Workshop on “Compact and Low Consumption Magnet Design for Future Linear and Circular Colliders”,
CERN, Geneva, 26-28 November 2014.

Electromagnetic and hybrid design experience for CLIC magnets R&D

M. Modena - CERN

The CLIC magnet R&D is evidently a ***Team effort****.*

Acknowledgments to:

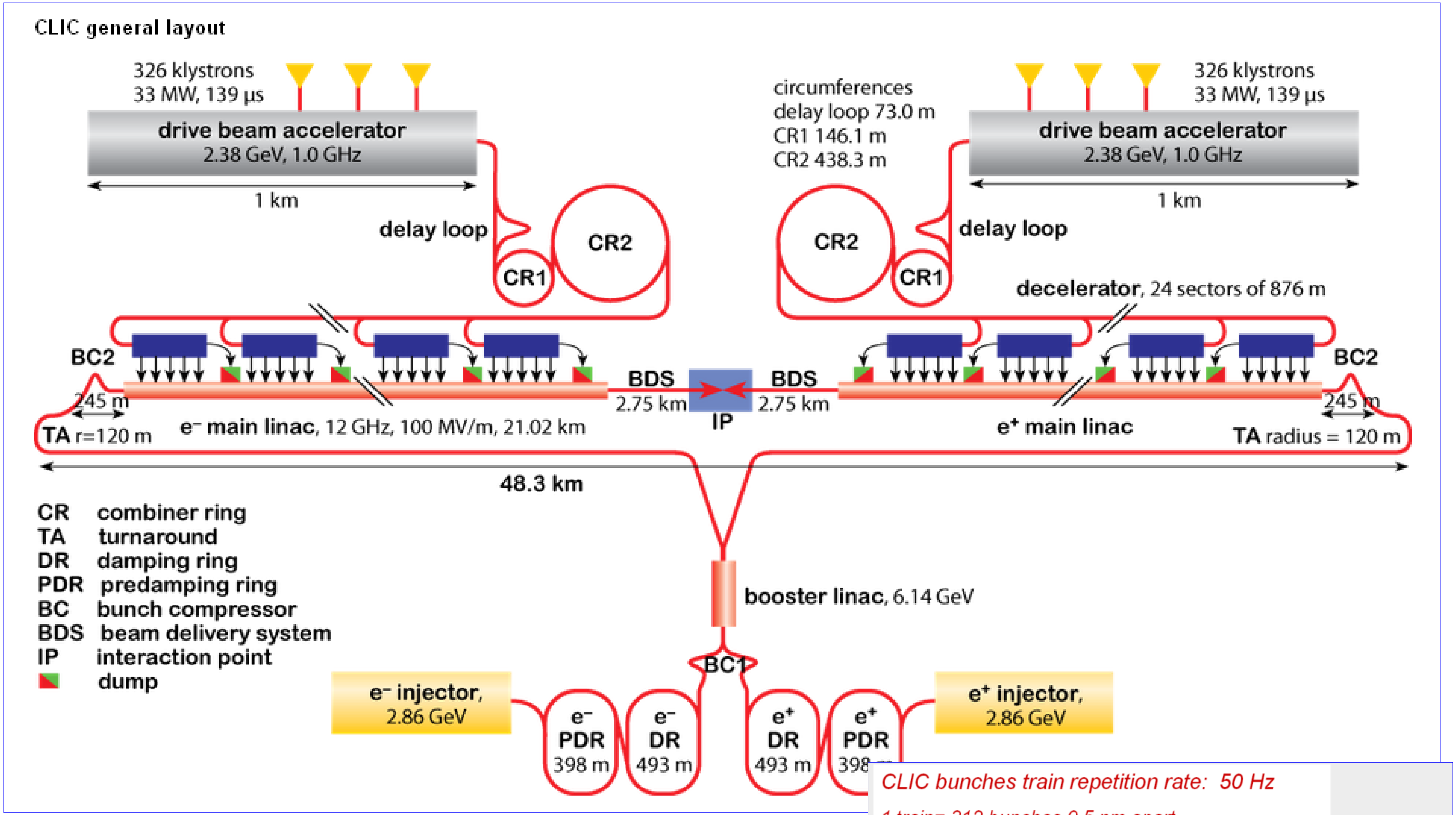
A. Aloev, A. Bartalesi, R. Leuxe, C. Lopez, E. Solodko, M. Struik, P. Thonet, A.Vorozhtsov *and to the* ***Colleagues of ASTeC Daresbury Laboratory.***

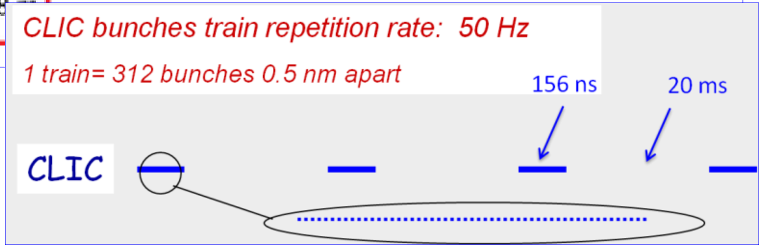
Outline:

A quick overview of the R&D activities on CLIC magnets:

- *CLIC 3-TeV layout and procurement cases*
- ***Magnets for the “2-Beams Modules”***
  - *Main Beam Quadrupole (MBQ)*
  - *Drive Beam Quadrupole (DBQ)*
  - *Beam Steering correctors*
- ***Magnets for the Final Focus system***
  - *QD0 quadrupole*
  - *SD0 sextupole*

CLIC 3-TeV layout and procurement cases





CLIC 3-TeV layout and procurement cases

A wide magnets population in the different parts of the CLIC complex → CLIC Magnet Catalogue:

1) CLIC Drive Beam complex (turnaround, delay line, combiners rings, TL, etc.) :
- **12096** magnets in total; divided in **14** types with population from **32** to **1872** units.

2) CLIC Main Beams Transport :
- **2291** magnets in total; divided in **17** types with population from **1** to **250** units.

3) CLIC Damping Rings :
- **4076** magnets in total; divided in **11** types with population from **76** to **1004** units.

4) CLIC Post-Collision line :
- **18** magnets in total; divided in **5** types with population from **2** to **8** units.

5) CLIC Beam Delivery System :
- about **400** magnets in total; divided in **70** types with population from **1** to **96** units.

6) CLIC DBQ (EM or PM design): - **41848** magnets in total.

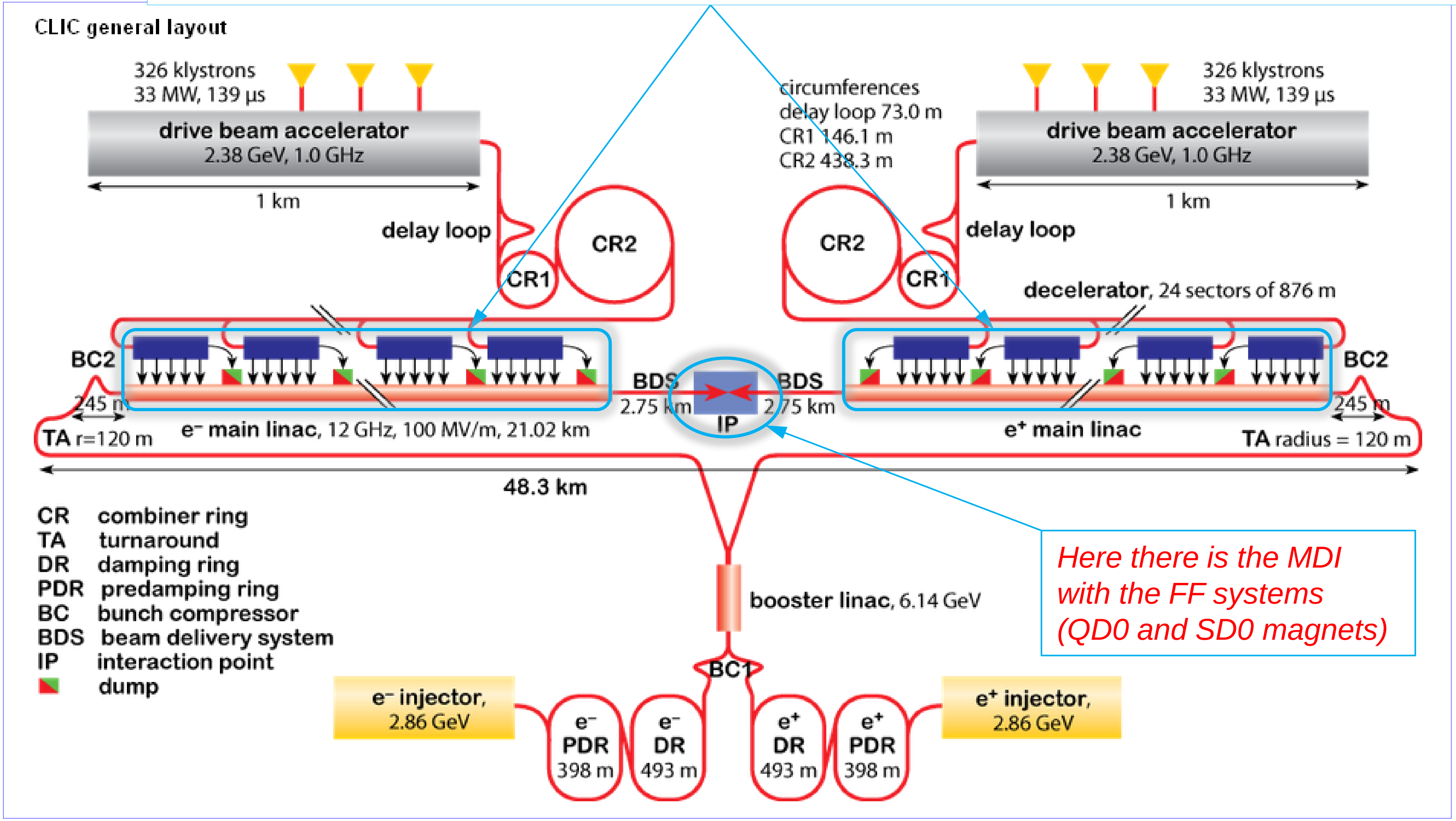
7) CLIC MBQ: - **4274** magnets in total; divided in **4** types with population from **368** to **1490** units

All that give **more than 65000 magnets** (**!**) …number approximated in defect since injector systems not included)

- We have unified similar magnets design (to get larger series for more convenient procurement) where possible.
- The total **procurement cost**, the **powering** and **cooling** needs for all the CLIC magnets Catalogue was evaluated by use of proved estimation formulas (CERN MSC-MNC sources), and including production learning curves estimation (*ref. CERN doc. EDMS:100426 by P. Lebrun).*

Special families:

Here there are the ~ 20000 “2-Beams Modules” with ~40000 DBQ and ~4000 MBQ magnets



Here there is the MDI with the FF systems (QD0 and SD0 magnets)

…in conclusion: a lot of interesting “test cases” to investigate new concepts in :

- Big series of magnets procurement
- Challenging magnet cases (ex. Final Focus elements)

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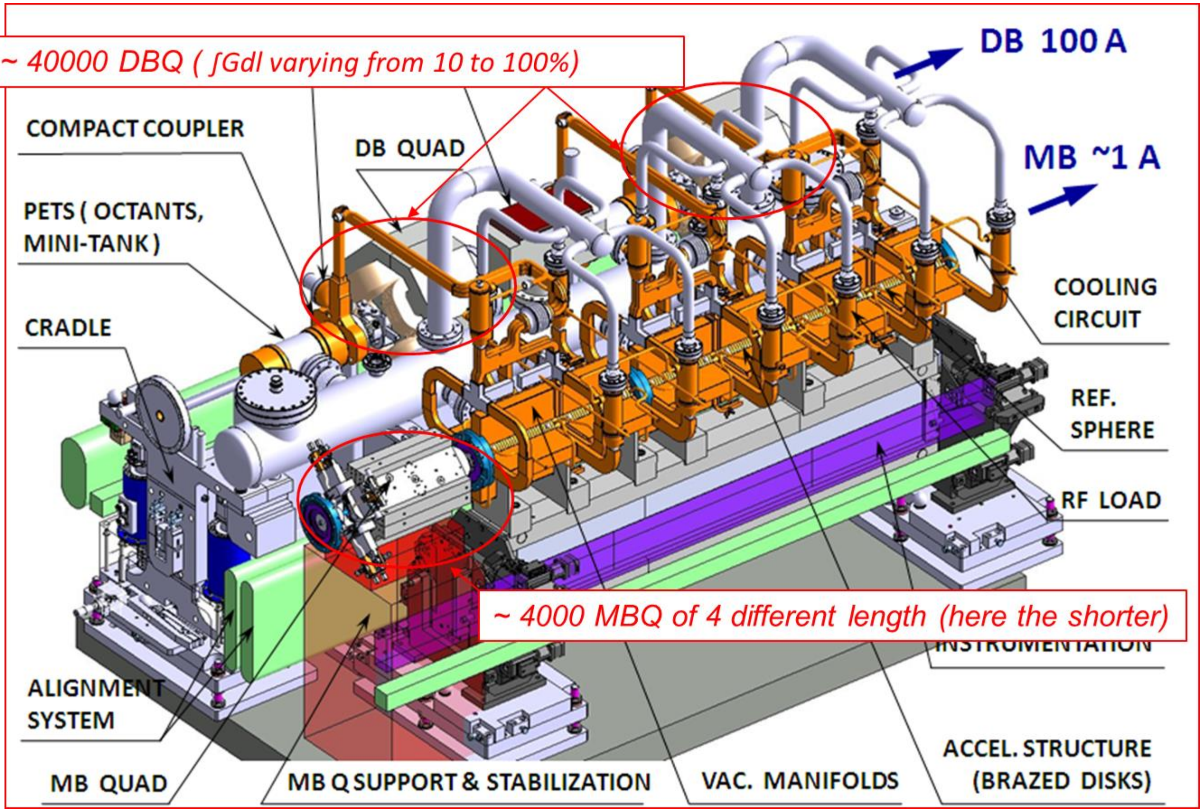
Magnets for the "2-Beams Modules"

MBQ challenges:

- Performances (gradient of 200 T/m and field quality less of 10 relative units.)
- Limited space (longitudinal and transversal)
- Minimize the weight (magnets will be individually stabilized in the nm range)
- Maximize the rigidity (for stabilization reasons)
- Simplify production, assembly, field quality achievement, cost



DBQ challenges:

- Big series
- Very wide $\int Gdl$ variation required (for a constant physical space available on the Modules)
- Extremely tight available space (considering the wide $\int Gdl$ required)
- Tight alignment tolerance (no active stabilization and beam feedback alignment for these magnets)
- Minimize economic and logistic (total power, service requirement, cooling needs, etc.)

Main Beam Quadrupole (MBQ)

In Total: 4142 MBQ needed.

