Options for Final Focusing Quadrupoles

Michele Modena CERN TE-MSC

Many thanks for the contributions of:
J. Garcia Perez, H. Gerwig, C. Lopez, C. Petrone, E. Solodko, D. Swoboda, P.Thonet, A. Vorozhtsov

Disclaimer: This contribution is coming after "coffee discussions" with Marco Zanetti on: ongoing activities at CERN on "compact" quadrupoles design;
No specific sizing to LEP3 parameters is done (yet)

Content:

- *Some possible solutions for compact medium and high gradient quadrupole design*
- *As example: What we are developing inside the CLIC Final Focus R&D*

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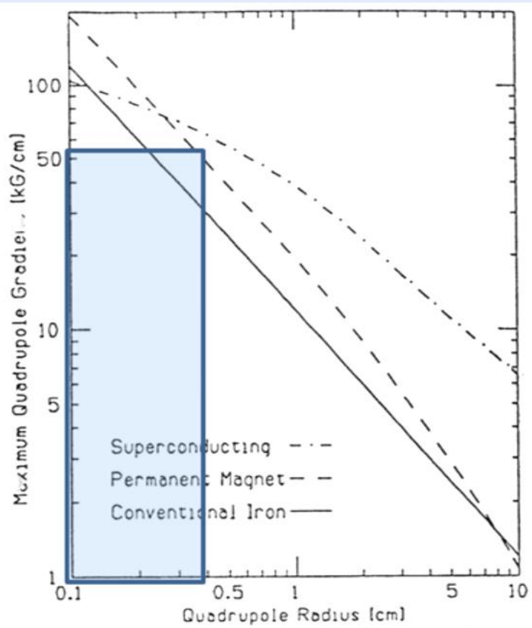
High Gradient quads:

Max. Gradients

Requirements

SC type	Temp [K]	Bcr [T]	J [A/m2]	G [T/m]
Nb-Ti	1.9	5	6*10^9	300
Nb3Sn	1.9	5	1*10^10	500



Strengths obtainable for the different quad types based on a peak pole-tip field B_p=12 kG for the iron, a maximum remanent field B_r=11.5 kG for the PM material and NbTi wire with J_c=2kA/mm^2 at 5T and 4.2°K.

Some Uses of REPMM's in Storage Rings and Colliders*
SLAC – PUB – 3647
April 1985

J. Spencer

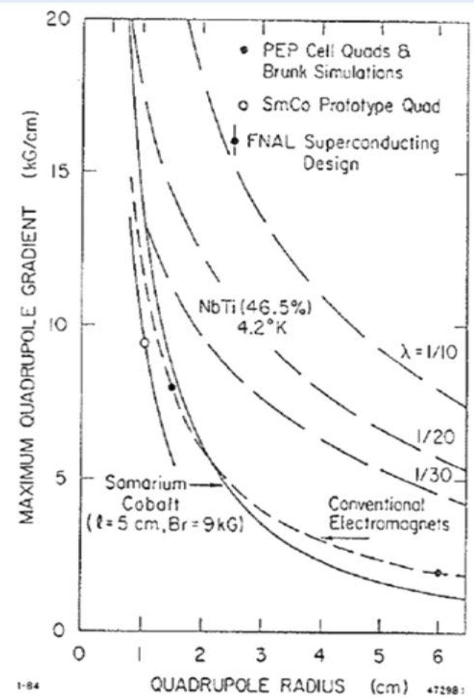
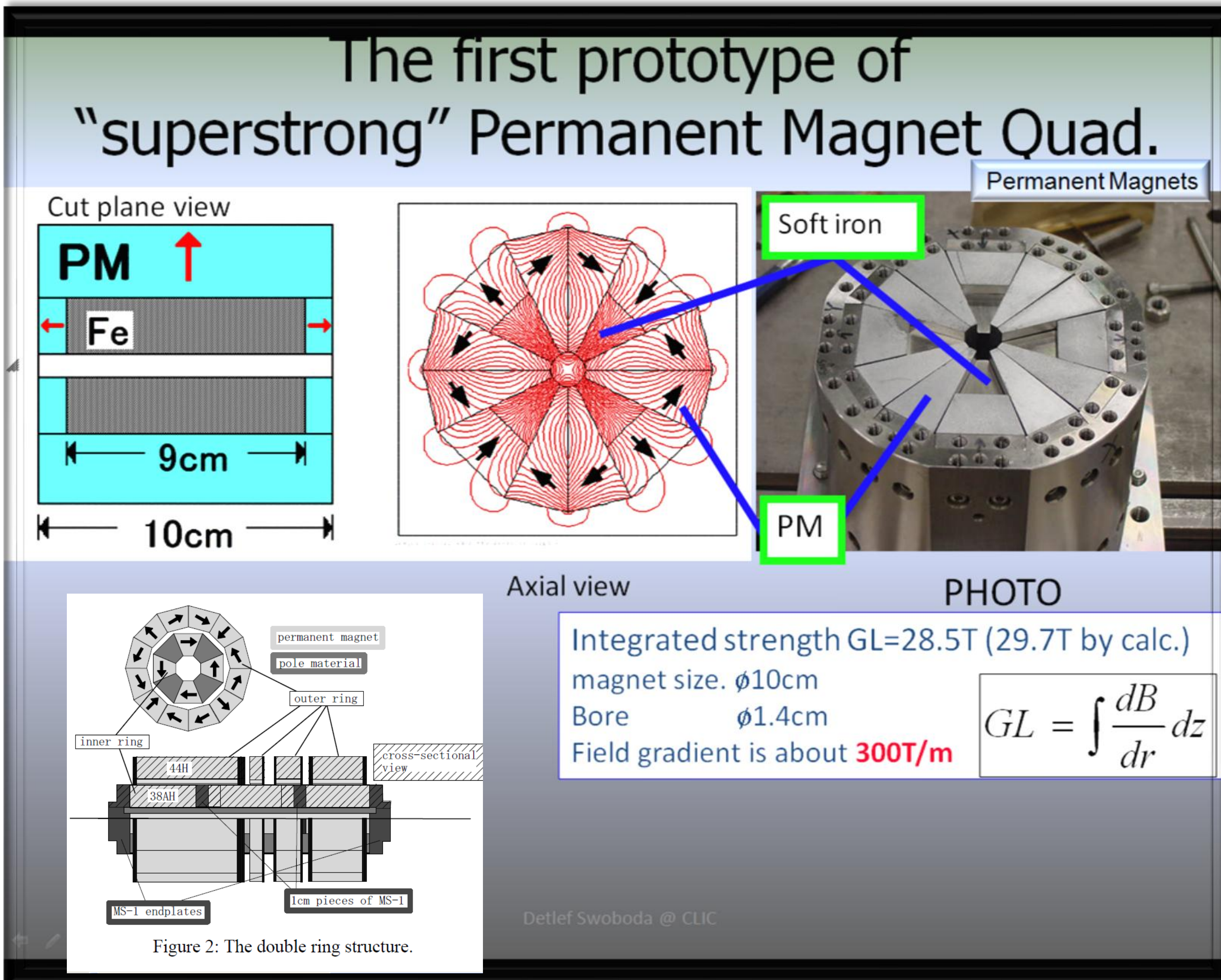


Fig. 1: Comparison of achievable gradients in conventional, superconducting and permanent magnet quads as a function of aperture radius. λ is the superconductor packing fraction.

