena: “3D FEA Computation of the CLIC Machine Detector Interface Magnets”, Proceeding of IPAC-2012, pag.1936)*

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CLIC – Note – 944

CERN-OPEN-2013-026
18/09/2012

DESIGN OF THE ANTI-SOLENOID SYSTEM FOR THE CLIC SID EXPERIMENT

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[1]CERN, Geneva, Switzerland

Abstract

In the CLIC SiD experiment design baseline, with the machine parameter L* set to 3.5 m, the final focus quadrupole QD0 will be placed inside the detector itself. This configuration is very challenging by an integration point of view.
Among several other aspects, the iron-dominated QD0 and the incoming beams will need an active magnetic shielding to avoid unacceptable interactions with the magnetic field generated by the main solenoid of the detector.
According to the baseline design, this shielding is provided by a superconducting antisolenoid, and this note aims to describe the procedure followed to design it.

Geneva, Switzerland
18 September 2012

TE Technology Department

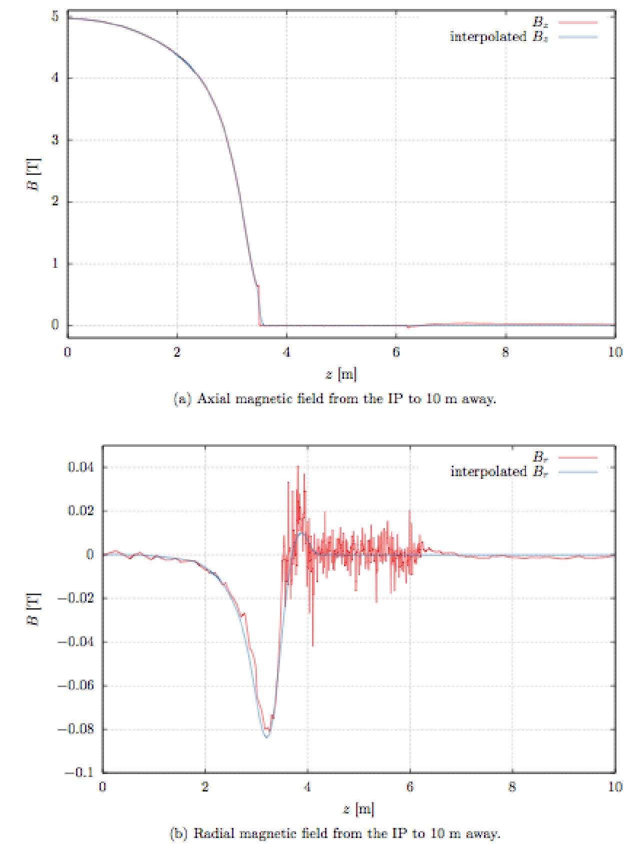

Figure 23: Computed and interpolated field on the beam line, second Opera3D™ design.

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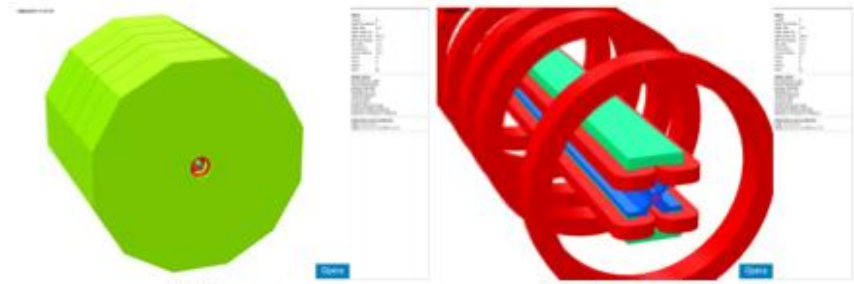
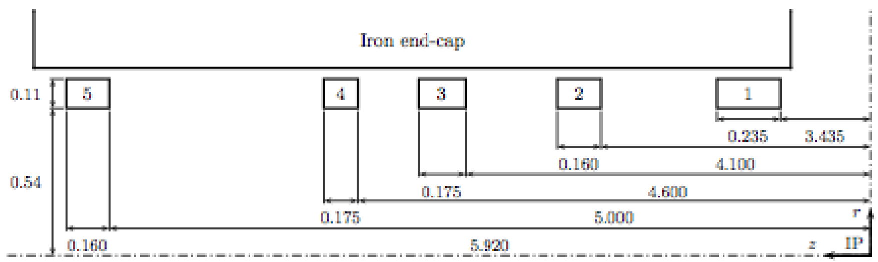


(a) Detector. (b) QD0 and anti-solenoid.

Figure 16: An overview of the Opera3D™ model.

Appendix B Final anti-solenoid dimensions



Section number	1	2	3	4	5	
Current density	80.0	23.5	15.0	3.8	2.0	$\frac{A}{mm^2}$

Figure 30: Anti-solenoid coils dimensions (in meters) and current densities.