308 of TYPE1

TYPE1	
Aperture (Ø)	10 mm
Length	420 mm
Gradient	200 T/m
Current density	6.1 A/mm2
Current	126 A
Voltage	8 V
Power	990W
Weight	85 kg

1276 of TYPE2

TYPE2	
Aperture (Ø)	10 mm
Length	920 mm
Gradient	200 T/m
Current density	6.1 A/mm2
Current	126 A
Voltage	16 V
Power	1980 W
Weight	170 kg

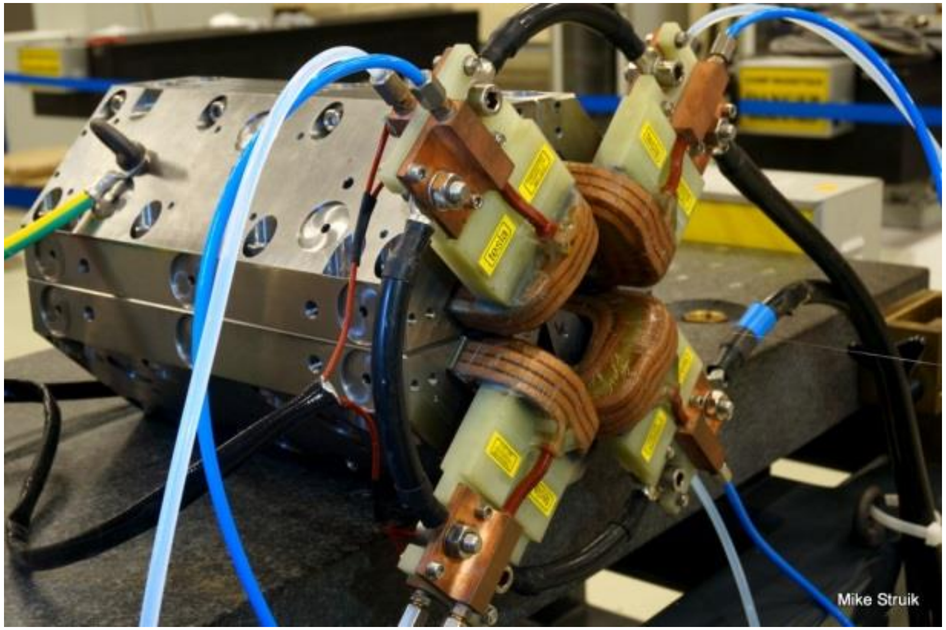
964 of TYPE3

TYPE3	
Aperture (Ø)	10 mm
Length	1420 mm
Gradient	200 T/m
Current density	6.1 A/mm2
Current	126 A
Voltage	24 V
Power	2970 W
Weight	280 kg

1594 of TYPE4

TYPE4	
Aperture (Ø)	10 mm
Length	1920 mm
Gradient	200 T/m
Current density	6.1 A/mm2
Current	126 A
Voltage	30.4 V
Power	3831 W
Weight	370 kg

3 Prototypes of TYPE1 and 1 of TYPE4 procured (for investigation on quadrants machining, achievable field quality, stabilization study and “2-Beam” Modules technical mock-up)

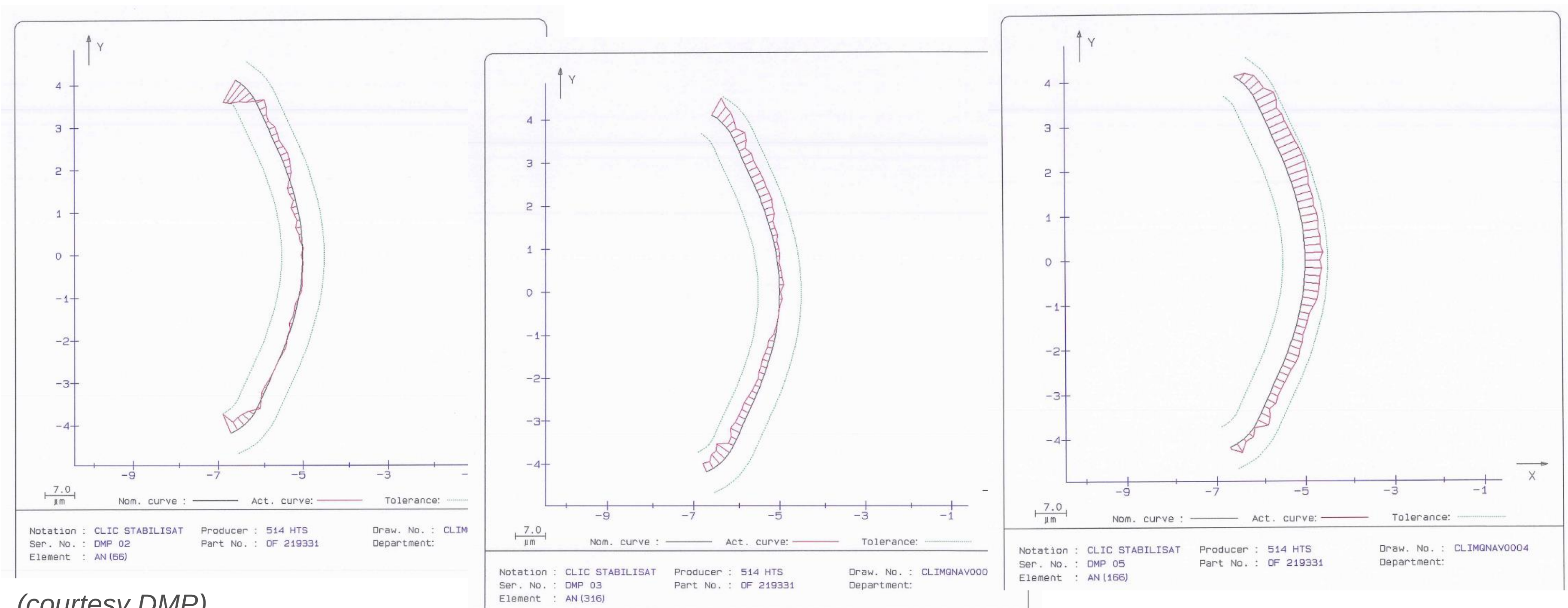


Main Beam Quadrupole (MBQ)

- The last MBQ TYPE1 prototype procured has shown excellent machining precision (±7µm) obtained with “standard” industrial techniques (fine grinding) on all the critical surfaces.

- This seems the best quality that we can reasonably achieve with fine grinding technique for these type of geometry and dimensions.

- Below are representative quadrants measurements (*by DMP, Spain*).

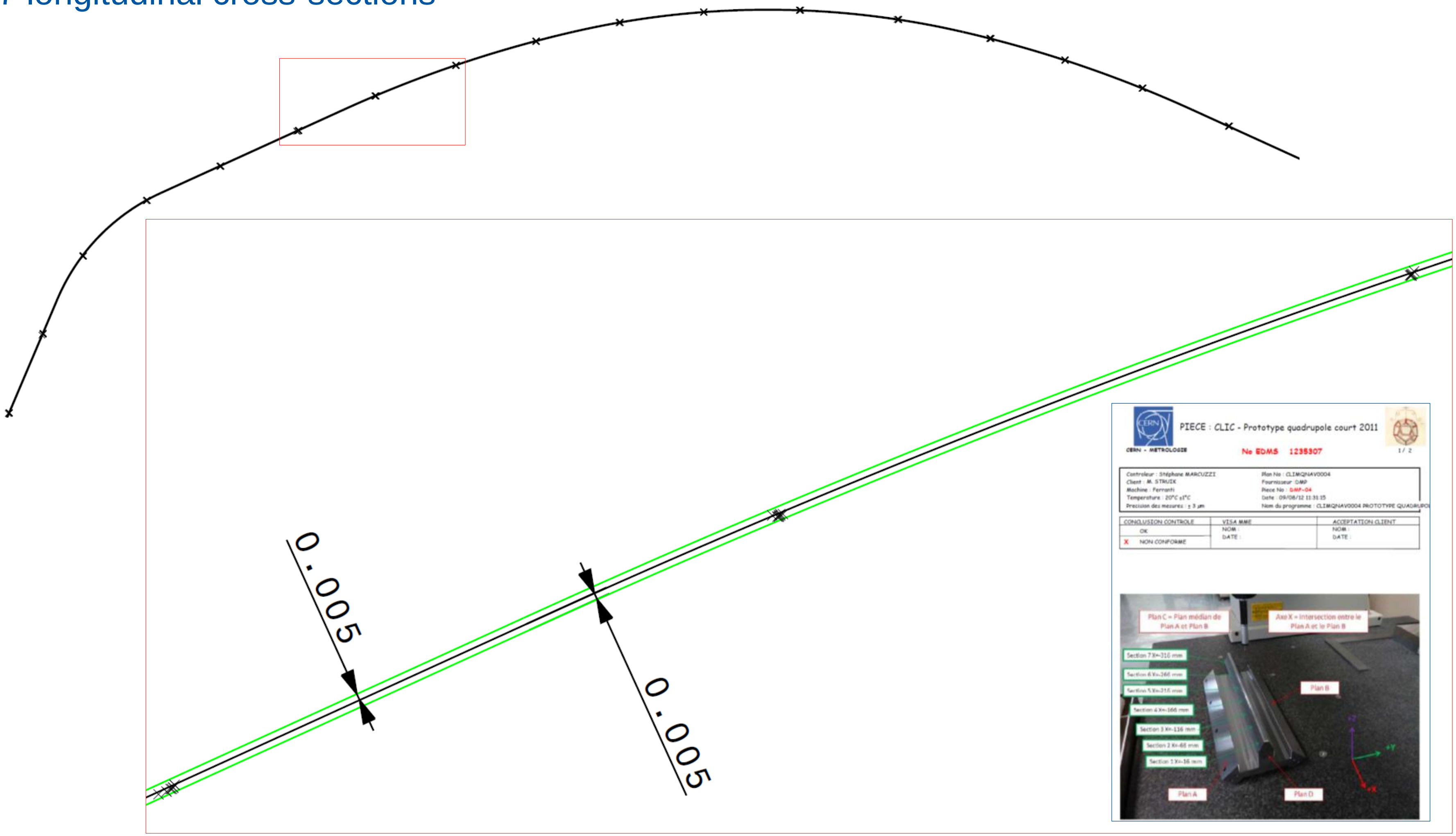


(courtesy DMP)

- More difficult situation for the TYPE4 quadrants (~1800 mm length): The same tolerances will be difficultly achievable. We are still looking for a minimum number of potential bidders.

Main Beam Quadrupole (MBQ)

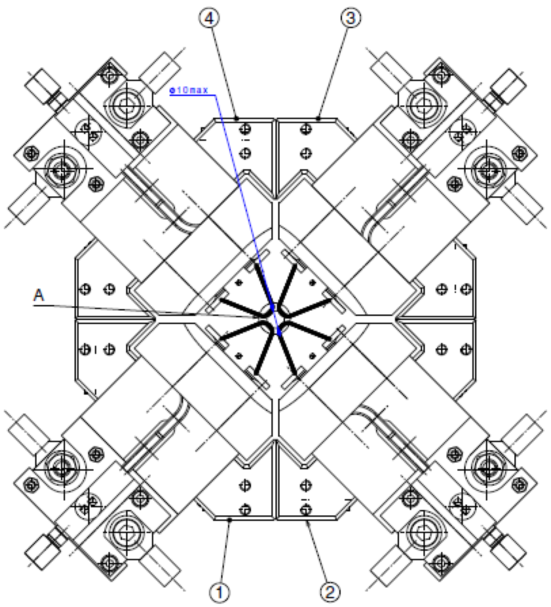
- Pole profile inside a tolerance of ± 7 μm
- Fine grinding provide extremely good longitudinal precision: on the graph below each measures “x” is in fact a cluster of 7 “x” (practically coincident) that are the measured points on the 7 longitudinal cross-sections

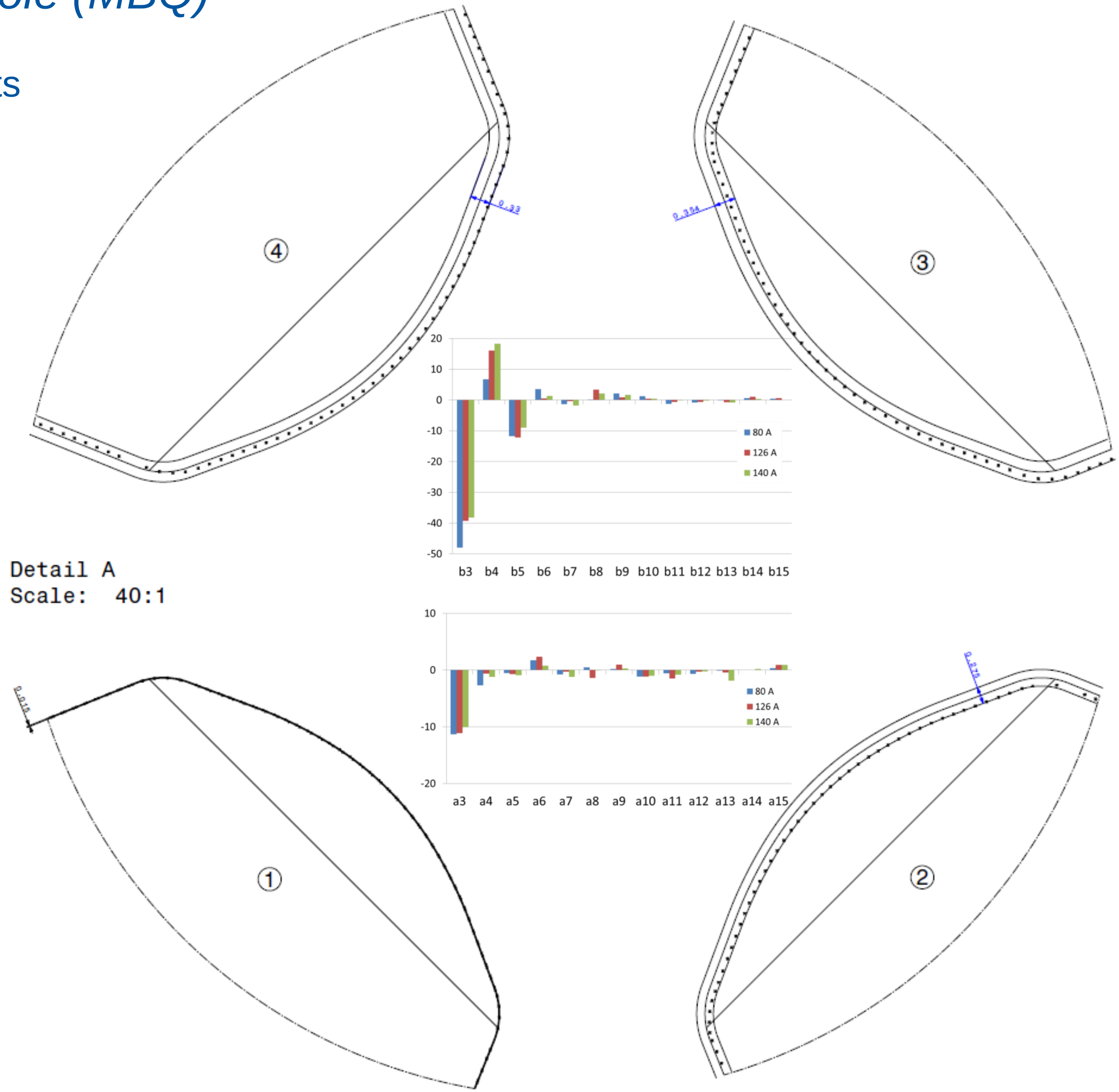


Main Beam Quadrupole (MBQ)

To have very precise quadrants is not the end of the history…

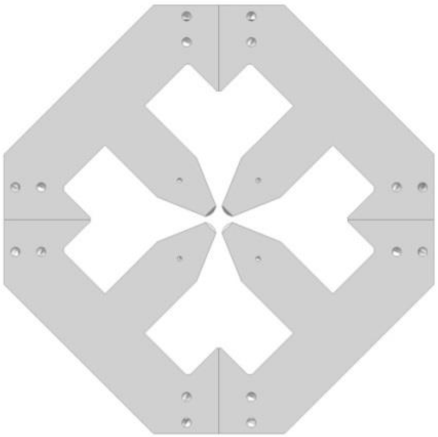
The <u>precise assembly </u>is also challenging.