5 June. 2009 Detlef Swoboda @ CLIC

SC High Gradient quads R&D (for ILC):

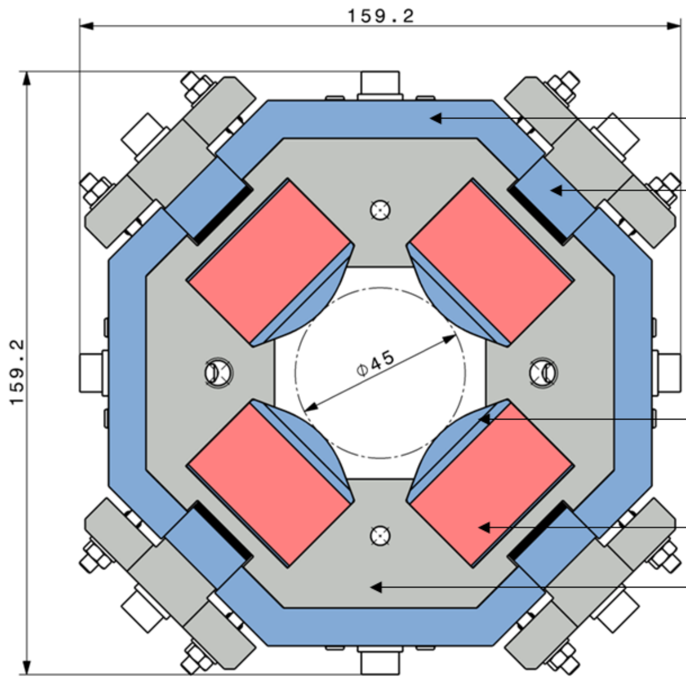
PM High Gradient quads R&D:



"Options for Final Focusing Quads", M. Modena TE/MSC at EuCARD LEP3 Day on 18 June 2012

A PM CERN realization for LINAC4:

LINAC4 Permanent magnet quadrupole general view



Return yoke C10R steel.

Tuning blocks C10R steel, to compensate the possible p.m. inequalities and set the field gradient (up to a reduction of 6 % of the nominal value). Mechanically movable up to 6 mm, independently for each pole. The exact position of the blocks is assured by non-magnetic spacers of different thickness.

Pole tip C10R steel, smooth the possible differences on the easy axis orientation of the permanent magnet blocks.

Permanent magnet blocks Sm_2Co_{17}, as a flux generator.

Core aluminium, structure maintaining all the parts together, giving a high precision on the poles positioning.

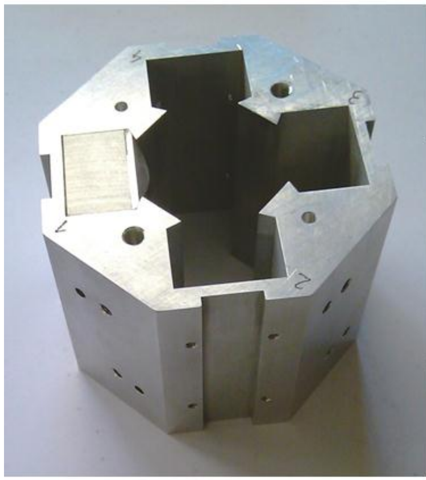
Advantage of this design:

- Possibility to compensate the differences on the permanent magnet blocks.
- Possibility to set the field gradient. 3 types of quadrupoles (low, medium and high gradient) cover an integrated gradient range from 1.3T to 1.6T (nominal gradient: 16 T/m; length: 100 mm)

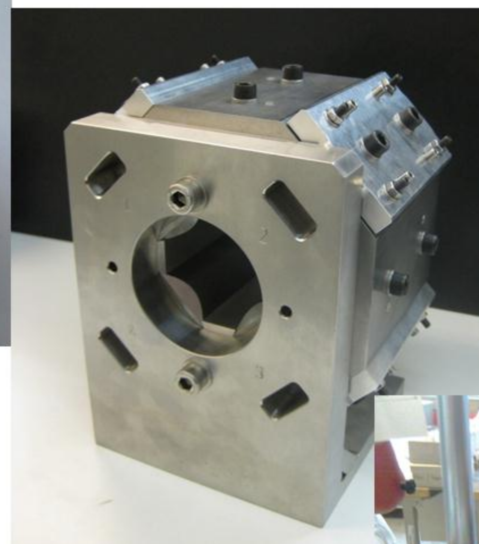
Pierre-Alexandre THONET Linac4 BCC - 15.02.2011 4

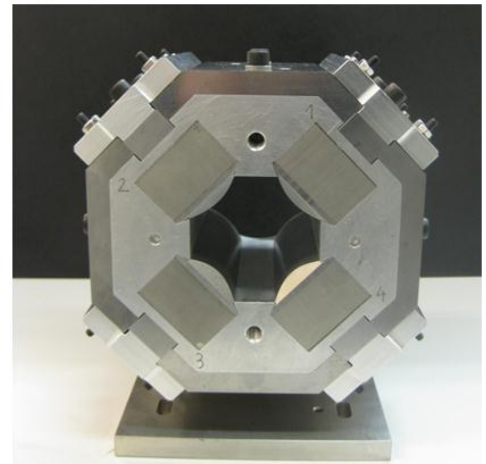
A PM CERN realization for LINAC4:

Fabrication of the prototype



- The aluminium core was made by EDM cutting.
- All the soft steel parts were machined and ground.





- The assembly of the magnet was done carefully by hand.