FORCES:

-The most relevant is the axial force is: Fz of $7.0 \cdot 10^6$ N acting on the first coil of the anti-solenoid, pushing it away from the IP.

-The magnetic forces acting on QD0 are estimated as:
Fz $\simeq -5.7$kN; Fx $\simeq 8.3$kN; Ty $\simeq 5.6 \cdot 10^3$ Nm.

Technology Department

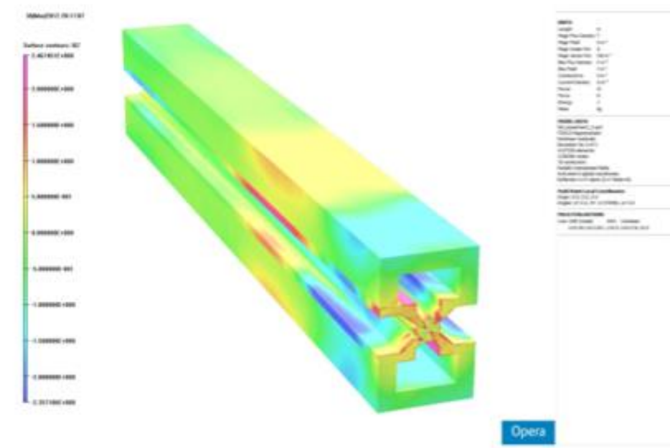


Figure 21: The axial field attracted by QD0, second Opera3D™ anti-solenoid design.

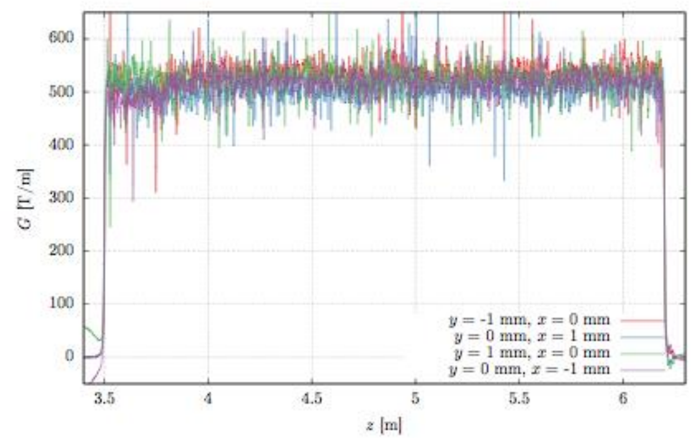


Figure 22: QD0 gradient, second Opera3D™ design.