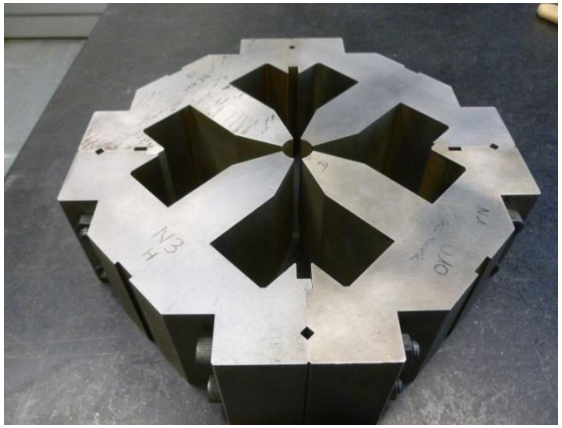
Main Beam Quadrupole (MBQ)

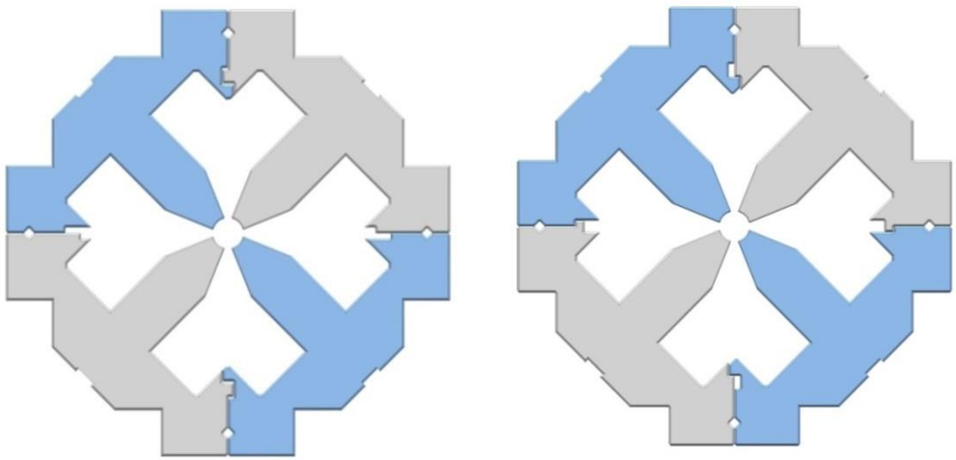
Studies to determine the best quadrants assembly cinematic are done with “smart” test pieces *(see Ref.)*

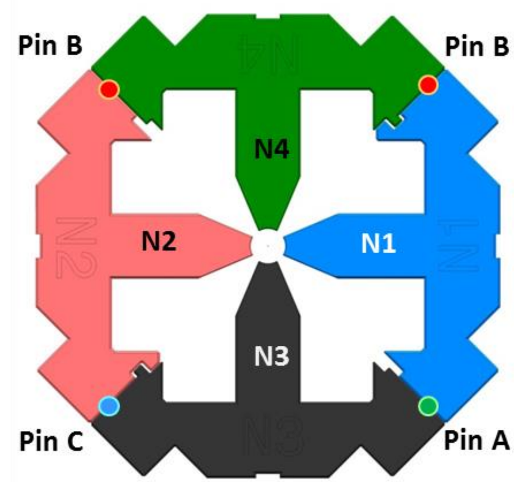


“Ad hoc” pieces (produced by EDM), permit to study different assembly methods.

With “Pins in V-shapes” method a cilindricity error of ~13 µm was achieved (in comparison to ~74 µm of “without pins” method (also utilized for the real prototype magnet)







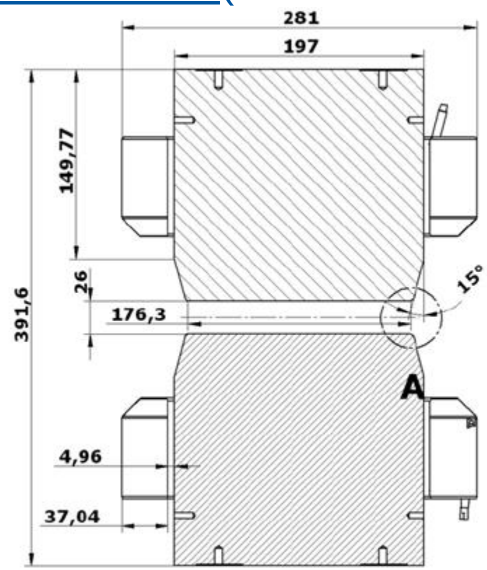
- **Next step**: to develop a precise, fast, robust (toward a semi-industrial production) design and assembly method for the 4 quadrants.
  (A PhD student from PACMAN Marie Curie program *(see talk of H. Mainaud-Durand in Session 7 on Friday*) is now working on this subject).

Drive Beam Quadrupole (DBQ) – EM Version

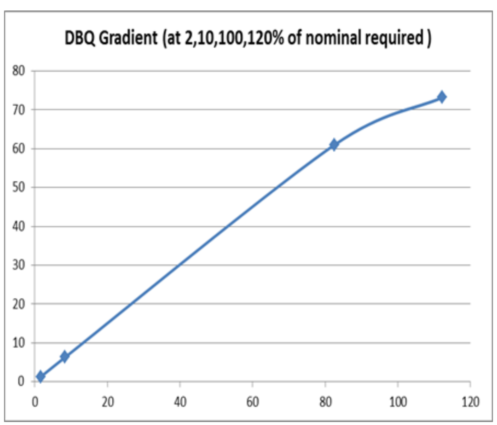
The design finalized with the procurement of 8 DBQ units (by Danfysik, DK).

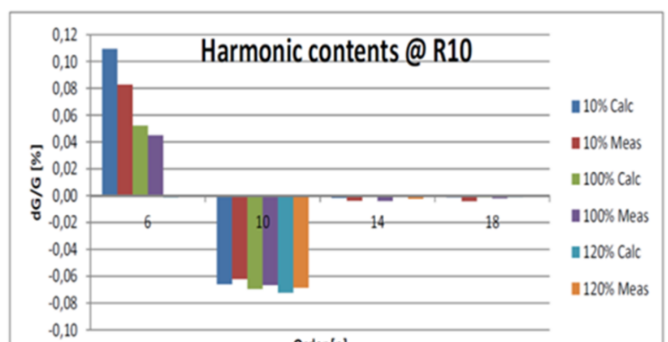
Tight boundary conditions: space availability; field quality (for the full gradient range), and minimization of power and cooling needs.

- 2 units delivered and now installed in CLEX (the CLIC Test Facility with beams)
- 6 other units ready for delivery.



Main Parameters		
	1st design values	**Final values**
Aperture Ø	26 mm	26 mm
Mag. Length	194 mm	197 mm
Nom. Grad.	62.8 T/m	61.8 T/m
Max. Length	281 mm	281 mm
Max. Width	390 mm	390 mm
Iron Length	180 mm	197 mm
Weight	~ 149 kg	~ 170 kg
Nom. Current	93	82.5
Nom. Voltage	9.2	6.74
Nom. Power	855 W	556 W
Cu conduct.	6X6 mm^2	6X6 mm^2
N. Of turn	208	208
Nom.Water flow	2.4 l/min	1.8 l/min
Nom.Press. drop	3 bar	3 bar
ΔT	5 °C	5 °C
Max.Power (at 120%)	3030 W	1028 W



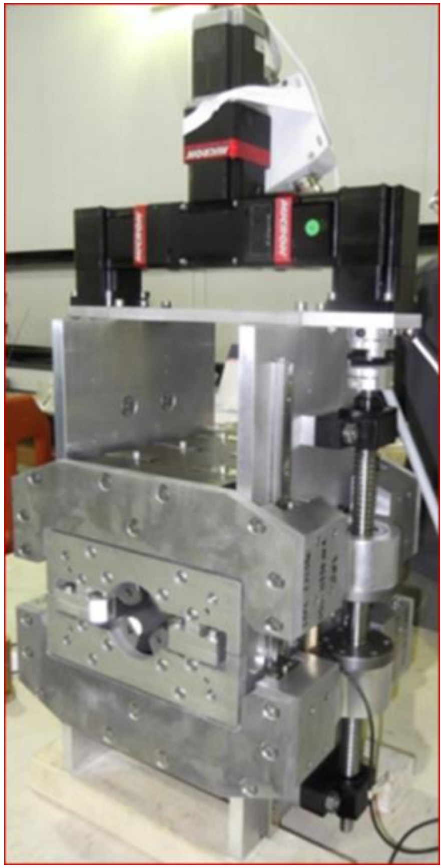


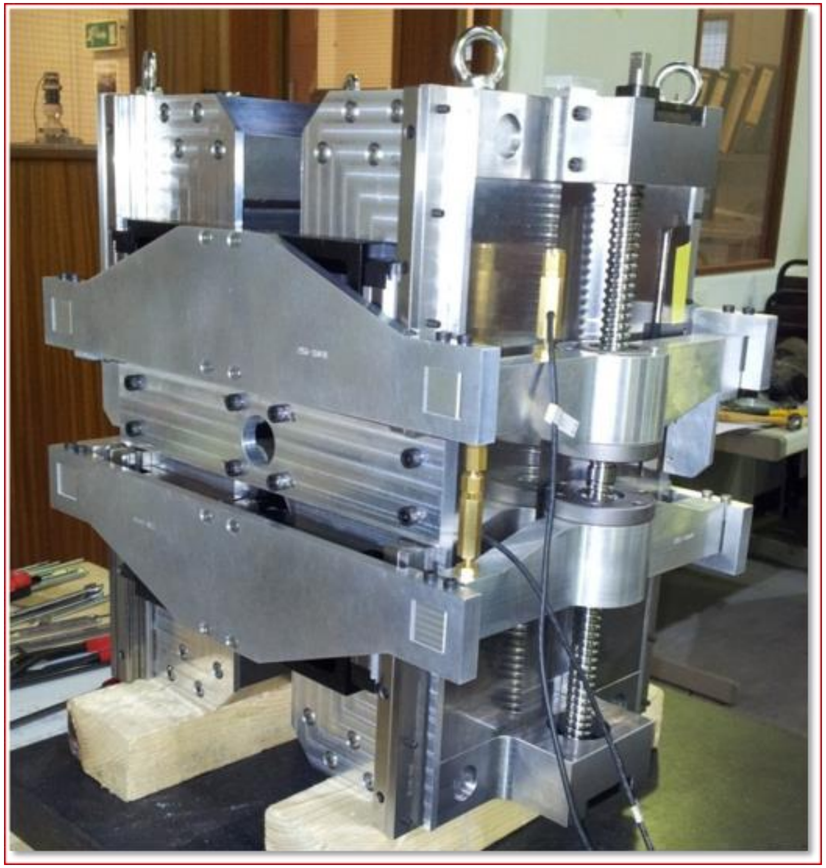
(Courtesy Danfysik)

Drive Beam Quadrupole (DBQ) – PM Version

2 designs to cover the needed gradient range of the Decelerator (integrated gradient from 1.2 to12.2 T) were developed at ASTeC (Daresbury Laboratory)

- the 1st prototype (High Gradient) was delivered at CERN and measured (Magnetic Meaurements and Metrology) in 2012.
- the 2nd prototype (Low Gradient) delivered and measured at CERN in 2014

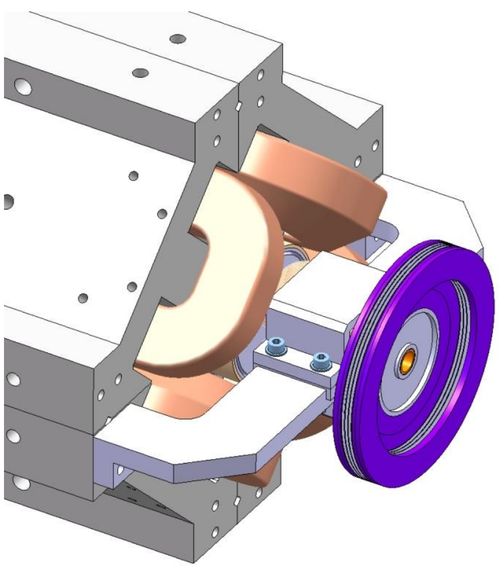




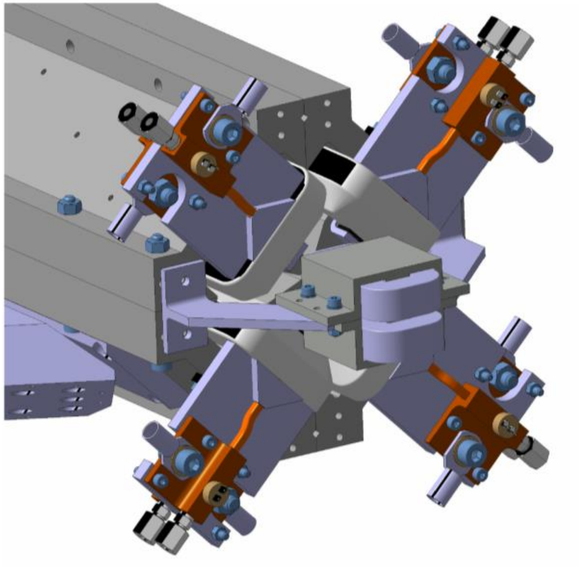
See next talk of B. Shepherd and the one of N. Collomb about these innovative designs and prototypes development

Beam Steering correctors

- A beam steering capability will be provide *"for free"* by the <u>nano-positioning</u> and stabilization system *(see presentation of K. Artoos on Session 7 on Friday)*.
- In the CLIC CDR the steering baseline is by <u>small dipole correctors attached to each MBQ</u>.
- Two prototypes (for TYPE1 and TYPE4) were built at CERN. They are not yet measured (resources and priority problems).
- A critical aspect will be the <u>functional tests</u> operating the correctors (at 100 Hz) mounted on the MBQ. This will surely have an impact on the active stabilization performances.