Pierre-Alexandre THONET   Linac4 BCC - 15.02.2011   12

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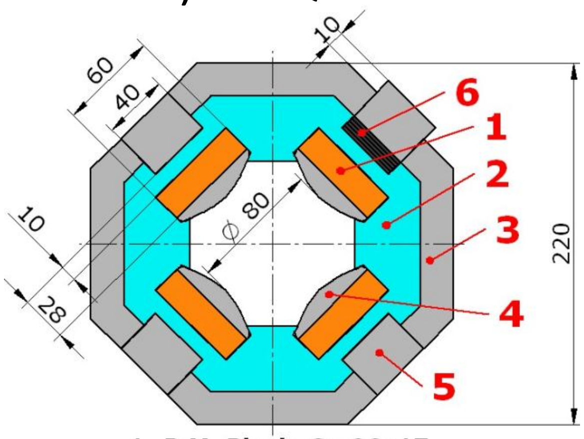
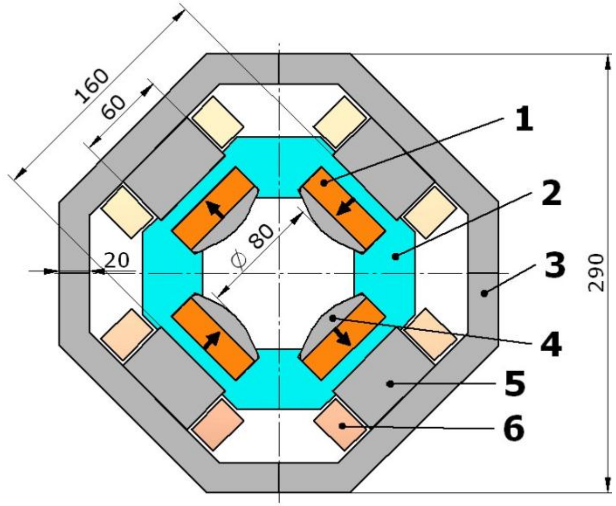
A proposal for ATF2 (KEK-Japan) new quadrupoles (G_{max}= 12.5 T/m):

1) PMQ



1- P.M. Block, Sm2Co17
2- Aluminium core
3- Return Yoke, AISI 1010
4- Pole Tip, AISI 1010
5- Tuning block, AISI 1010
6- Spacers, Stainless steel

2) HYBRID (based on PMQ)



Main advantages of the PMQ

- Compactness
- No vibrations induced by coil cooling system
- No power supply failures risks
- Zero power consumption
- Few pieces in the assembly → mechanical precision
- Possibility to correct multipole components by moving (shimming) the PM blocks.

EXTRA advantages of the HYBRID repect to PMQ :

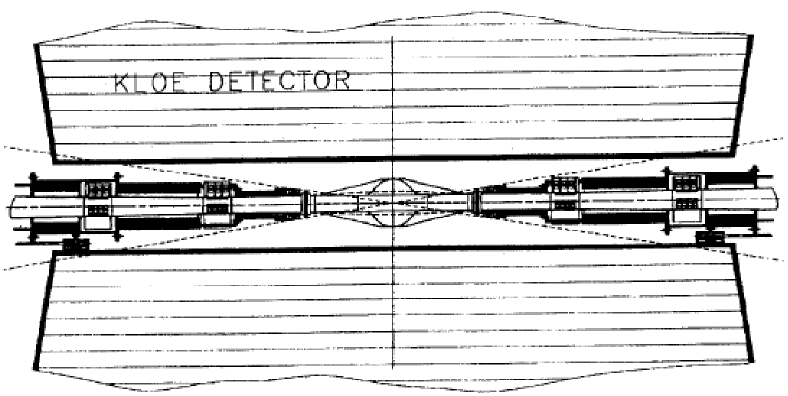
- Remote fine gradient tunability (for energy scan et al)
- Correction of gradient drift due to temperature drift or other)
- Coils current density can be lower enough (~ 1 A/mm²) to avoid water cooling, anyway “quiet” water cooling can be envisageable to “thermalize” the magnet.

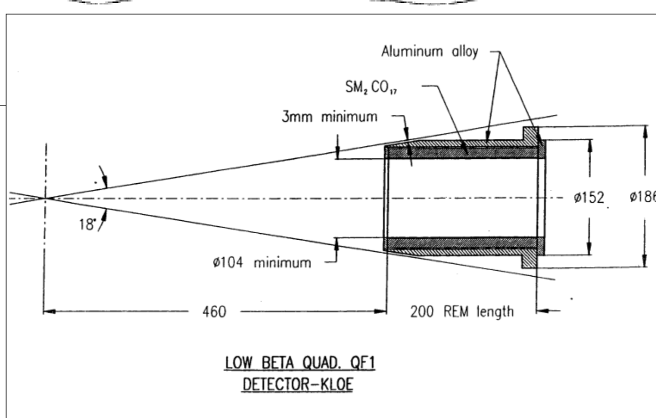
A. Vorozhtsov, M.Modena at: FJPPL-FKPPL Workshop on ATF2 Accelerator R&D, Paris, 20 March 2012

Another example of "adjustable" Final Focus System placed inside a Detector:

"Daphne" ϕ-Factory (at INFN-LNF, Italy):

- Triplet systems of Halbach-type quadrupoles (fixed gradient)
- No gradient tunability required, but each quad can be remotely rotated respect to the others (to decouple the H and V betatron phases spaces)





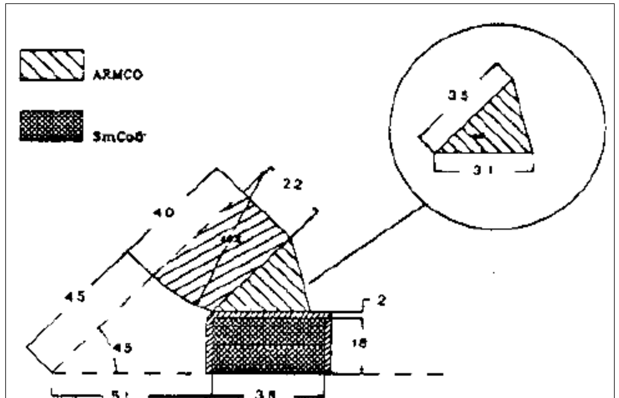


Fig. 3.1 - Basic geometry, 1/8th of the quadrupole

Table 1 - Permanent magnet quadrupoles Specification

Nominal gradient (T/m)	5.93
Integrated gradient (T)	1.186±0.5%
Good field region (mm)	30
Integrated field quality |ΔB/B|	$5x10^{-4}$
Maximum mismatch of integrated gradient between two quads	$1x10^{-3}$
Minimum inside radius (mm)	52
Maximum outside radius (mm)	see Spec. Drawing
Magnetic length (mm)	200±1
REM Stabilization Temperature (°C)	150
REM Type	SM_2CO_{17}
Magnet construction	2-half vertically split