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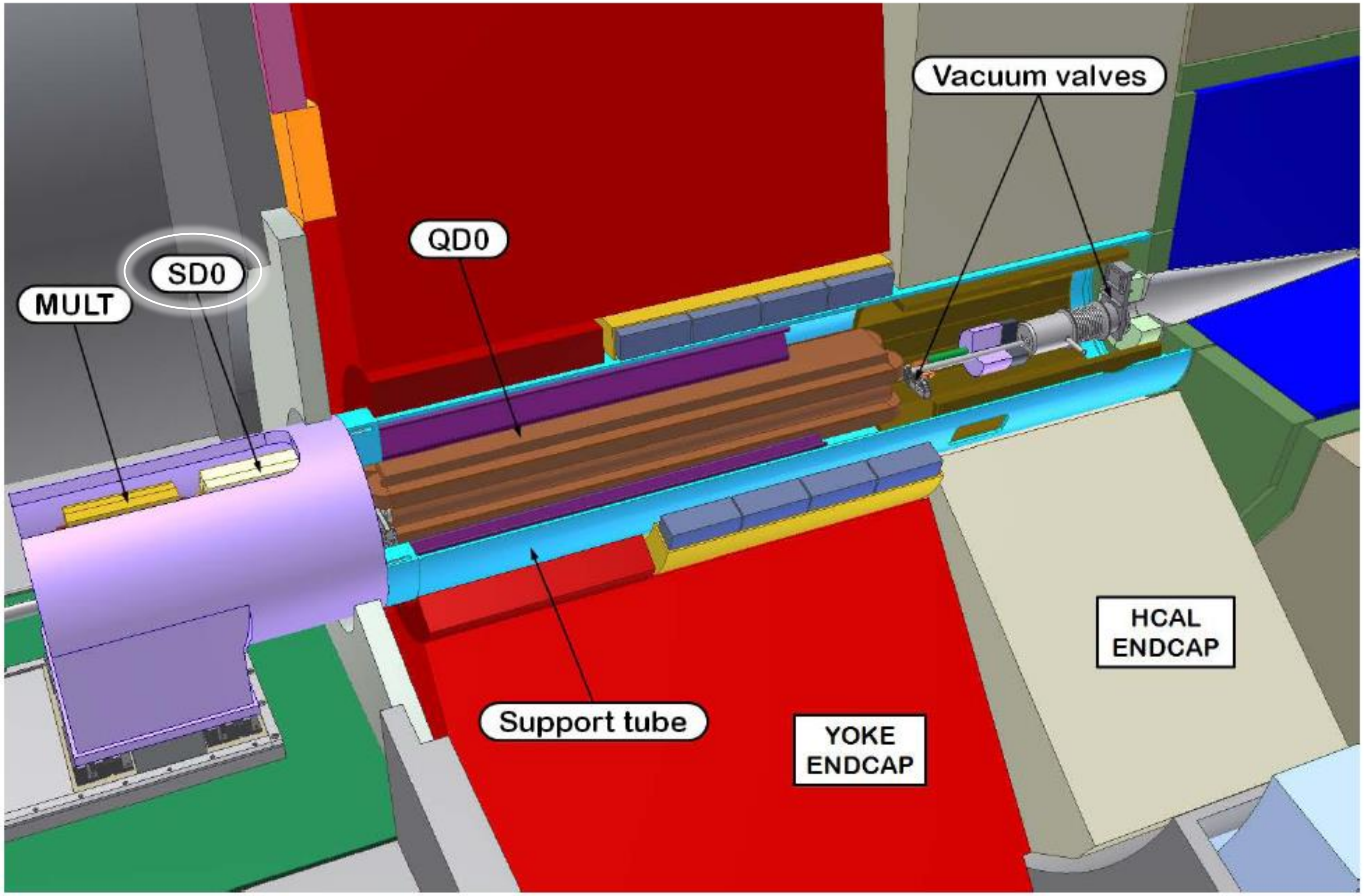
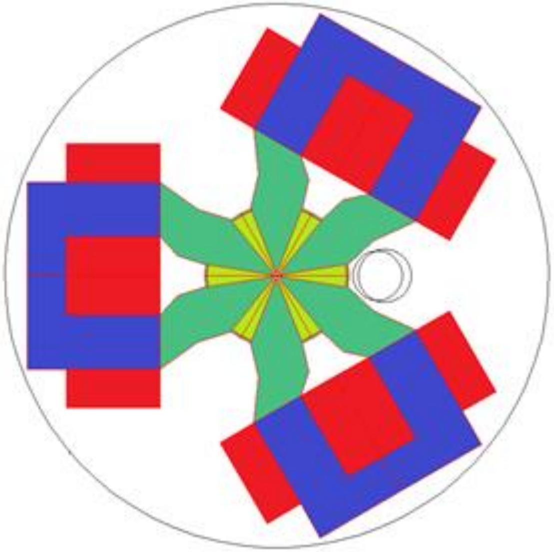
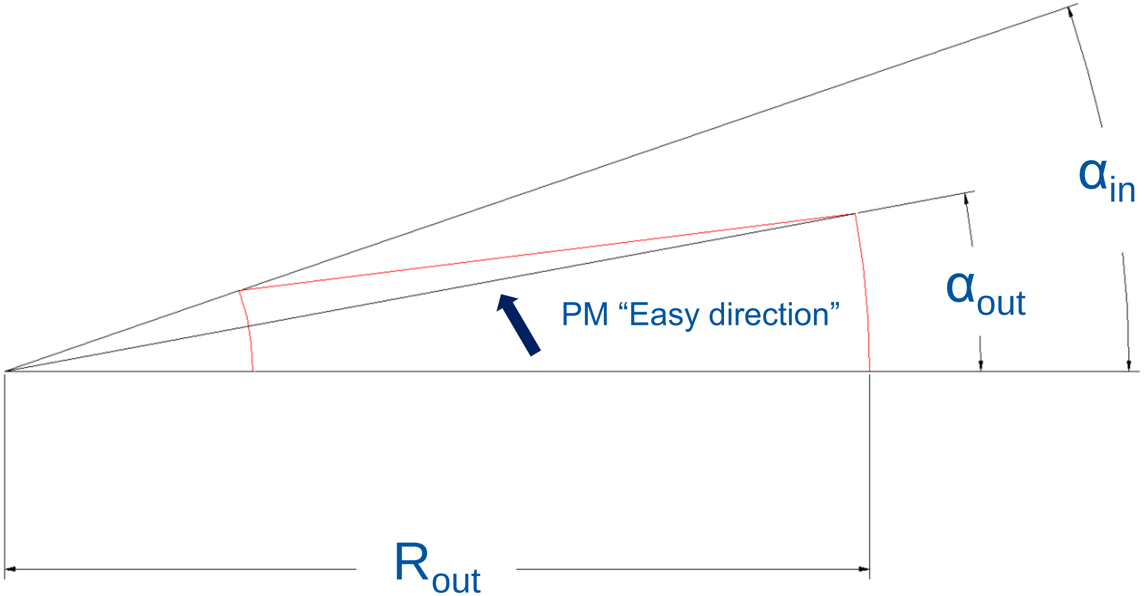
- **SDO** is also considered a BDS critical magnet as it is requires the stronger as possible gradient.
- It is the last magnet of the BDS placed on the tunnel, just at the border with the experimental Hall
- Being much shorter and not placed inside the Detector, this magnet has less tight geometric boundary conditions.