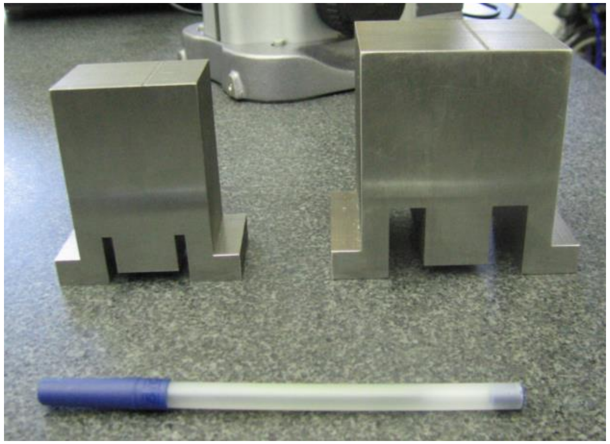


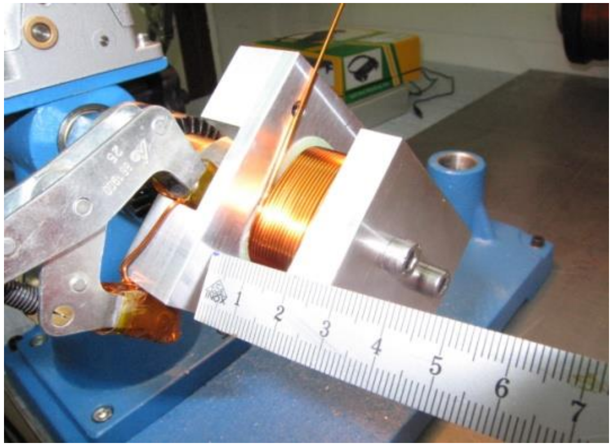
	Dipole Type1	Dipole Type4
∫Bdl	1.16×10^{-3} Tm	4.057×10^{-3} Tm
Gap aperture	12 mm	12 mm
N.of turn per coil	112	374
Current / Voltage	1.02 A / 0.91 V	0.72 A / 3.26 V
Power / Weight	0.93 W / 0.6 kg	2.35 W / 2.1 kg

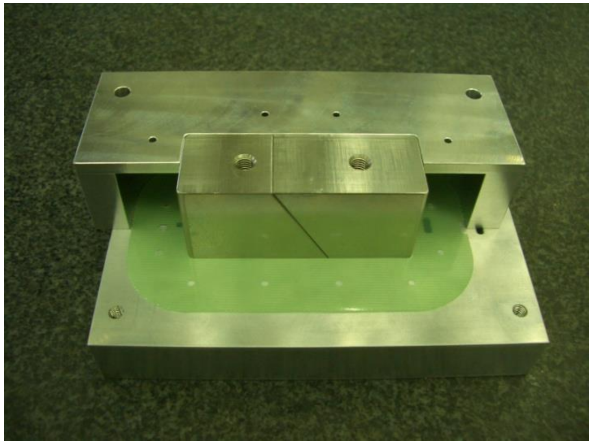


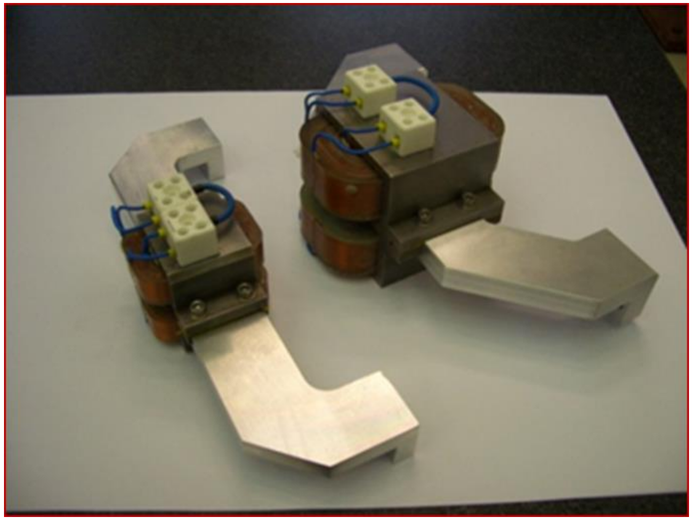
Beam Steering correctors: manufacturing details

- Laminated iron yokes (0.5 mm lamination thickness).
- Required tolerances on some surfaces are very tight (possibly 10 μm), so accurate pole shapes and mating surfaces are machined by wire cutting (EDM).
- Coils winding and curing done at CERN.



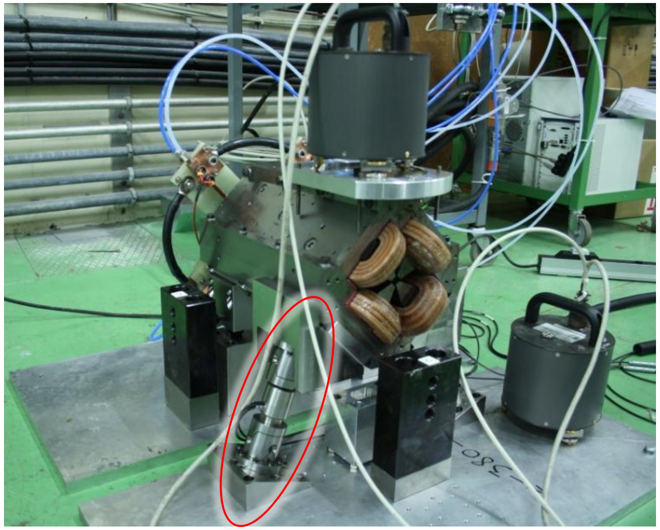






(Left) The two completed prototypes

(Right) A typical nano stabilization test assembly (highlighted the actuators that will provide also the steering capability)



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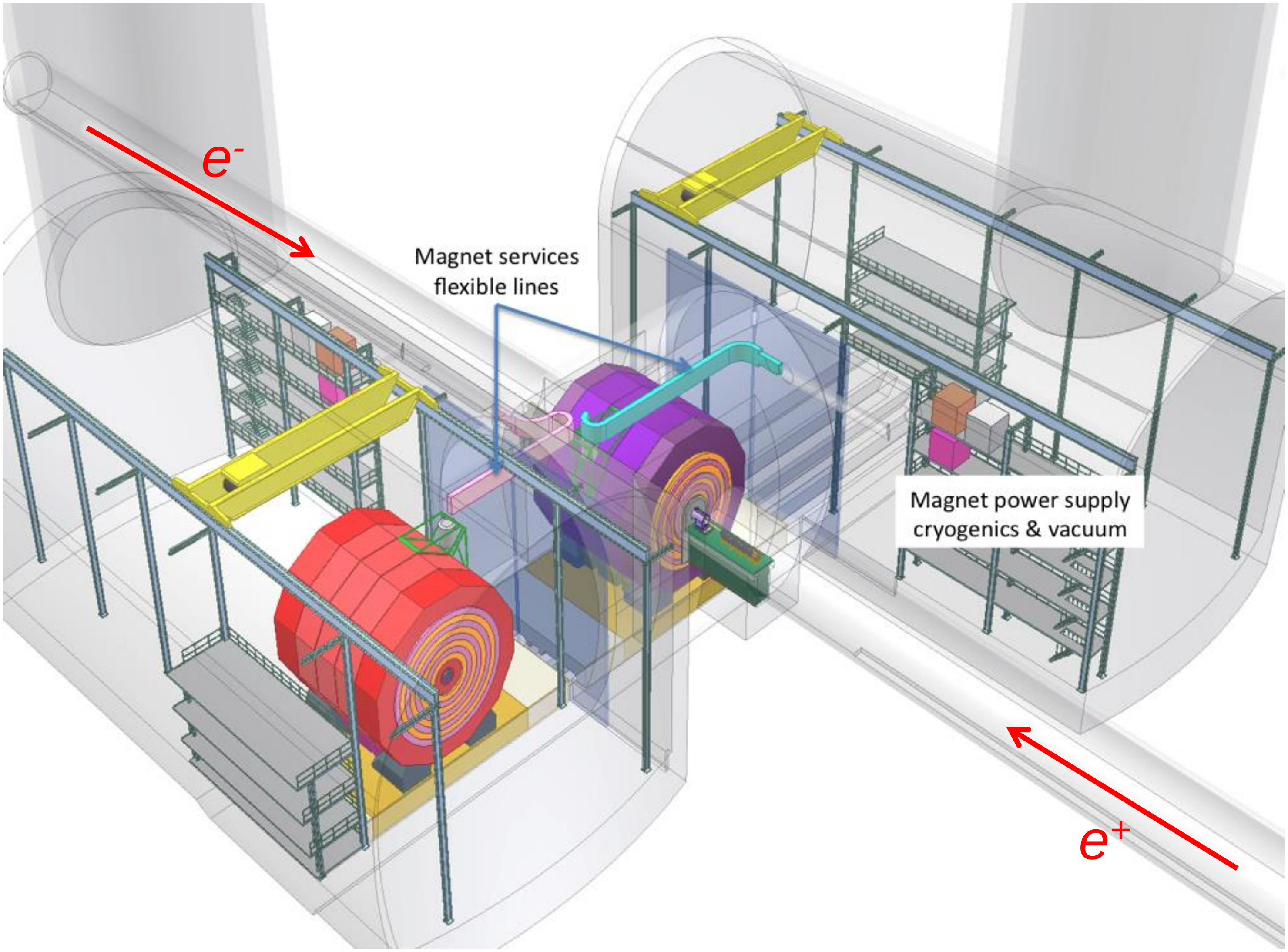
CLIC two-experiments (ILD and SiD) "roll-in" concept and layout (3 TeV, $L^* = 3.5$ m):



CLIC two-experiments "roll-in" layout:

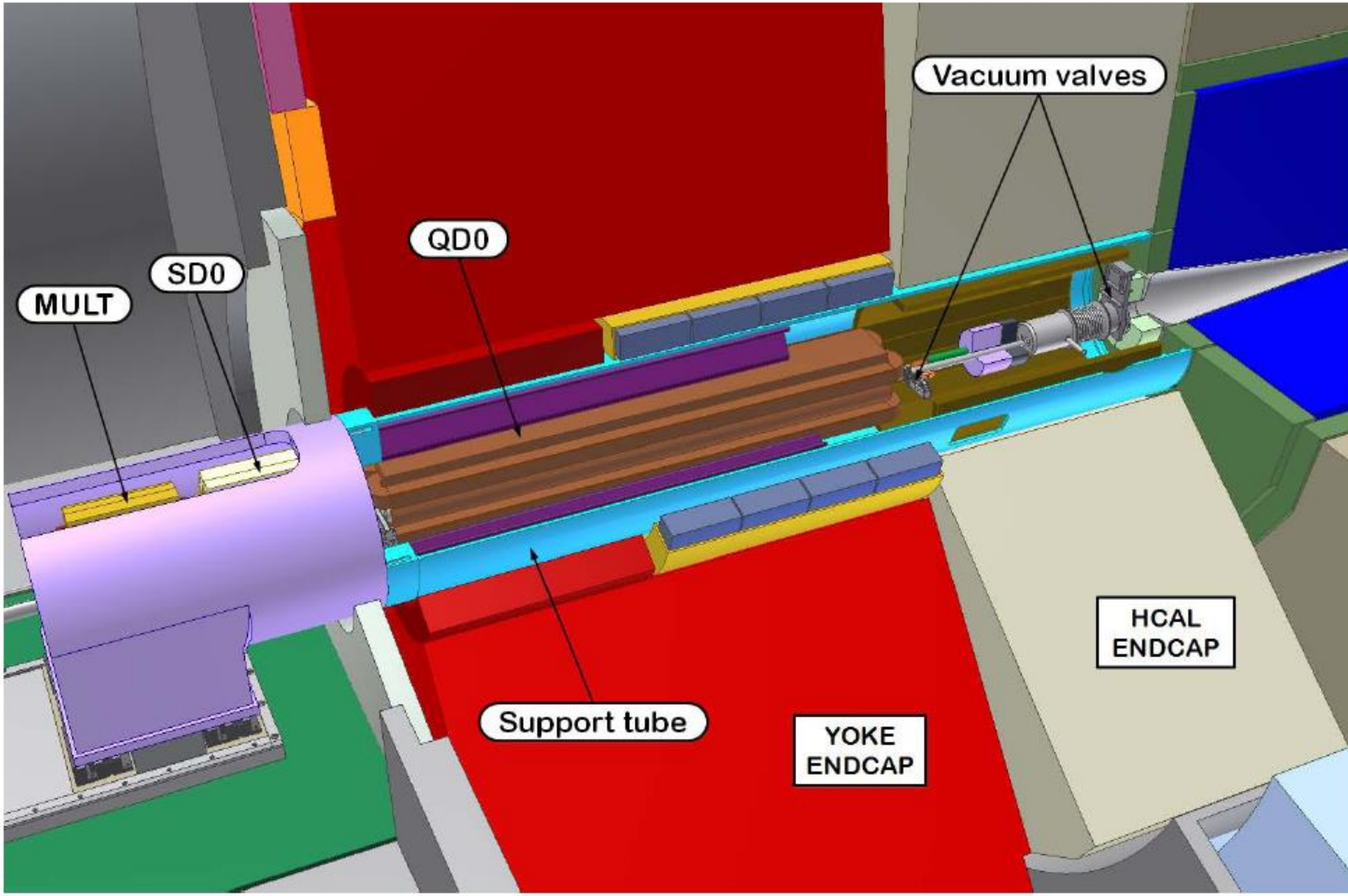
"Nominal" Requirements for CLIC FF Quad *(3TeV, L*=3.5 m)*:

- **Gradient:** highest as possible towards a nominal value of: **575 T/m**
- **Required total Length**: **2.73 m** *(…could probably be split in 2 longitudinal modules…)*
- **Magnet Bore Radius:** for beam: 3.8 mm; + 0.3mm estimated for the vacuum chamber thickness; + 0.025(tolerance) = **4.125 mm**
- **Field Quality:** not frozen values, **≤10** relative units…
- **Tunability:** -20% minimum

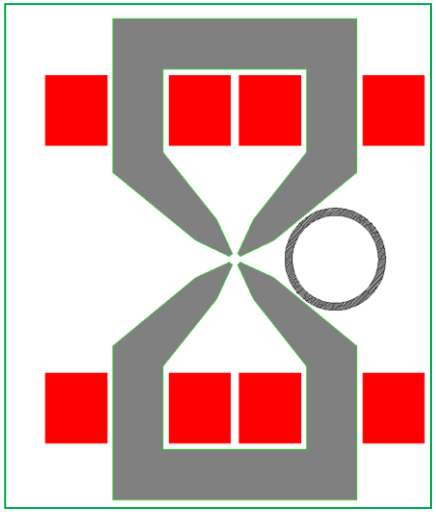
Geometric and other boundary conditions:

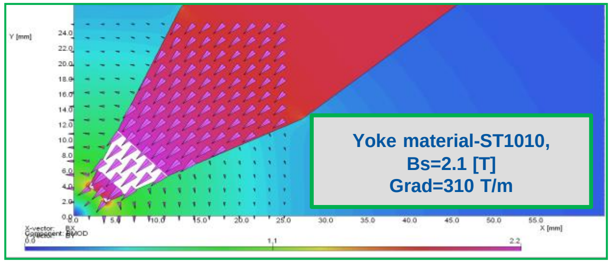
- **Spent beam chamber** presence: a conical pipe with 10 mrad angle, with a minimum transversal distance from the QD0 (at the front-end): **35 mm** → *the QD0 horizontal midplane must be free*
- **Stabilization**: *similar to MBQ magnets in the linac modules, QD0 needs to be actively stabilized in the nm range → weight must be minimized as well as any vibration sources.*
- ***Alignment** will be critical: **10 µm** total budget for fiducialization and alignment → we need to "see" the quadrupole active part (poles)*
- ***Anti-solenoid** presence (for beam dynamic reasons).*

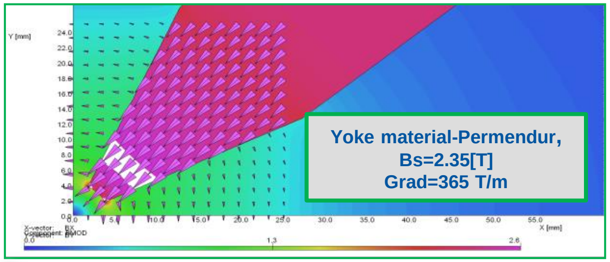
CLIC 3 TeV, L* = 3.5 m Machine Detector Interface (MDI) simplified layout:



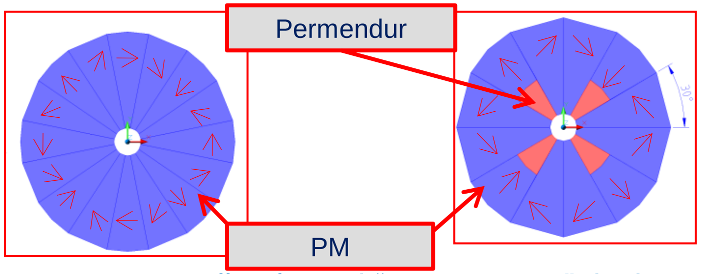
QD0 design evolution:





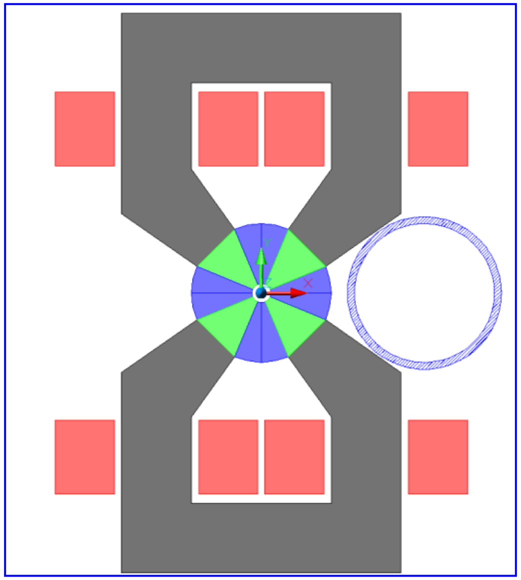


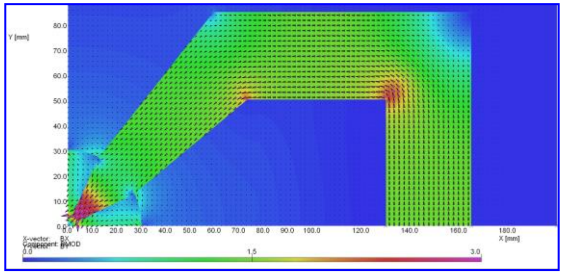
Pure EM design

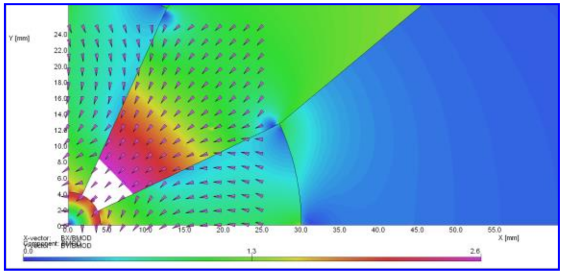


Pure Halbach and "super-strong" design

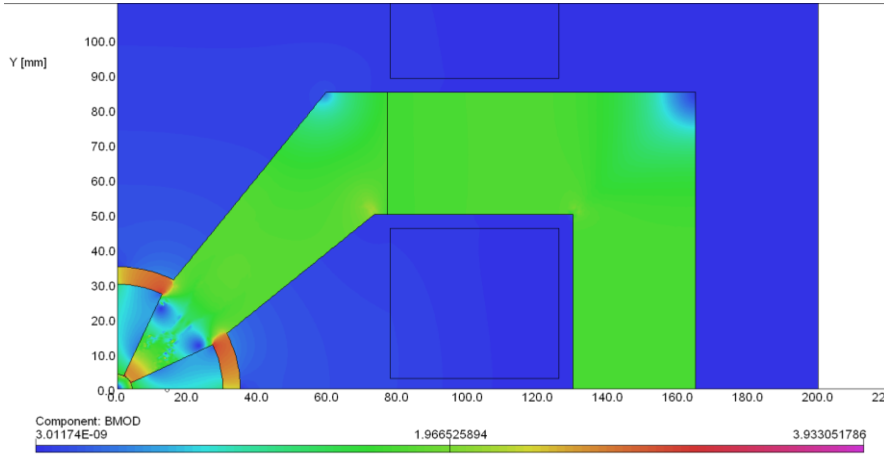
"hybrid" design







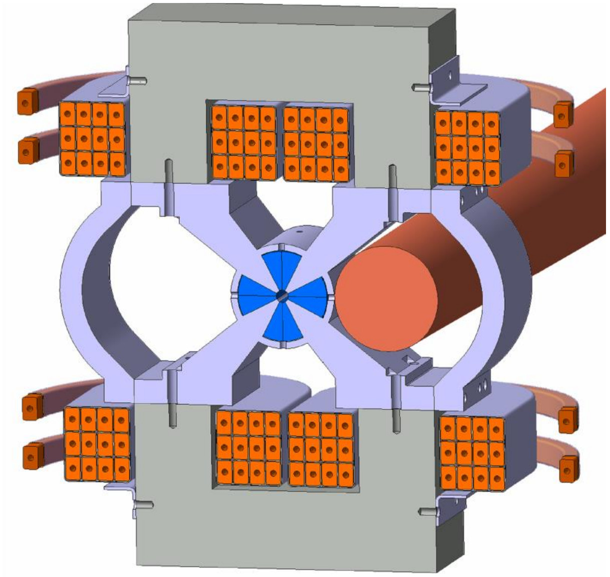
QD0 design evolution, hybrid approach:



"hybrid" version 2

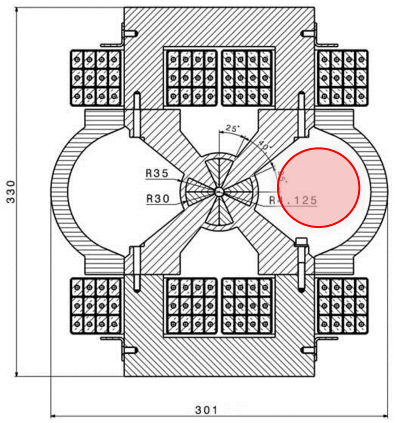
- The presence of the "ring" decrease slightly the achievable gradient (of 15-20 T/m) but it assure big advantages for precise manufacturing and assembly of the four poles as a precise housing for the PM blocks.

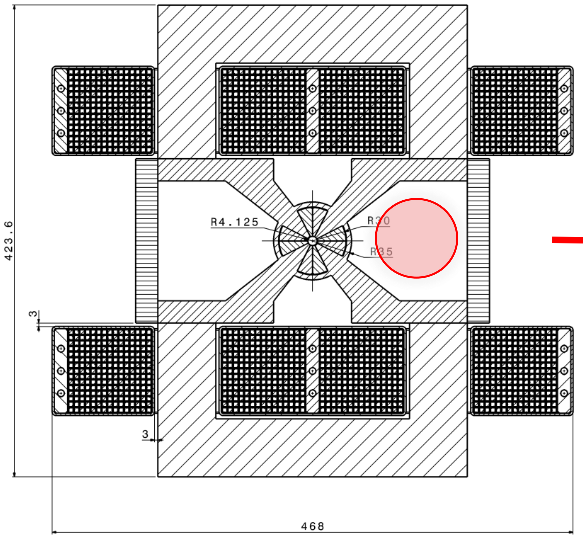
- The coils will also permit a wide operation range setting: at 0 current gradients will be respectively: ~ 145 and ~175 T/m.

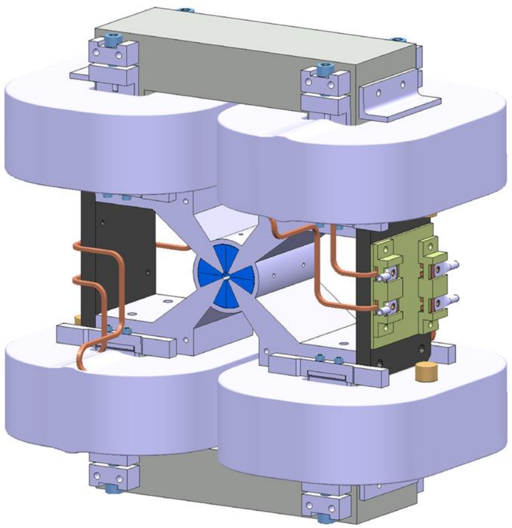


Configuration	G [T/m] for r=4.125 mm (2D calculation)	
Pure EM	**310** (Steel1010) ; **365** (Permendur)	
	Sm_2Co_{17}	$Nd_2Fe_{14}B$
"Pure Halbach"	**409**	**540**
"Super Strong"	**550**	**615**
"Hybrid"	**550**	**615**
"Hybrid with ring"	**531**	**599**

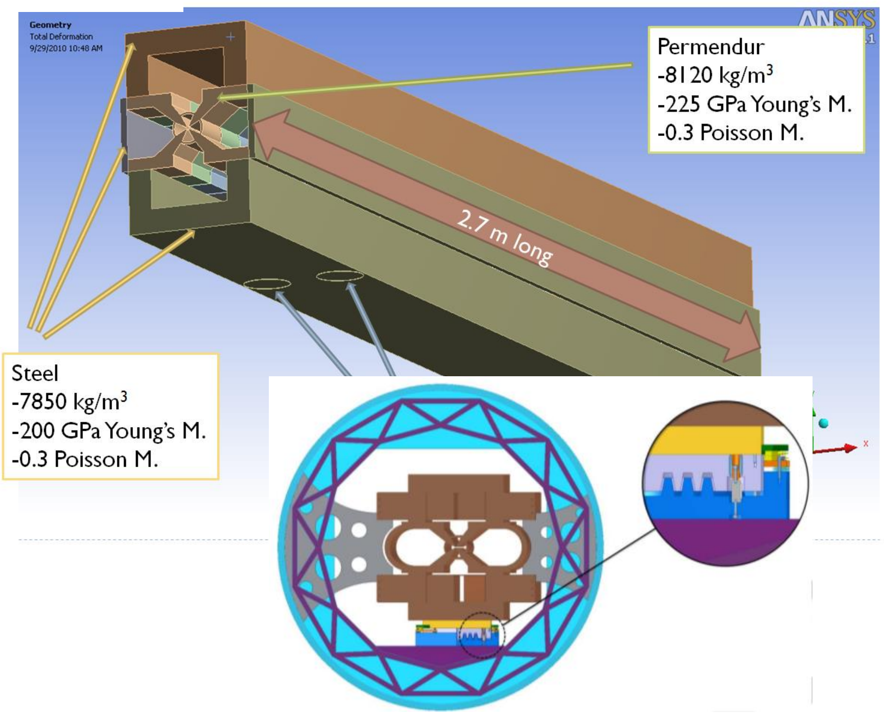
QD0 design evolution, hybrid final design:

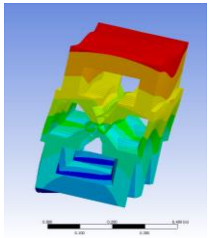


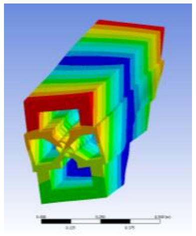




CLIC QD0 Main Parameters		100mm prototype	Real magnet 2.7m
Yoke			
Yoke length	[m]	0.1	2.7
Coil			
Conductor size	[mm]	4×4	4×4
Number of turns per coil		18×18=324	18×18=324
Average turn length	[m]	0.586	5.786
Total conductor length/magnet	[m]	0.586×324×4=760	5.786×324×4=7500
Total conductor mass/magnet	[kg]	26.8×4=107.2	265.2×4=1060.8
Electrical parameters			
Ampere turns per pole	[A]	5000	5000
Current	[A]	15.432	15.432
Current density	[A/mm²]	1	1
Total resistance	[mOhm]	896	8836
Voltage	[V]	13.8	136.4
Power	[kW]	0.213	2.1

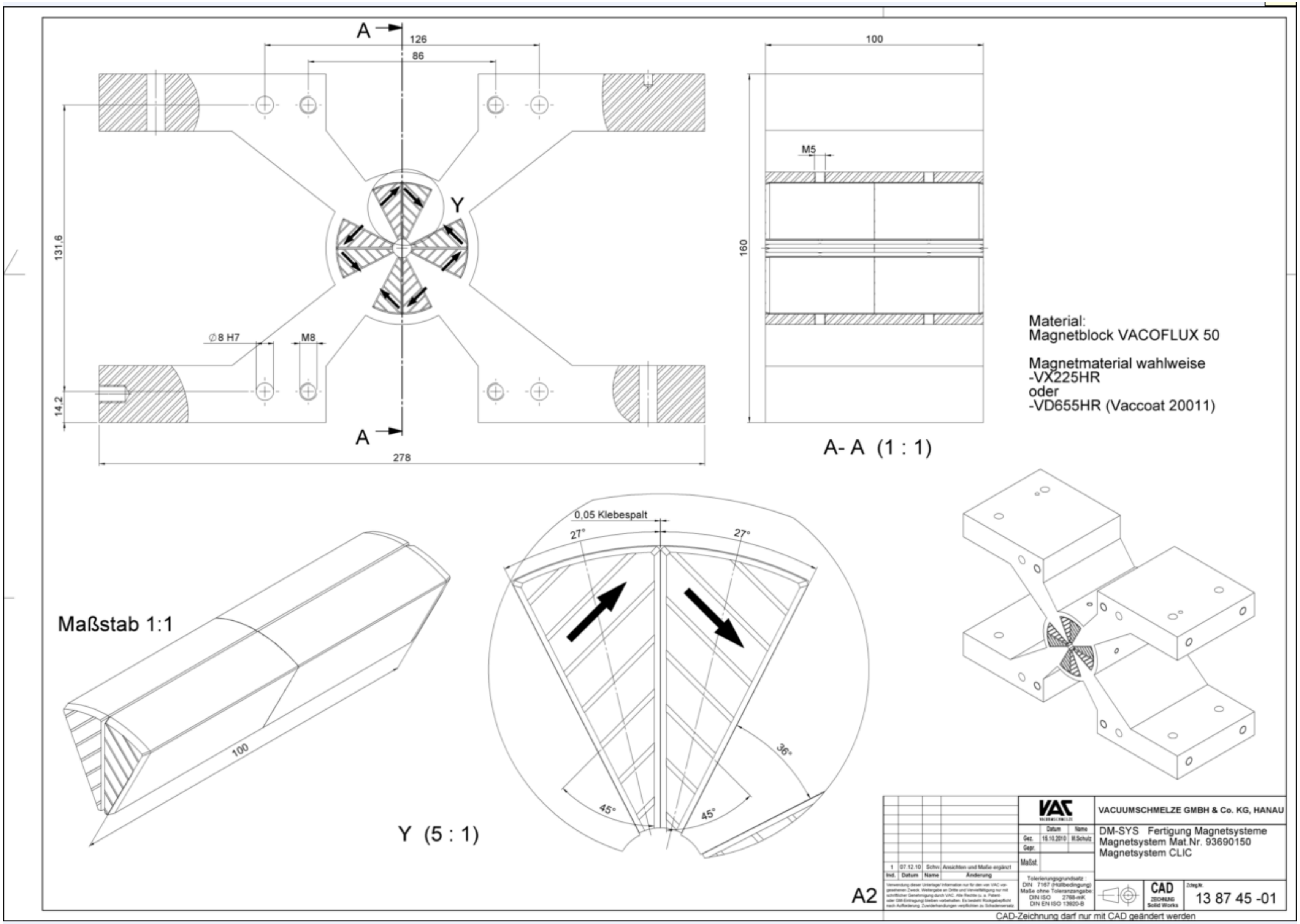






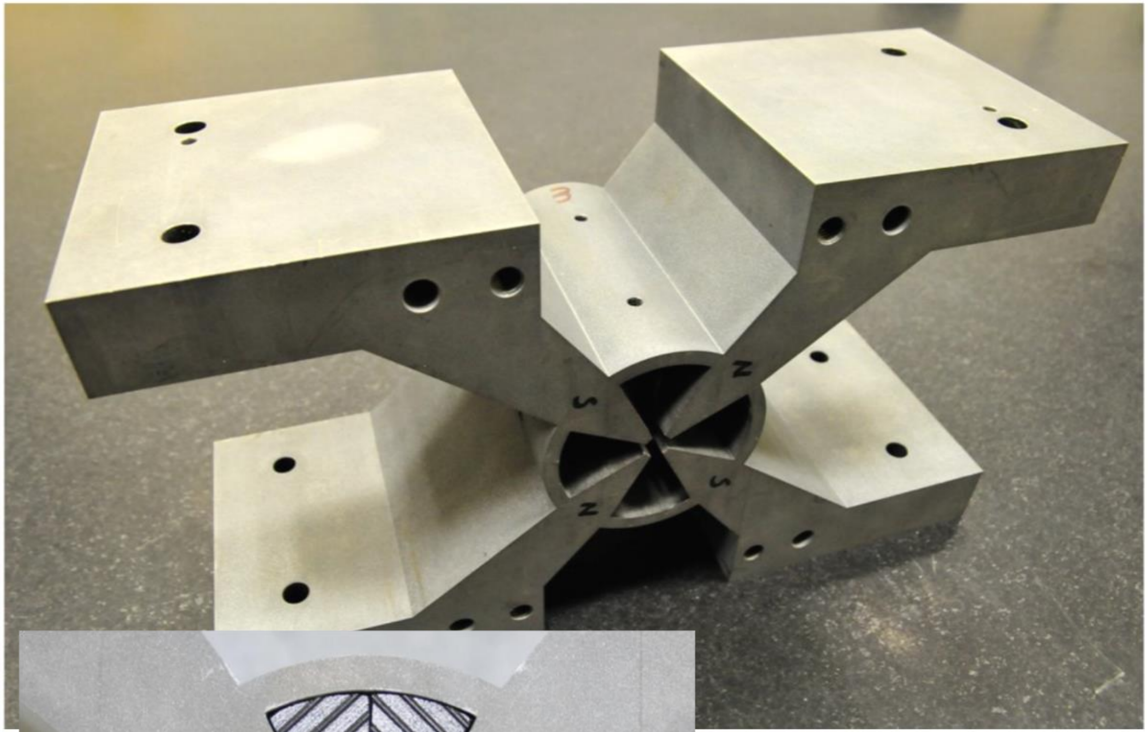
Mode	1st	2nd	3rd	4th
Freq [Hz]	190	260	310	366