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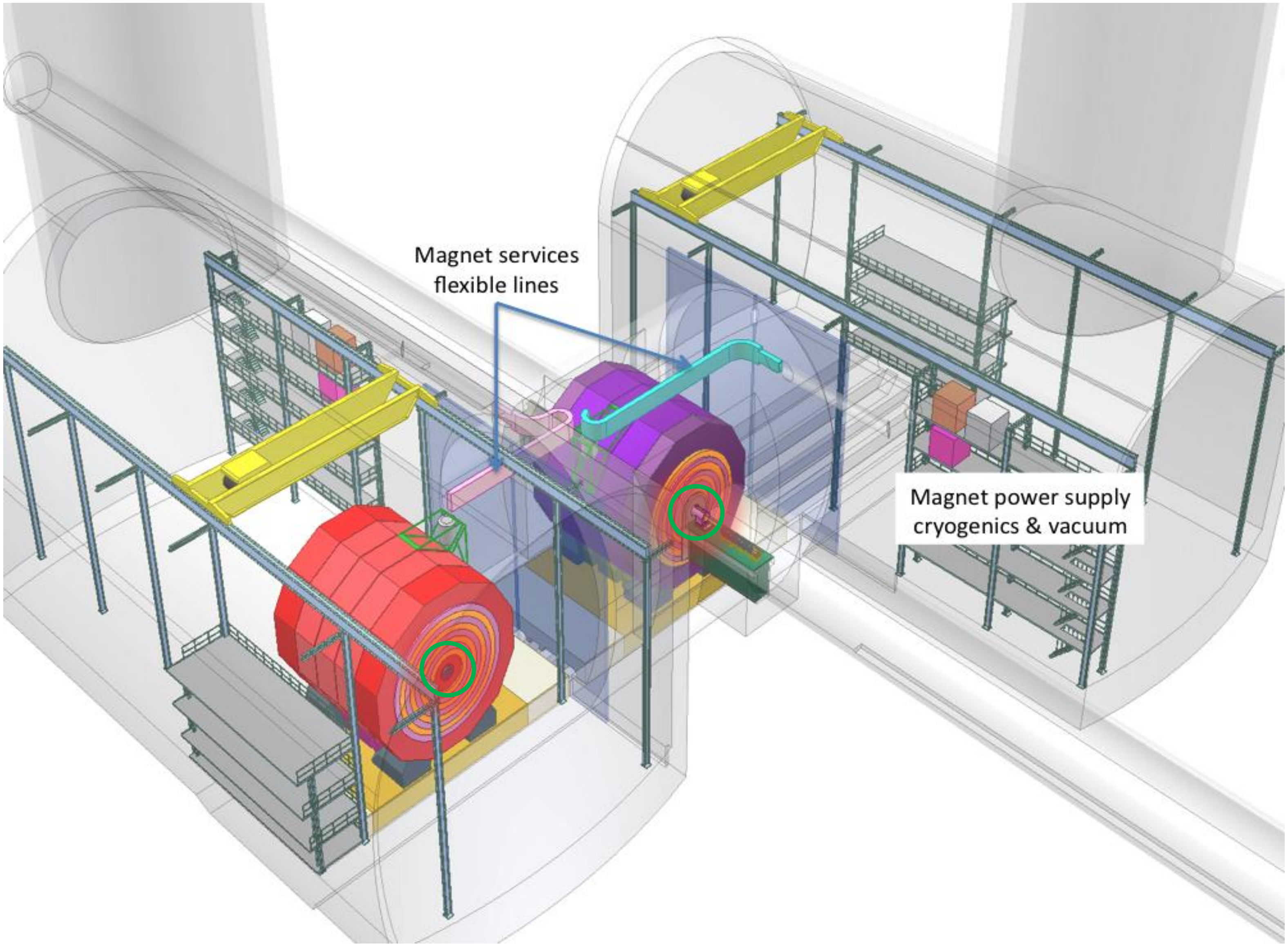
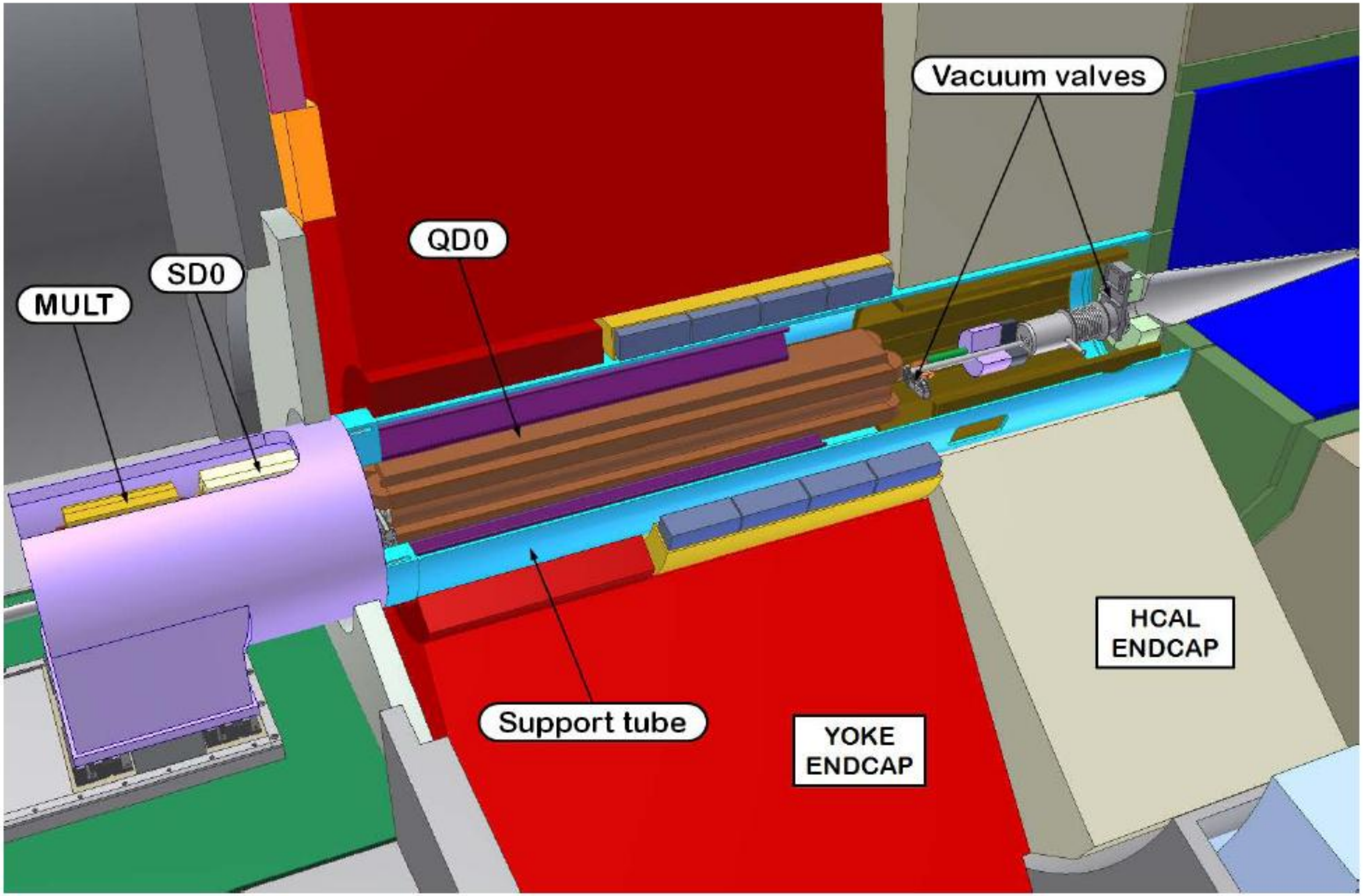
- *As example: What we are developing inside the CLIC Final Focus R&D*