Parameter	*Value*
Inner radius	4.3 mm
Nom. Sext. Gradient	219403 T/m2
Magnetic Length	Lm: 0.248 m





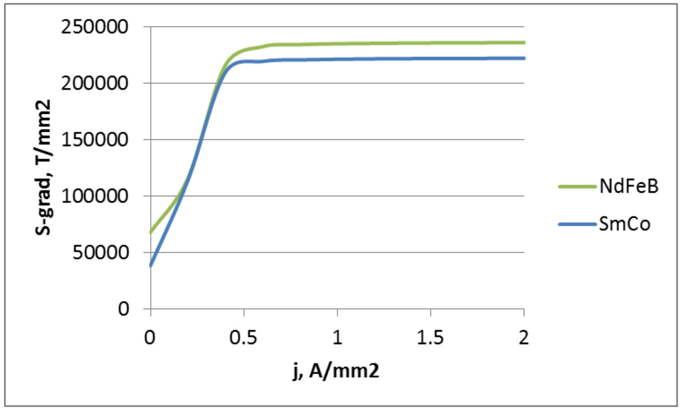
SD0 conceptual layout



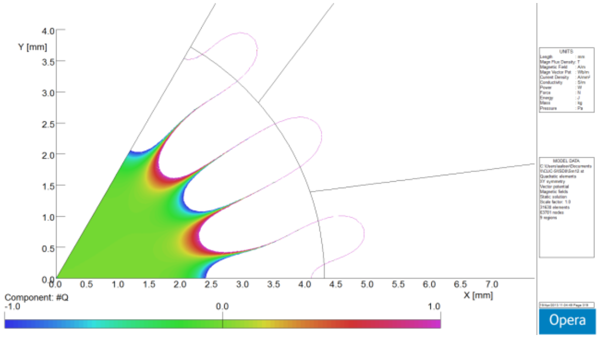
PM block analysed parameters

Optimization process provides these values : α_{in} = 18.9° α_{out} = 8.4 ° R_{out} = 40 mm

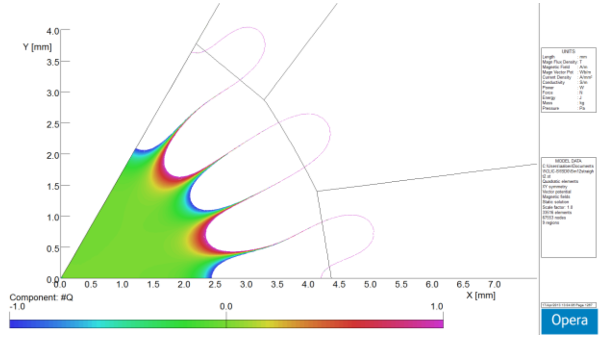
	NdFeB	SmCo
R_{out} mm	*S-gradient, T/m^2*	
20	217 271	200 368
40	234 438	220 891
70	235 926	222 188
90	236 000	222 188