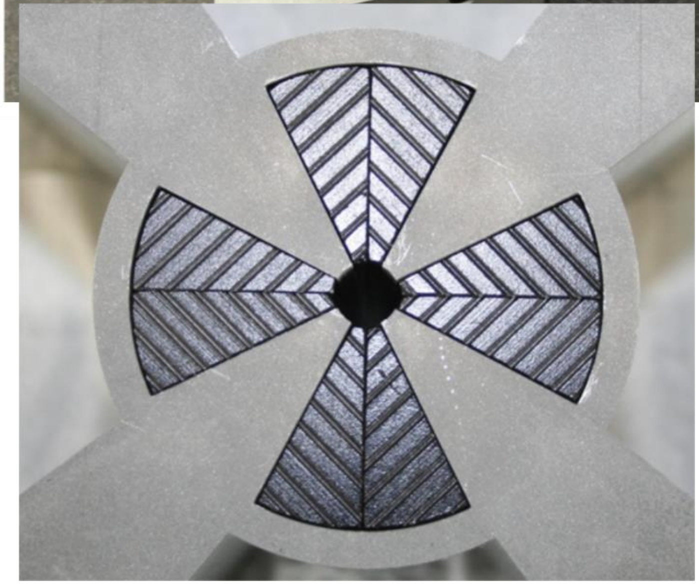
QD0 design evolution, hybrid final design:

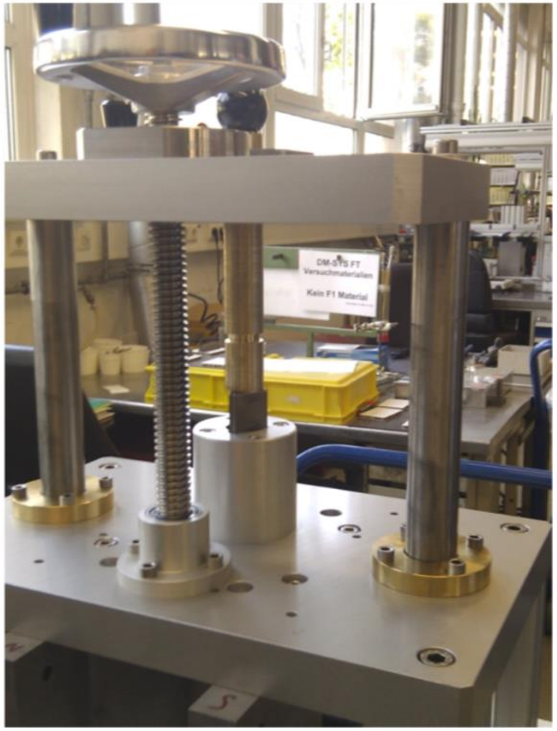


(courtesy Vacuumschmelze)

QD0 design evolution, hybrid final design, manufacturing:



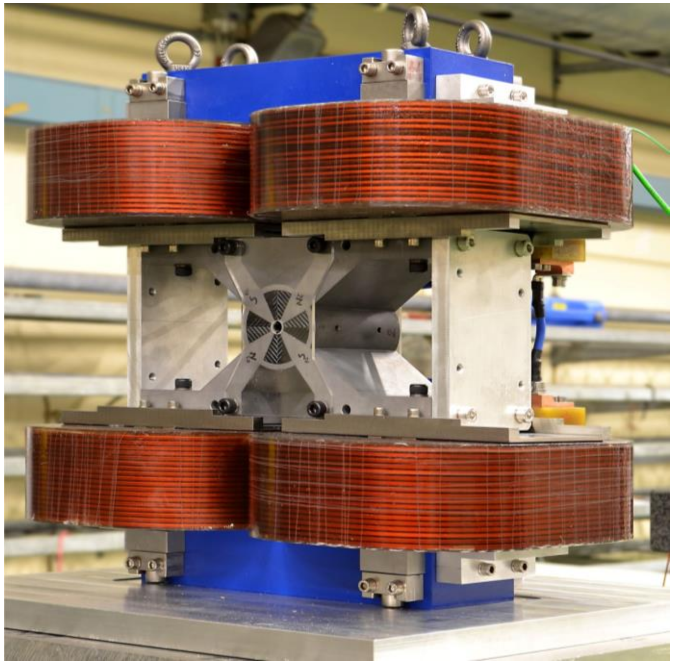




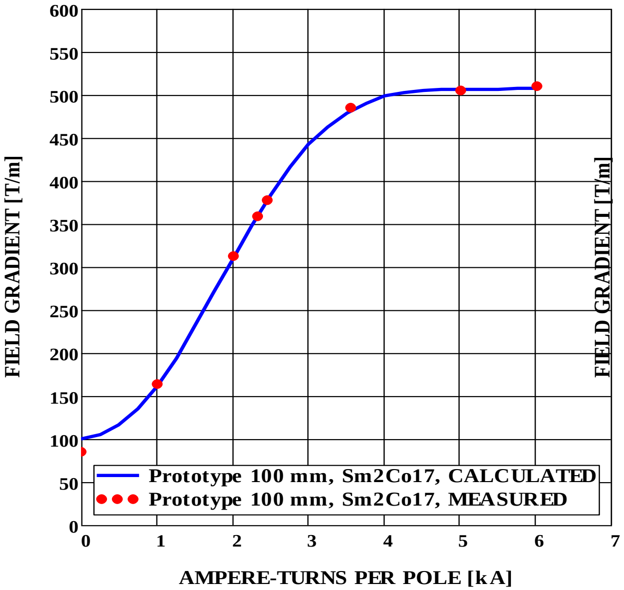
(courtesy Vacuumschmelze)

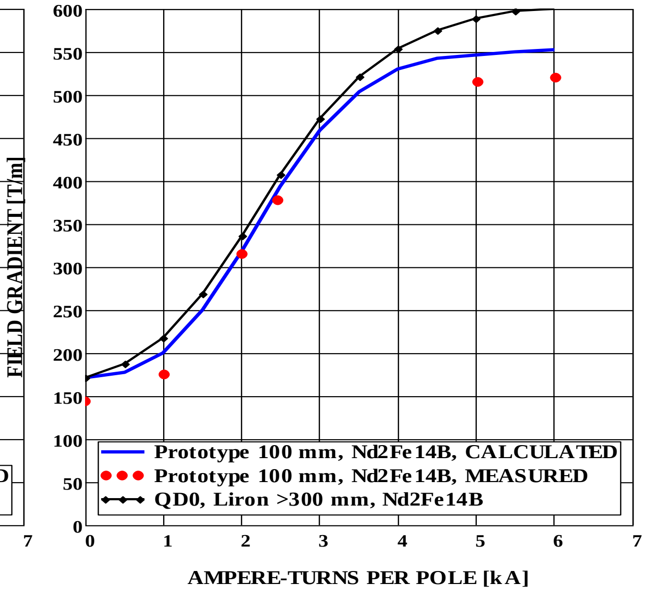
- Permendur parts and PM blocks produced by Electric Discharge Machining (EDM) technique
- Each of the four PM insert is composed by 4 blocks glued together.
- An extracting/inserting tooling is needed for the strong magnetic forces and due to the fragility of PM material.

QD0 design evolution, hybrid final design, measurements:



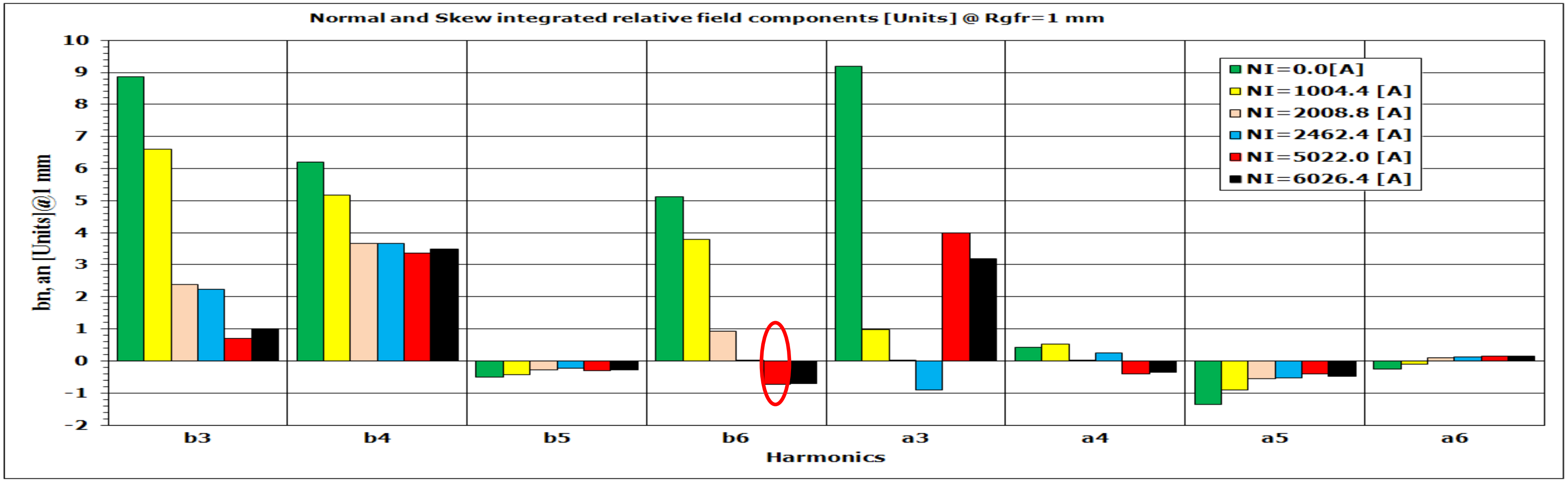
Main Parameter	*Value*
Prototype gradient computed/measured	**503/504 T/m *(SmCo)* 547/514 T/m *(NdFeB)***
Magnetic length (full size QD0)	**2.73 m**
Magnet aperture *(required for beam)*	**7.6 mm**
Magnet bore diameter *(assuming a 0.30 mm vacuum pipe thickness)*	**8.25 mm**
Good field region(GFR) radius	**1 mm**
Integrated field gradient error inside GFR	**< 0.1%**
Gradient adjustment required	**+0 to -20%**

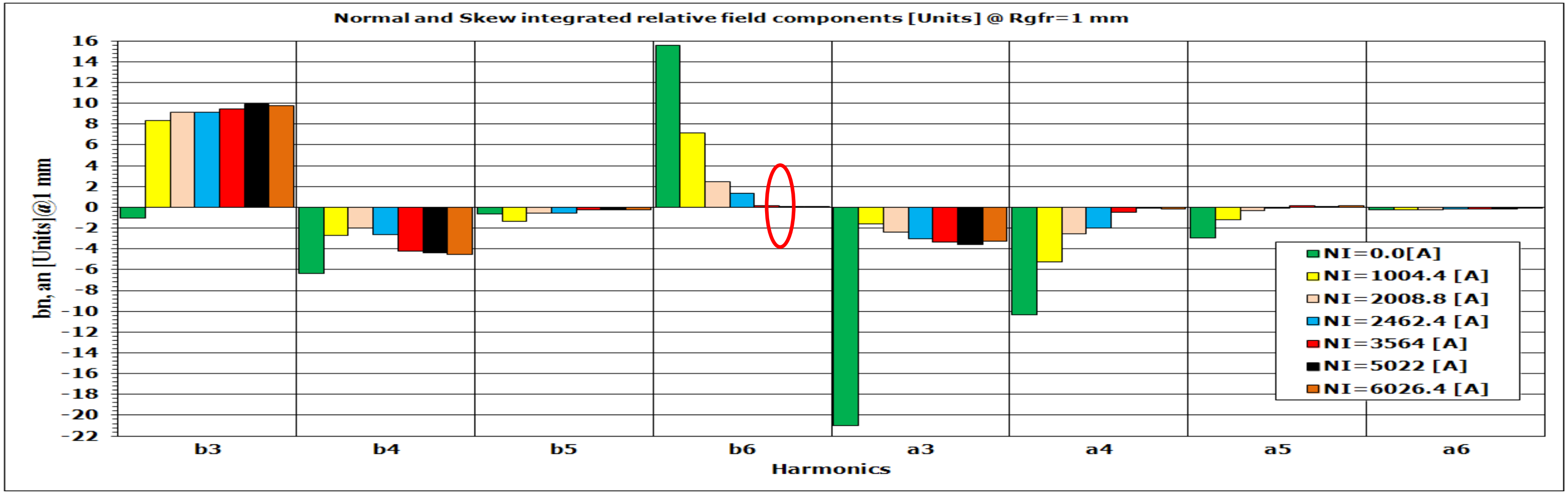




QD0 design evolution, hybrid final design, measurements:

The histograms show the magnetic harmonic content (multipoles) versus the magnet powering for the two QD0 configurations. Upper graph for $Nd_2Fe_{14}B$, lower graph for Sm_2Co_{17}. For comparison: the first computed (integrated) permitted mutipole at NI=5000A is: b6=1.4 units (for $Nd_2Fe_{14}B$) and b6=0.7 units (for Sm_2Co_{17}).