where we are located in the BDS/Experiments layout:



where we are located in the Detectors layout (L=3.5 m layout):*



the main requirements for CLIC QD0:

Parameter	***Value***
Nominal field gradient	575 T/m
Magnetic length	2.73 m
Magnet aperture (for beam)	7.6 mm
Magnet bore diameter	8.25 mm * ** Including a 0.30 mm vacuum chamber thickness*
Good field region(GFR) radius	1 mm
Integrated field gradient error inside GFR	< 0.1%
Gradient adjustment	+0 to -20%

QD0 study & design requirements :

To develop a high gradient quadrupole towards a required nominal gradient value of 575 T/m.

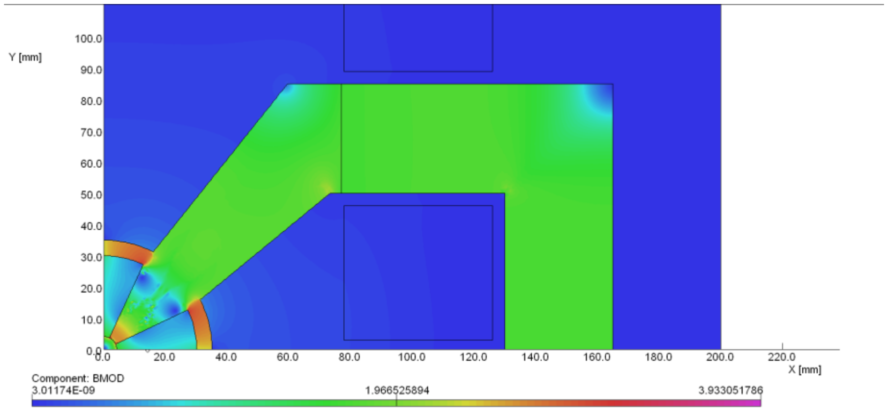
Magnet design must be compatible with:

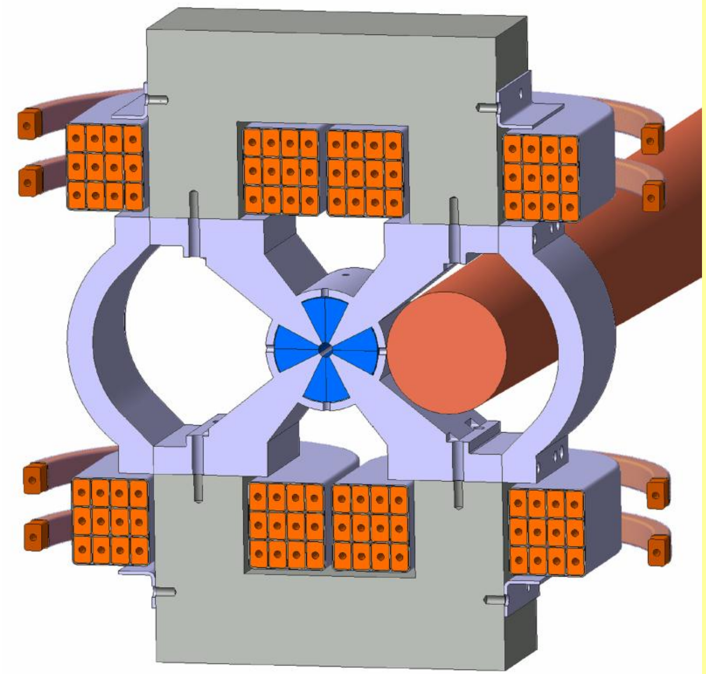
-**Active stabilization** (i.e. vibration and weight)

-Presence of the **post-collision line beam vacuum chamber** (at its closer position: 35 mm from main beam axis)

- As much as possible **compact design** (to be compatible with an L* of 3.5 m, so minimizing the solid angle subtracted to the Detector)

"Hybrid" design Version 2 :



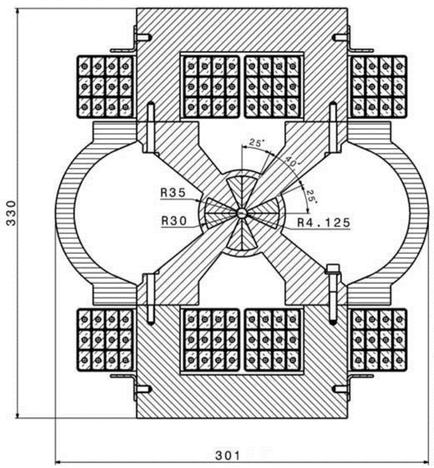


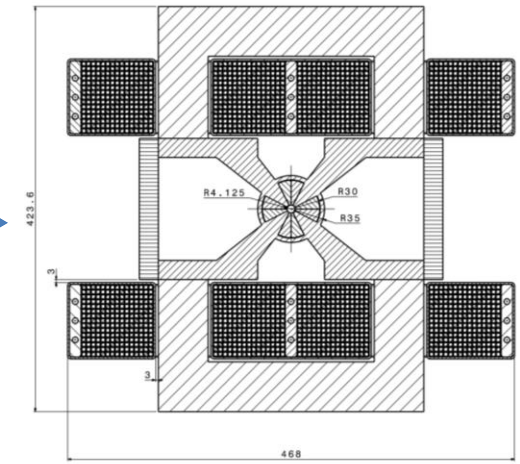
	NI=5000 [A]
Grad [T/m] Sm_2Co_{17}	531
Grad [T/m] $Nd_2Fe_{14}B$	599