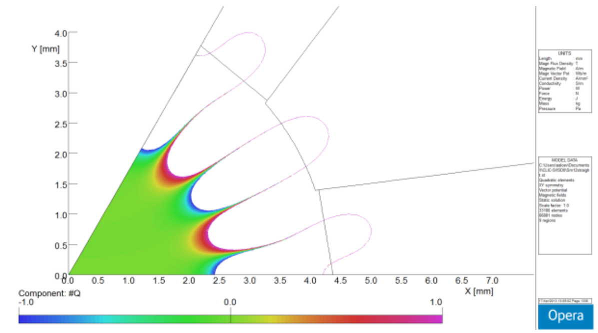
Magnet powering curve



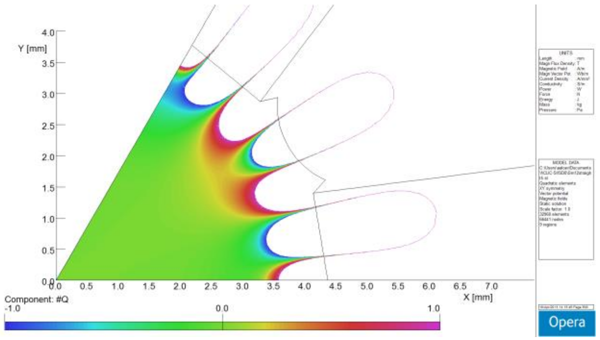
Opt.1 S-grad 222020 T/m^2



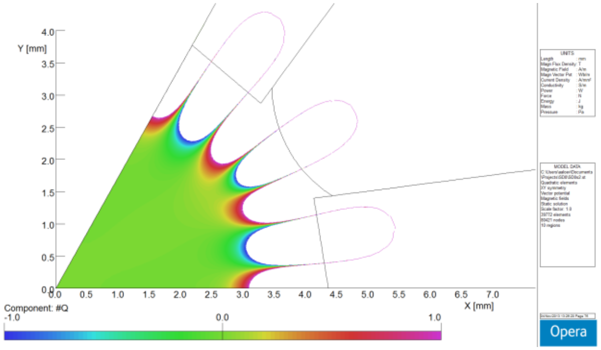
Opt.2 S-grad 220349 T/m^2



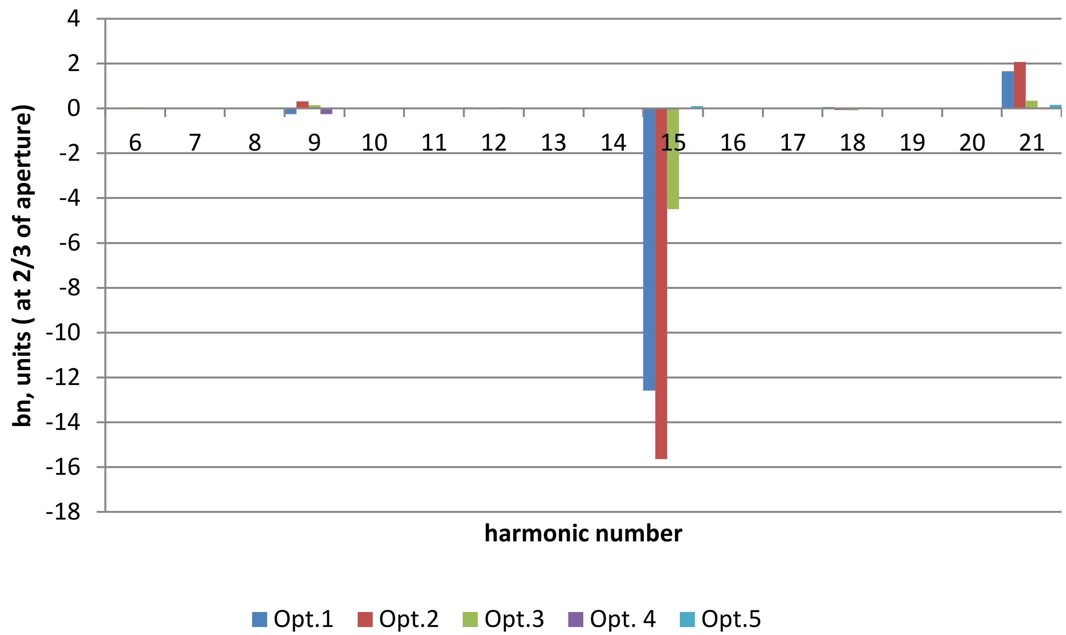
Opt.3 S-grad 221247 T/m^2



Opt.4 S-grad 215785 T/m^2

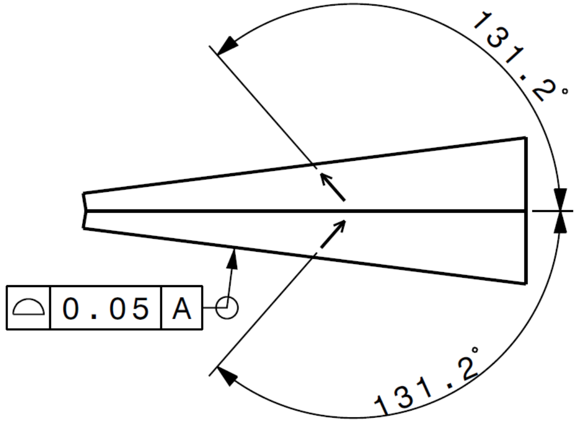


Opt.5 S-grad 216013 T/m^2



	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Opt.1	0.02338			-0.25272			0.03797			-12.5842			0.05568			1.66380165
Opt.2	0.01156			0.32237			-9.02E-03			-15.6347			-0.06368			2.07597517
Opt.3	0.04744			0.15097			5.19E-03			-4.49391			-0.08142			0.34706331
Opt. 4	8.64E-03			-0.25438			0.04409			1.04E-04			0.04693			0.03784612
Opt.5	9.02E-03			-0.01351			5.38E-03			0.09589			-2.20E-04			0.15660942