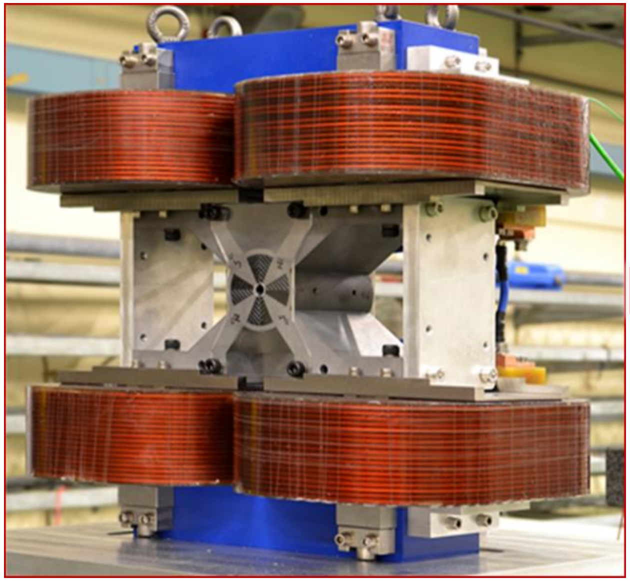


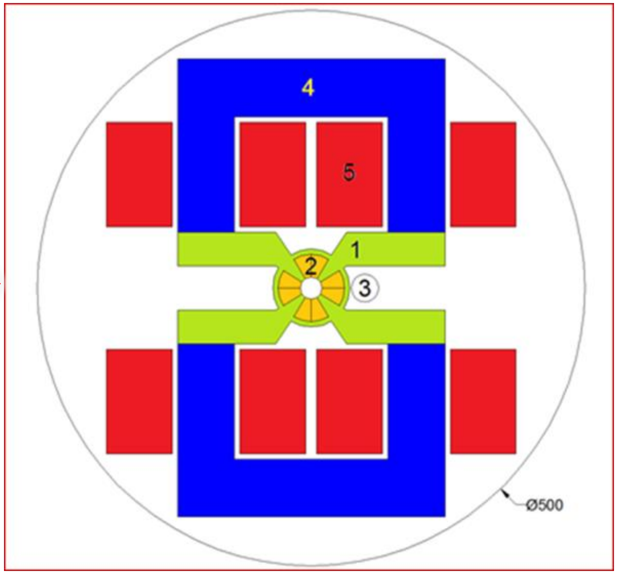
Possible QD0 design evolution, a super-ferric version:

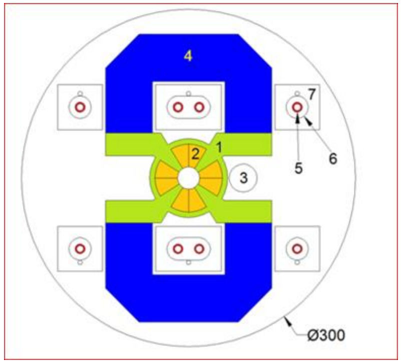
The super-ferric variant (i.e. same hybrid core design but with small superconducting coils at the place of the low current density resistive coils) will even more minimize the cross section (dimensions and weight) preserving one of the most interesting aspects that is: iron part is “visible” and accessible making easier and much precise the alignment and eventually the stabilization the FF quadrupole.

ILC parameters:

Gradient	127 T/m
Aperture radius	10 mm
Ampere-turns	5 kA

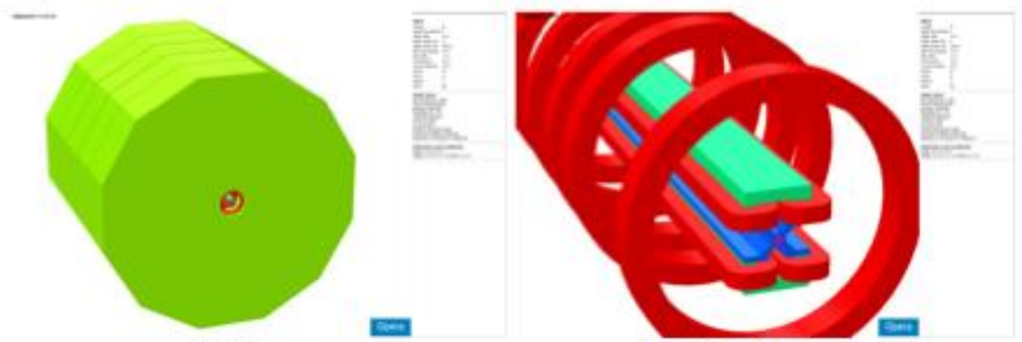






1. *Quadrupolar core in Permendur*
2. *SmCo PM inserts*
3. *Post-collision line vacuum chamber*
4. *Return iron yokes*
5. *Coil packs: 9 NbTi SC wire turns wound around the 4.5 K LHe cooling circuit pipe.*
6. *Cryostat @75K shield*
7. *Cryostat assembly*

QD0 antisolenoid studies:



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

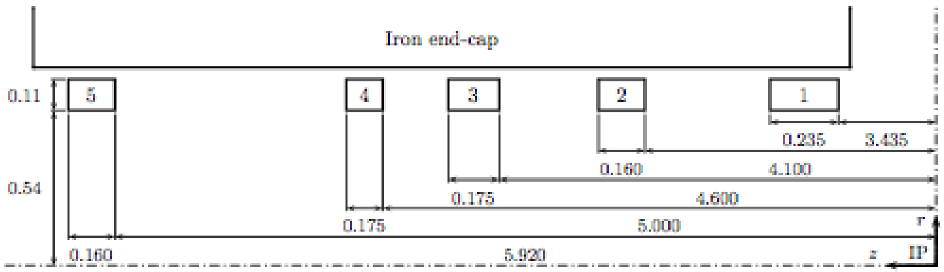
Figure 16: An overview of the Opera3D™ model.

Forces:

- The most relevant is the axial force: *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: $F_z \simeq -5.7$kN; $F_x \simeq 8.3$kN; $T_y \simeq 5.6 \cdot 10^{3}$ Nm.*

Final anti-solenoid dimensions

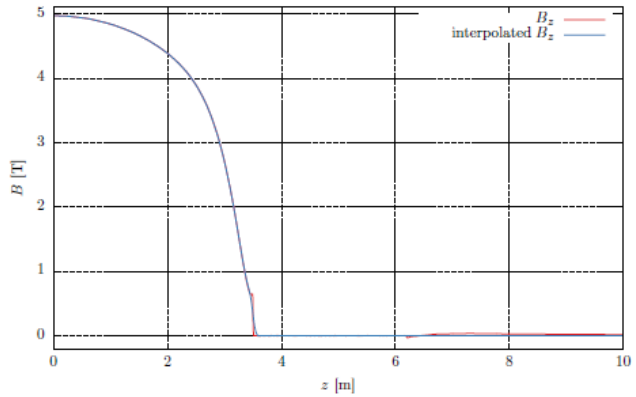


Section number	1	2	3	4	5	
Current density	80.0	23.5	15.0	3.8	2.0	$\frac{A}{mm^2}$

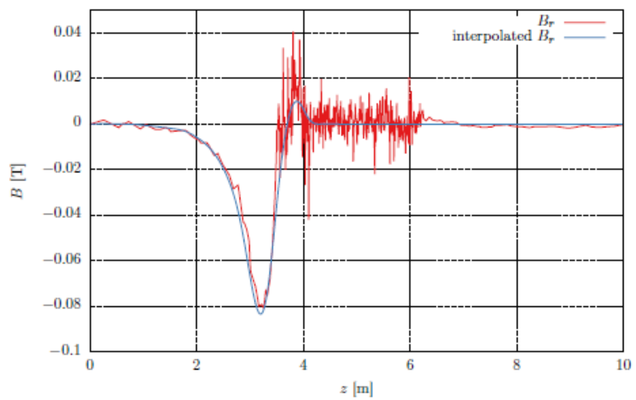
Figure 30: Anti-solenoid coils dimensions (in meters) and current densities.

QD0 antisolenoid studies:

TE Technology Department



(a) Axial magnetic field from the IP to 10 m away.



(b) Radial magnetic field from the IP to 10 m away.

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

29

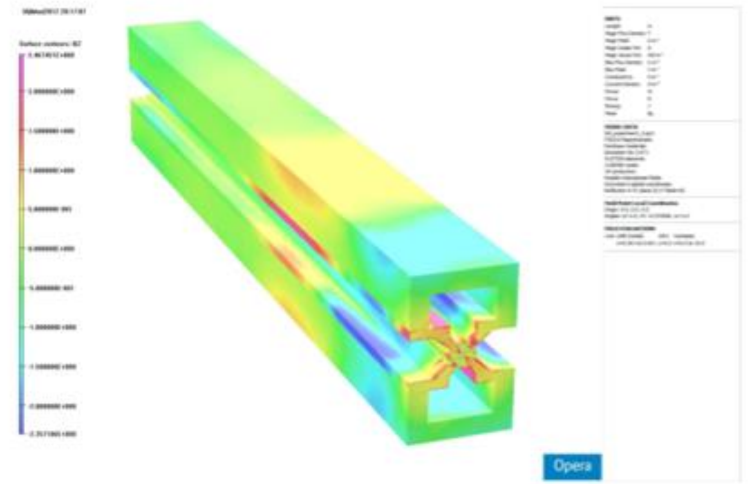


Figure 21: The axial field attracted by QD0, second Opera3D™ anti-solenoid design.

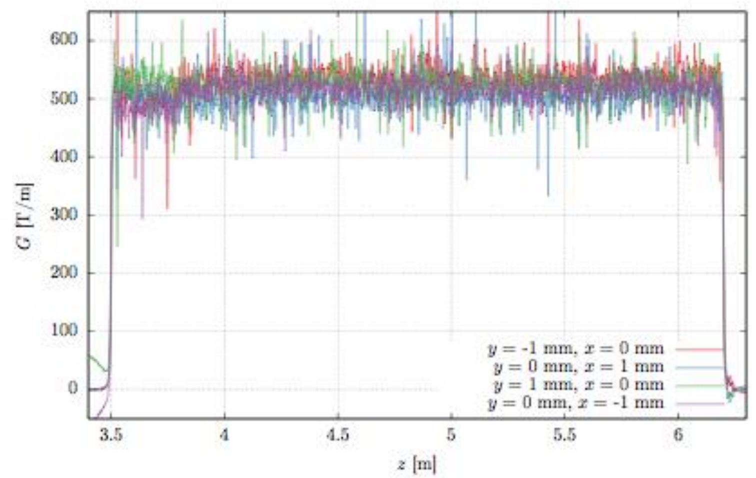
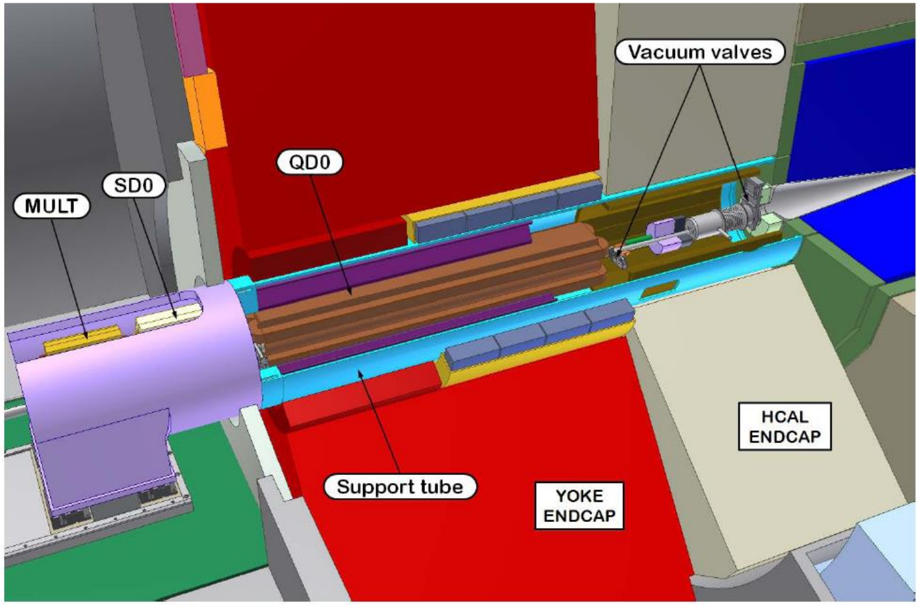
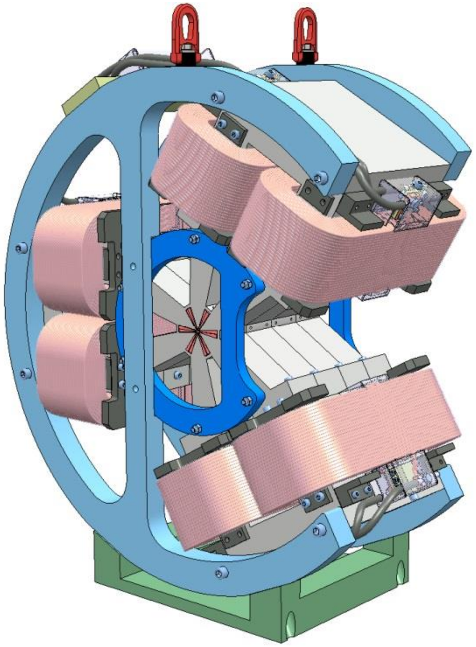


Figure 22: QD0 gradient, second Opera3D™ design.

SD0 hybrid design :





Parameter	Value
Inner radius	4.3 mm
Nom. Sext. Gradient	219403 T/m2
Magn. Length	0.248 m

The main requirements & boundary conditions for SD0 magnet are (as for QD0):

1) Strongest as possible gradient
2) Tunability of min. -20 %
3) Minimized weight and vibrations (magnet must be actively stabilized)
4) Integration with the Post Collision vacuum pipe.

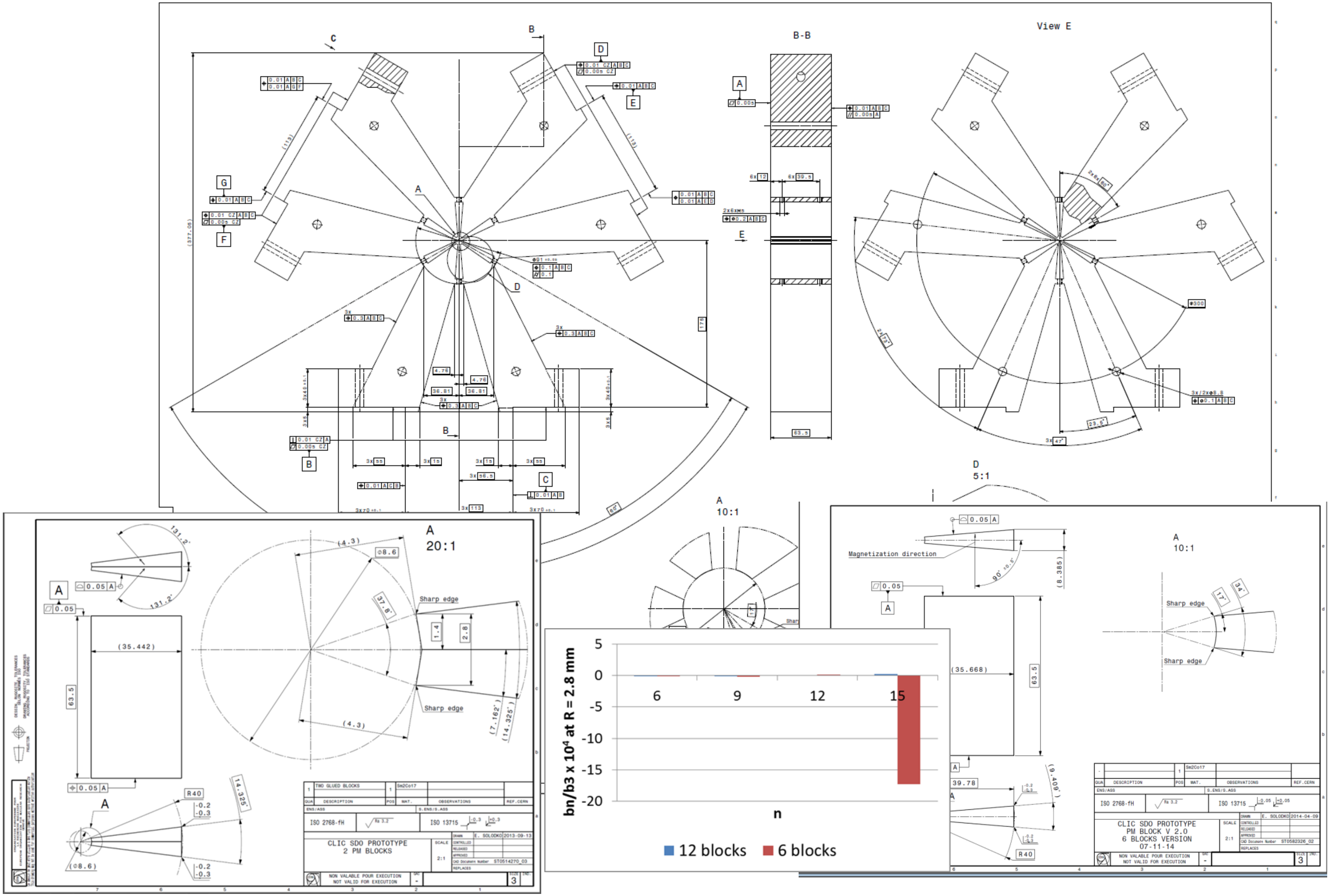
Compactness is less critical respect to QD0 (magnet is placed in the Accelerator Tunnel just at the border with the Experimental Hall).