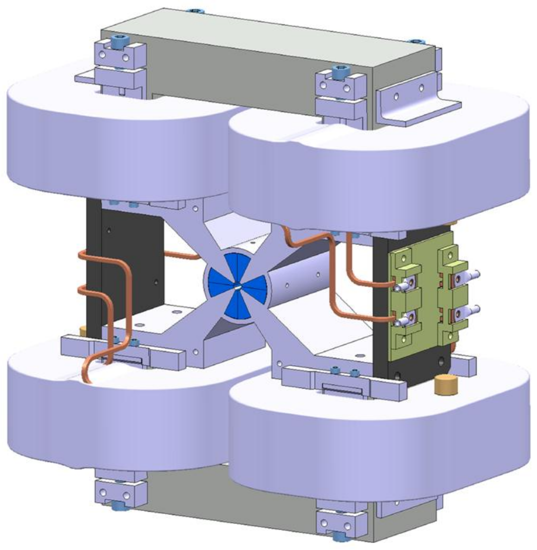
- The presence of the "ring" decrease slightly the Gradient (by 15-20 T/m) but it assure a very stiff assembly of the four poles and a precise housing for the PM blocks.
- EM Coils design would permit wide operation conditions: at 0 current Gradients will be respectively: ~ 145 and ~175 T/m.

(Note how in this Version 2 it was still planned to have water cooled coils, this was finally modify in order to improve the stabilization aspects.

further evolution and final prototype design:

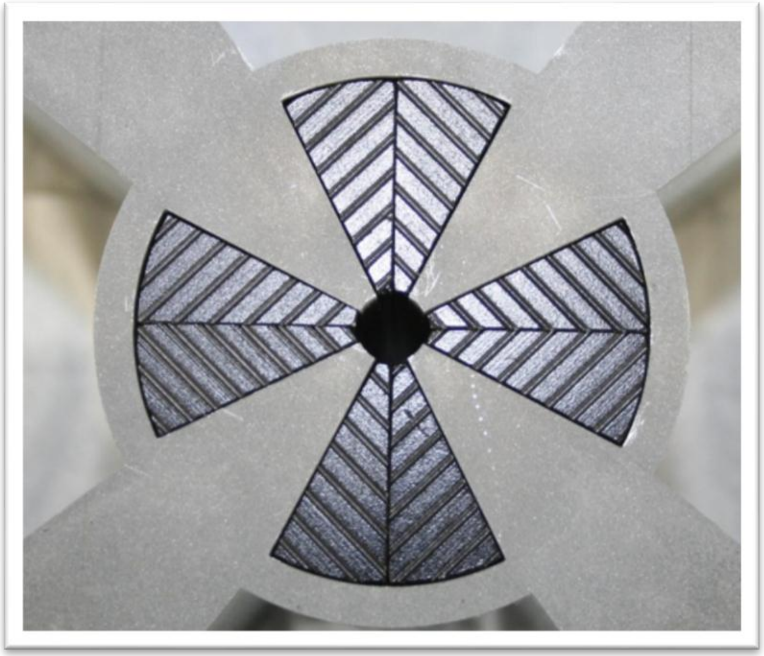


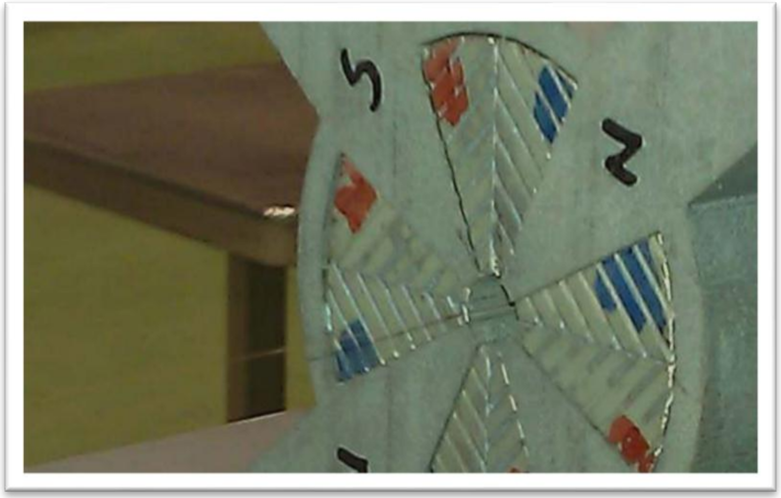


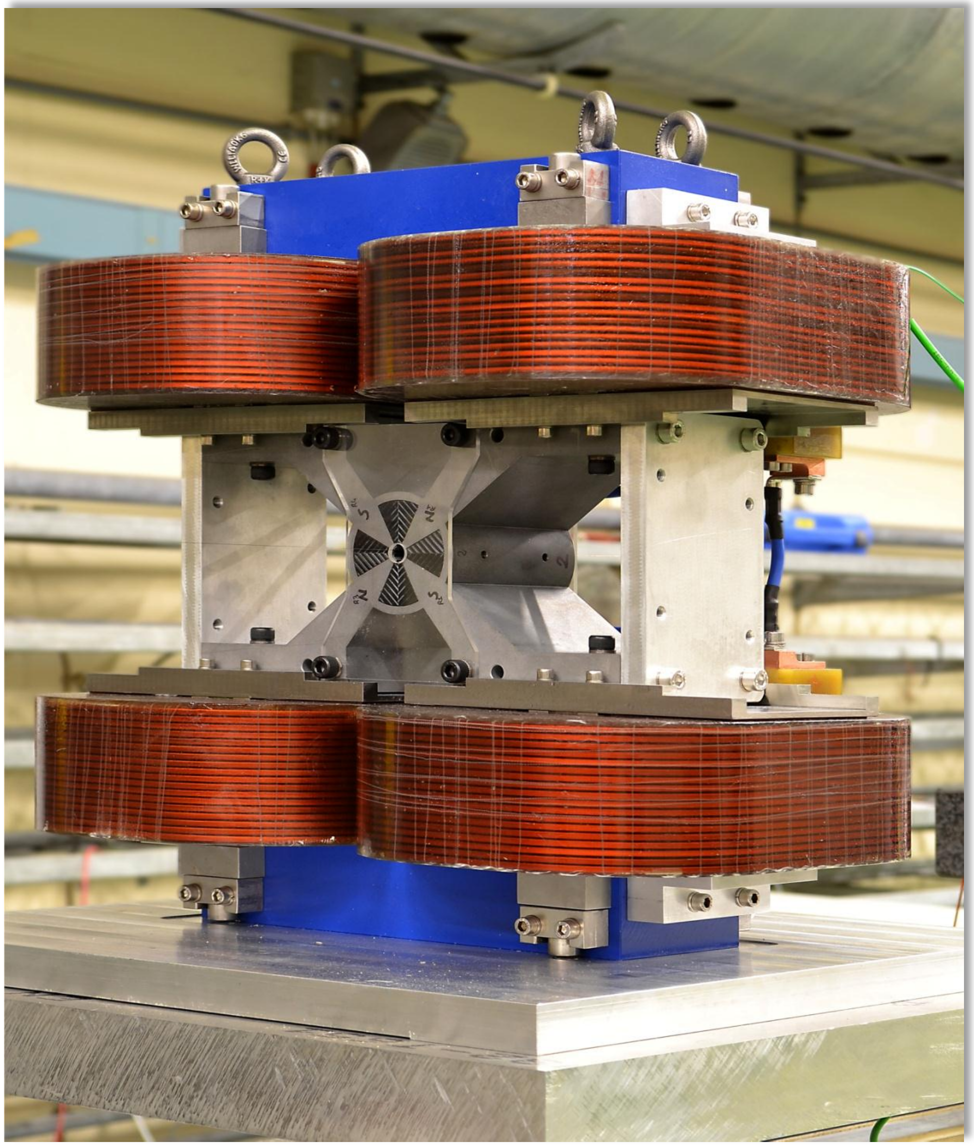


CLIC QD0 Main Parameters		**100mm prototype**	**Real magnet 2.7m**
Yoke			
Yoke length	[m]	0.1	2.7
Coil			
Conductor size	[mm]	4×4	4×4
Number of turns per coil		18×18=324	18×18=324
Average turn length	[m]	0.586	5.786
Total conductor length/magnet	[m]	0.586×324×4=760	5.786×324×4=7500
Total conductor mass/magnet	[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

final assembly of the magnet in Fall 2011:







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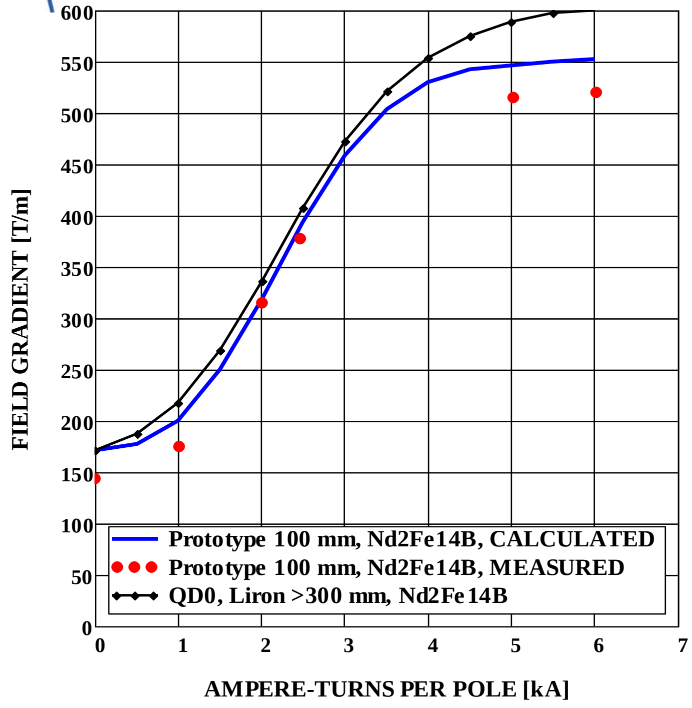
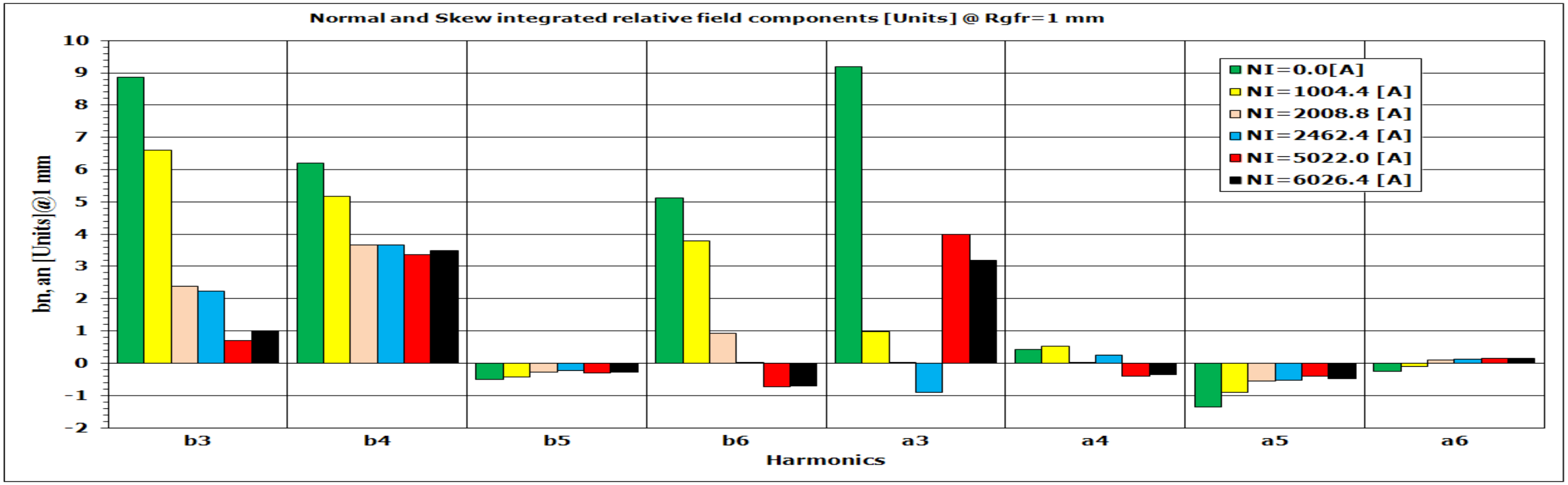
CLIC QD0 magnet prototype (with permanent magnet blocks in $Nd_2Fe_{14}B$): 1st measurement with SSW system versus calculations