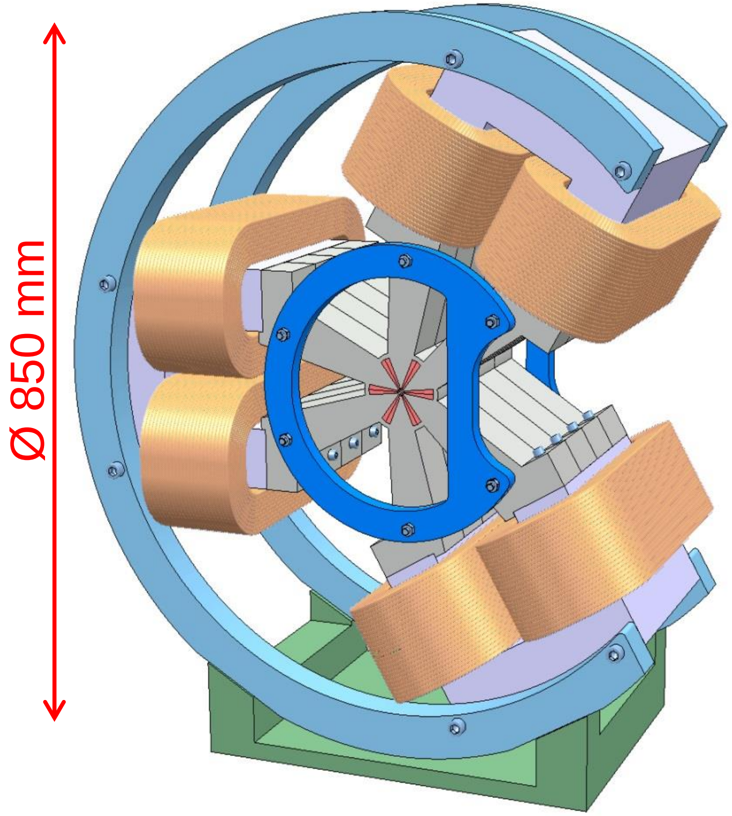
A sensitivity study of the the field quality versus error in the magnetization angle was also initiated:
The table below shows the appearance of undesirable multipole components when an error of 1 degree in the magnetization angle appears in ONE block.
(NOTE: this case is much worse than the case where the same error appear in 6 symmetrically positioned blocks)