The prototype manufacturing should permit to investigate the precise assembly of several (4) longitudinal sections, each one equipped with PM blocks (same concept of QD0).

Key aspects:

- Manufacturing (precision) of each Permendur sector, PM block, etc.
- Sorting of PM blocks
- Assembly of the sectors (magnetic forces between blocks, fragility of PM blocks,…)
- Fiducialisation and alignment

SD0 hybrid design :



References:

CLIC: a Compact Linear Collider

- CLIC Conceptual Design Report, CERN, 2012. Available at http://clic-study.org/accelerator/CLIC ConceptDesignRep.php .
- CLIC Magnet Catalogue composed by the following CLIC Notes: 863, 864, 865, 873, 984 available at: http://clic-study.org/publication/CLIC CLICNotes.php .

Main Beam Quadrupoles

- M. Modena, A. Bartalesi, J. Garcia Perez, R. Leuxe, G. Perrin-Bonnet, C. Petrone, M. Struik, and A. Vorozhtsov: “Performances of the Main Beam Quadrupole Type1 Prototypes for CLIC” MT23, Boston, US, July 2013, IEEE Transactions on Applied Superconductivity, Vol. 24, NO. 3, JUNE 2014, 4002504 .
- M. Modena, R. Leuxe, M. Struik: “Results on Ultra-Precise Magnet Yoke Sectors Assembly Tests”, MT23, Boston, July 2013, IEEE Transactions on Applied Superconductivity, Vol. 24, NO. 3, JUNE 2014, 9001304 .

Drive Beam Quadrupoles (EM version) and Steering correctors

- M. Modena, "Status of Design and Prototypes Procurement for CLIC 2-Beams Modules Magnets" Proceedings of the 2012 International Workshop on Future Linear Colliders (LCWS12), University of Texas, Arlington, US, October 2012 .
- M. Modena et al.: “Status of CLIC Magnets Studies and R&D” presented at IPAC14, June 2014, Dresden, D .

Drive Beam Quadrupoles PM version *(please refer to **B.Sheperd and N Collomb** presentations at this WS)*

- J.A. Clarke et al: “Novel Tunable Permanent Magnet Quadrupoles For The CLIC Drive Beam”, MT23, Boston July 2013, IEEE Transactions on Applied Superconductivity, Vol. 24, NO. 3, JUNE 2014 4003205 .
- P. Wadhwa et al.: “Design and Measurement of a Low-energy Tunable Permanent Magnet Quadrupole Prototype”, presented at IPAC14 (TUPRO113)

Final Focus QD0

- M. Modena, O. Dunkel, J. Garcia Perez, C. Petrone, E. Solodko, P. Thonet, D. Tommasini, A.Vorozhtsov, “Design, Assembly and First Measurements of a short Model for CLIC Final Focus Hybrid Quadrupole QD0”, IPAC12, New Orleans, May 2012, Conf. Proc. C1205201 (2012) pp.THPPD010 .
- A. Vorozhtsov, M. Modena, D. Tommasini: “Design and Manufacture of a Hybrid Final Focus Quadrupole Model for CLIC” Presented at MT22 .
- Michele Modena, Alexander Aloev, Hector Garcia, Laurent Gatignon, Rogelio Tomas: “Considerations for a QD0 with Hybrid Technology in ILC” presented at IPAC14, June 2014, Dresden, D.

Antisolenoid studies

- A. Bartalesi, M. Modena: “Design of the Anti-Solenoid System for the CLIC SiD Experiment” CLIC Note 944 .

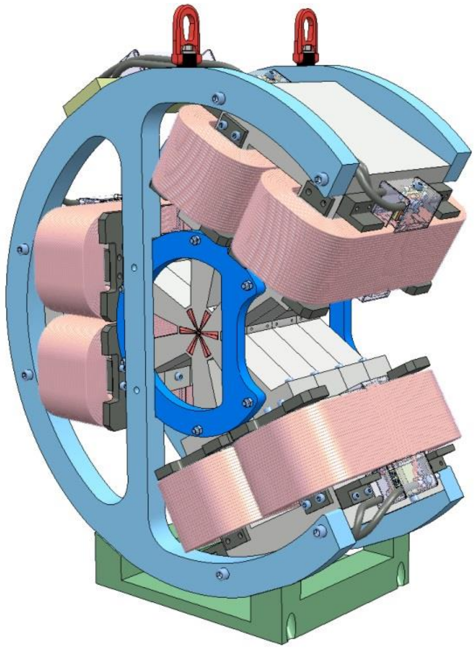
Final Focus SD0

- A. Aloev, M. Modena at 32nd MDI meeting (13th June 2014) (https://indico.cern.ch/event/318670/) .

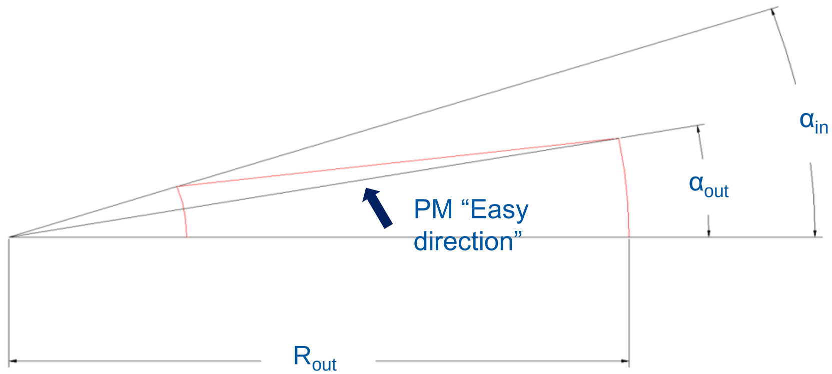
Thank you !

- Extra slides

SD0 hybrid design :

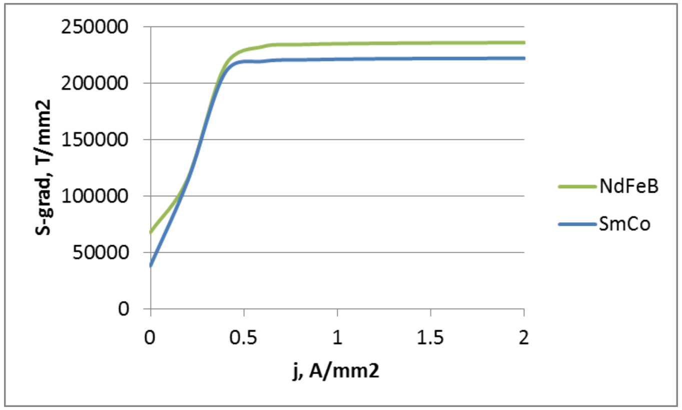


PM block analysed parameters



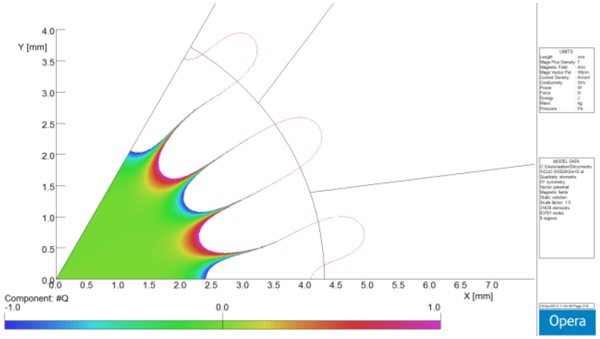
Optimization process provides the following values : α_{in} = 18.9° α_{out} = 8.4 ° R_{out} = 40 mm

	NdFeB	SmCo
R_{out} mm	*S-gradient, T/m²*	
20	217 271	200 368
40	234 438	220 891
70	235 926	222 188
90	236 000	222 188

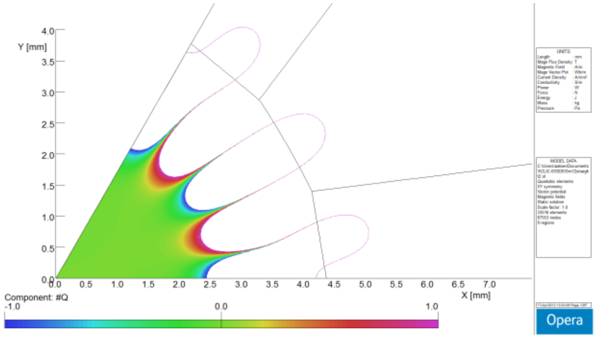


Magnet powering curve

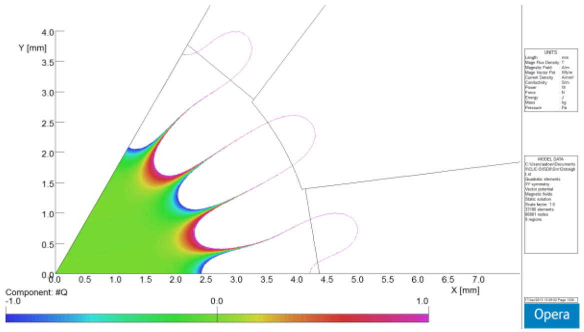
SD0 hybrid design :



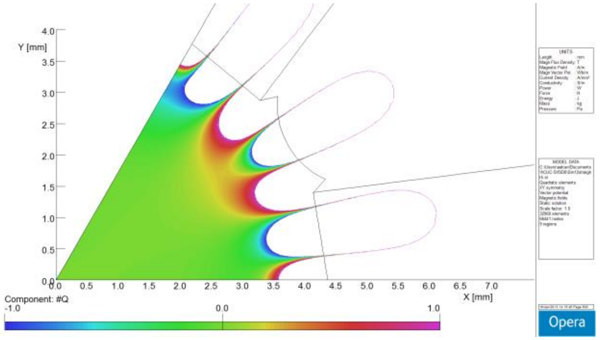
Opt.1 S-grad 222020 T/m^2



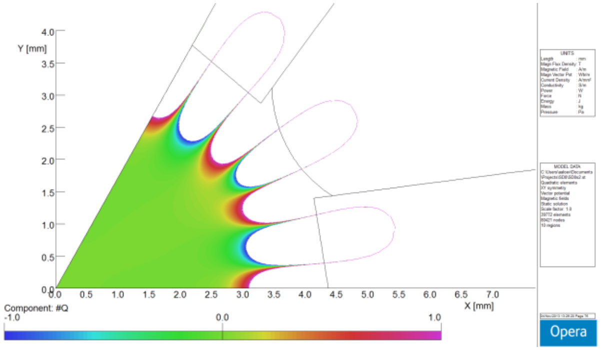
Opt.2 S-grad 220349 T/m^2



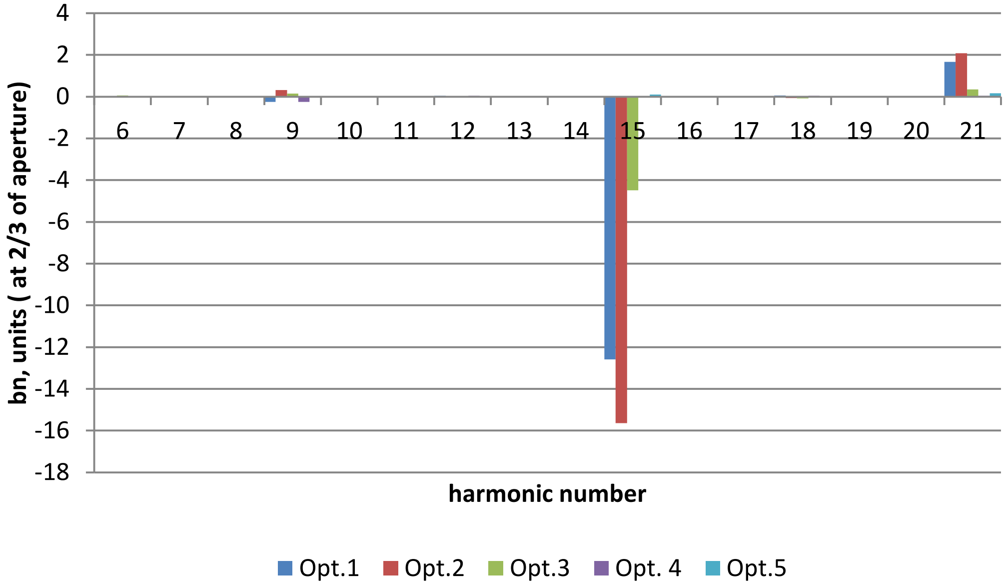
Opt.3 S-grad 221247 T/m^2



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



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

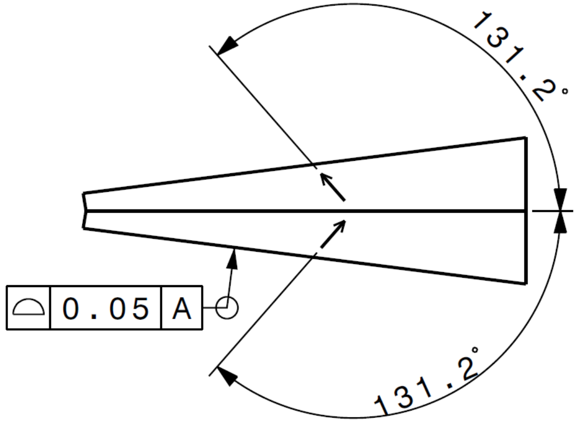


	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Opt.1	0.02338			-0.25272			0.03797			-12.5842			0.05568			1.66380165
Opt.2	0.01156			0.32237			-9.02E-03			-15.6347			-0.06368			2.07597517
Opt.3	0.04744			0.15097			5.19E-03			-4.49391			-0.08142			0.34706331
Opt. 4	8.64E-03			-0.25438			0.04409			1.04E-04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

SD0 hybrid design :

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 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

Collaboration with ASTeC (Daresbury Lab)

NOTE: ASTeC Daresbury Lab (that is part of the CLIC collaboration) will now investigate potential innovative designs (based on PM) for CLIC transfer lines dipoles:

-dipoles of MB RTML (Main Beam Ring Transfer line to Main Linac)

-dipoles of DB TAL (Drive Beam Turn Around Loop)

Type	Quantity	Length (m)	Strength (T)	Pole Gap (mm)	Good Field Region (mm)	Field Quality	Range (%)
MB RTML	666 (500 + 158 + 8)	2.0	0.5	30	20 x 20	1×10^{-4}	–
DB TAL	576	1.5	1.6	53	40 x 40	1×10^{-4}	10–100