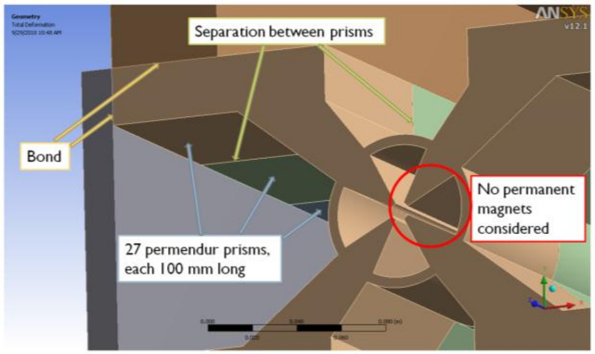
Graph 1: *Magnet excitation curve*

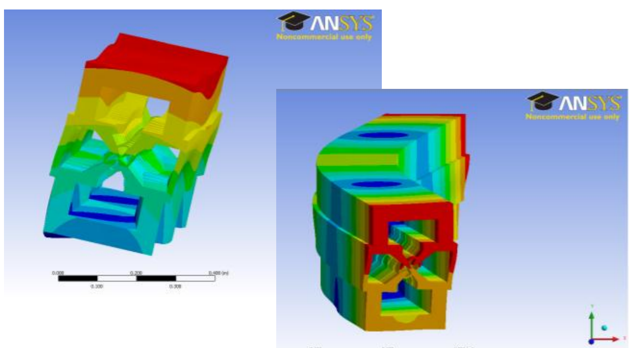
About magnetic axis stability:
Following the stability of magnetic axis along the powering cycles of the magnet, the drifting of the magnetic axis vs. current is <u>estimated inside a maximum range of ~5 µm.</u>

Table3: MEASURED integrated field components (Note: values scaled at R=1 mm from measurement done at R=3 mm).

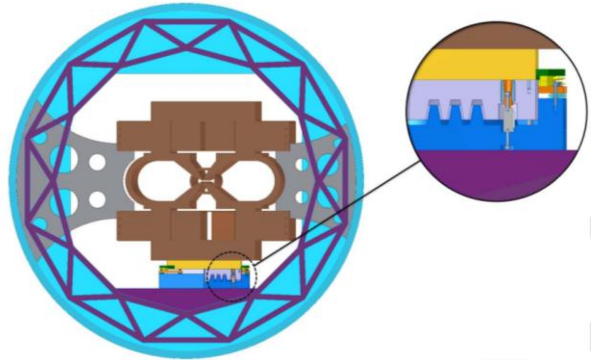


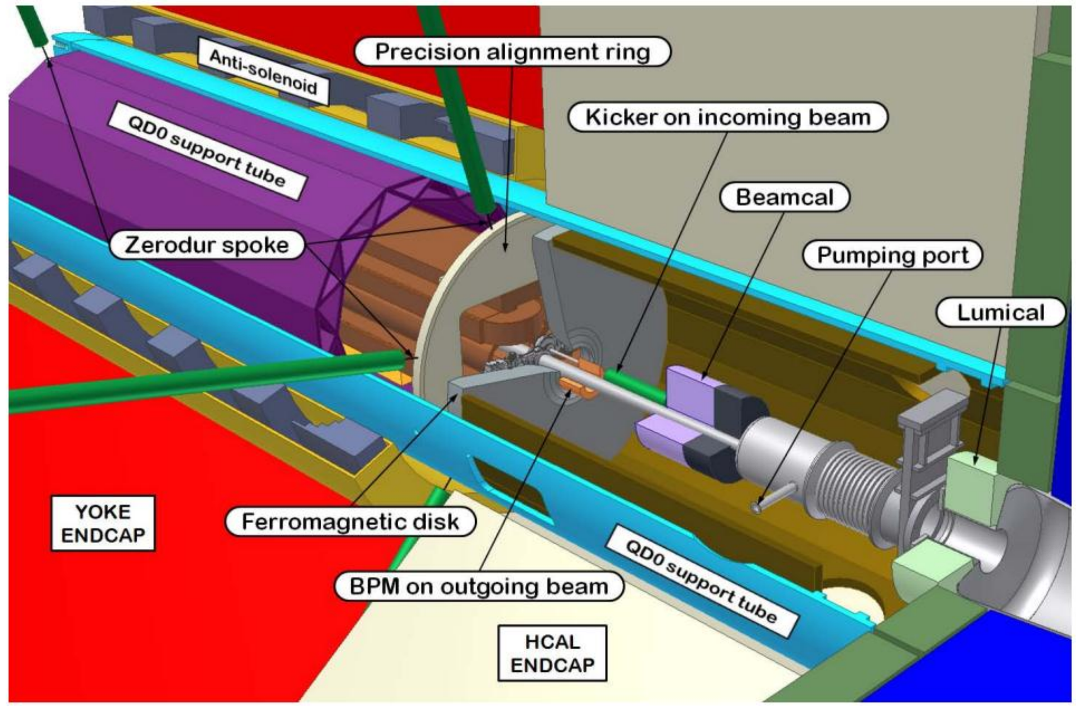
design toward a full size QD0: FEA and integration





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





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- T. Mihara et al.: "SUPERSTRONG ADJUSTABLE PERMANENT MAGNET FOR A LINEAR COLLIDER FINAL FOCUS", Proceedings of LINAC 2004, Lubeck, Germany
- A. Vorozhtsov et al.: "DESIGN, MANUFACTURE AND MEASUREMENTS OF PERMANENT QUADRUPOLE MAGNETS FOR LINAC4", Proceeding MT22, 2011 Marseille, France.
- M. Bassetti et al.: "DAϕNE INTERACTION REGION DESIGN", PAC 1993, Washington D.C. , USA.
- M. Modena et al.: "DESIGN, ASSEMBLY AND FIRST MEASUREMENTS OF A SHORT MODEL FOR CLIC FINAL FOCUS HYBRID QUADRUPOLE QD0" IPAC 2012, New Orleans, USA see also: http://indico.cern.ch/conferenceDisplay.py?confId=180716

THANKS FOR YOUR ATTENTION