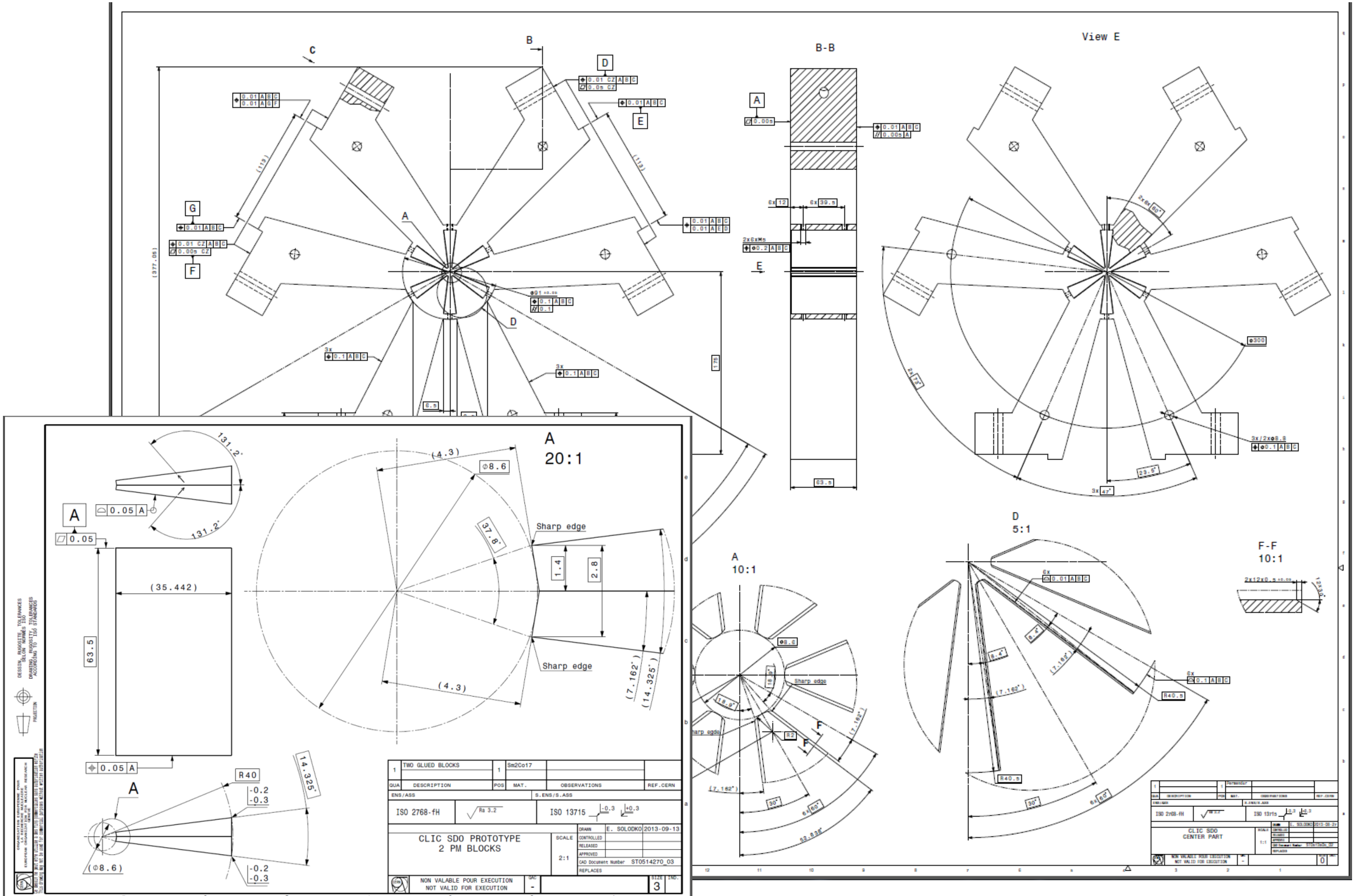


	bn				an		
N (b)	60°	360°	1° error in only one block	N (a)	60°	360°	1° error in only one block
1	0.00	-0.05	-8.05	1	0.00	-0.15	9.40
2	0.00	-0.01	-3.34	2	0.00	-0.01	6.48
3	10000.00	10000.00	10000.00	3	0.00	-0.01	4.01
4	0.00	0.00	-0.46	4	0.00	0.01	2.42
5	0.00	0.00	-0.17	5	0.00	0.01	1.48
6	0.01	0.00	0.57	6	0.00	0.00	1.37
7	0.00	0.00	0.34	7	0.00	0.00	0.96
8	0.00	0.00	0.31	8	0.00	0.00	0.55
9	-0.01	-0.05	0.20	9	0.00	0.00	0.30
10	0.00	0.00	0.18	10	0.00	0.00	0.16
11	0.00	0.00	0.13	11	0.00	0.00	0.08
12	0.01	0.00	0.06	12	0.00	0.00	0.01
13	0.00	0.00	0.04	13	0.00	0.00	-0.01
14	0.00	0.00	0.02	14	0.00	0.00	-0.01
15	0.10	0.09	0.10	15	0.00	0.00	-0.01

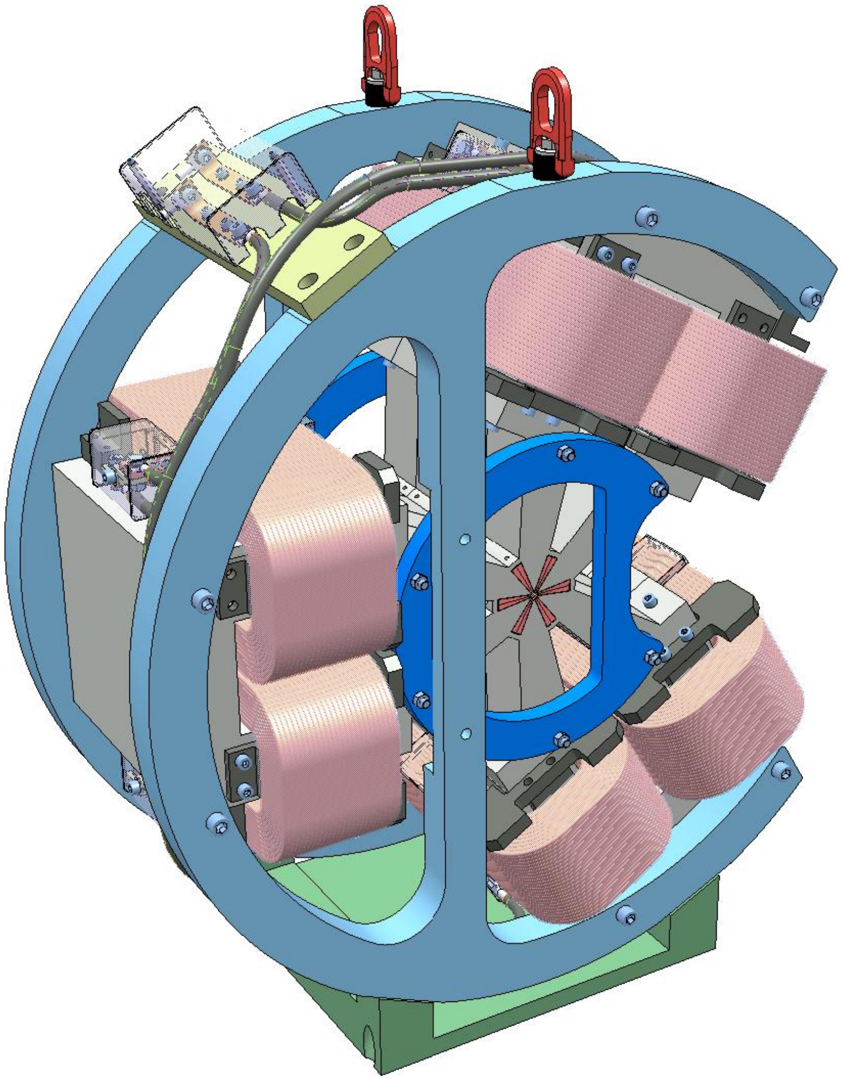
- ***Main requirements & boundary conditions:***
  - Tunability of min: -20 %
  - Minimized vibrations (magnet is planned to be actively stabilized)
  - Integration with the post collision vacuum line needed.
- Compactness is less critical respect to QD0. Magnet is placed outside the Detector at the Accelerator Tunnel border.

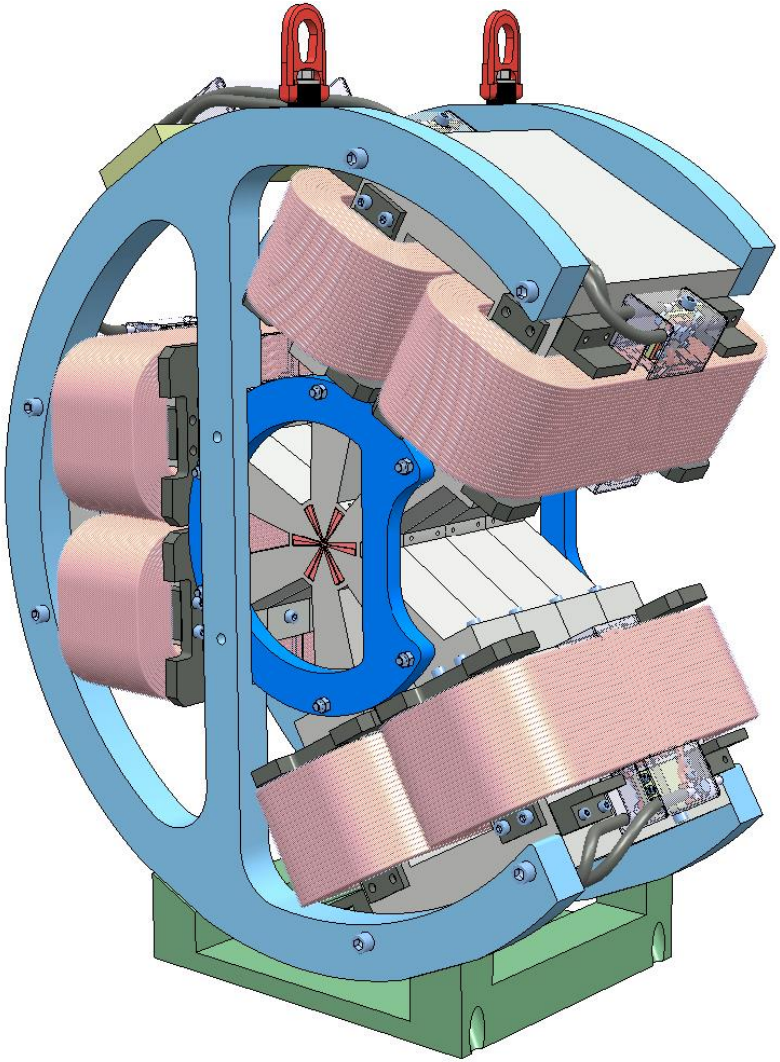
- **Prototype key aspects:**
  - The proposed design permit a nominal tunability of -80%.
  - Manufacturing (with highest precision) of each Permendur sector, PM insert, "C" shape return yokes.
  - Measuring, Assembly and sorting of PM blocks.
  - The mechanical design should permit to investigate the precise longitudinal assembly of four central sections, each equipped with PM.
  - Assembly of the sectors (individual and global assembly procedure: magnetic forces between blocks impact? PM blocks are very fragile!).
  - Magnetic measurements.
  - Final alignment aspects..





View E
B-B
A
20:1
Sharp edge
(35.442)
63.5
D
5:1
A
10:1
F-F
10:1
TWO GLUED BLOCKS
Sm2Co17
ISO 2768-fH
ISO 13715
CLIC SDO PROTOTYPE
2 PM BLOCKS
E. SOLODKO 2013-09-13
ST0514270_03
NON VALABLE POUR EXECUTION
NOT VALID FOR EXECUTION
CLIC SDO
CENTER PART





Some conclusions:

QD0:

- CLIC QD0 baseline design (for L*=3.5 m) is an hybrid quadrupole.
- A short prototype of the magnet was successfully built to validate the concept.
- Some QD0 key aspects will be now studied on SD0 design and procurement.

Antisolenoid:

- An antisolenoid was successfully studied and dimensioned (magnetic design) in order to be integrated in the MDI

SD0:

- Similar hybrid concept as QD0. Conceptual design is completed and technical design under completion.
- Started to contact components manufacturers to discuss the procurement and technical details (mainly the assembly procedures).
- Investigation and optimization towards field quality are also addressed.

- ***Thanks***