Hybrid QD0 Studies

M. Modena CERN

Acknowledgments:
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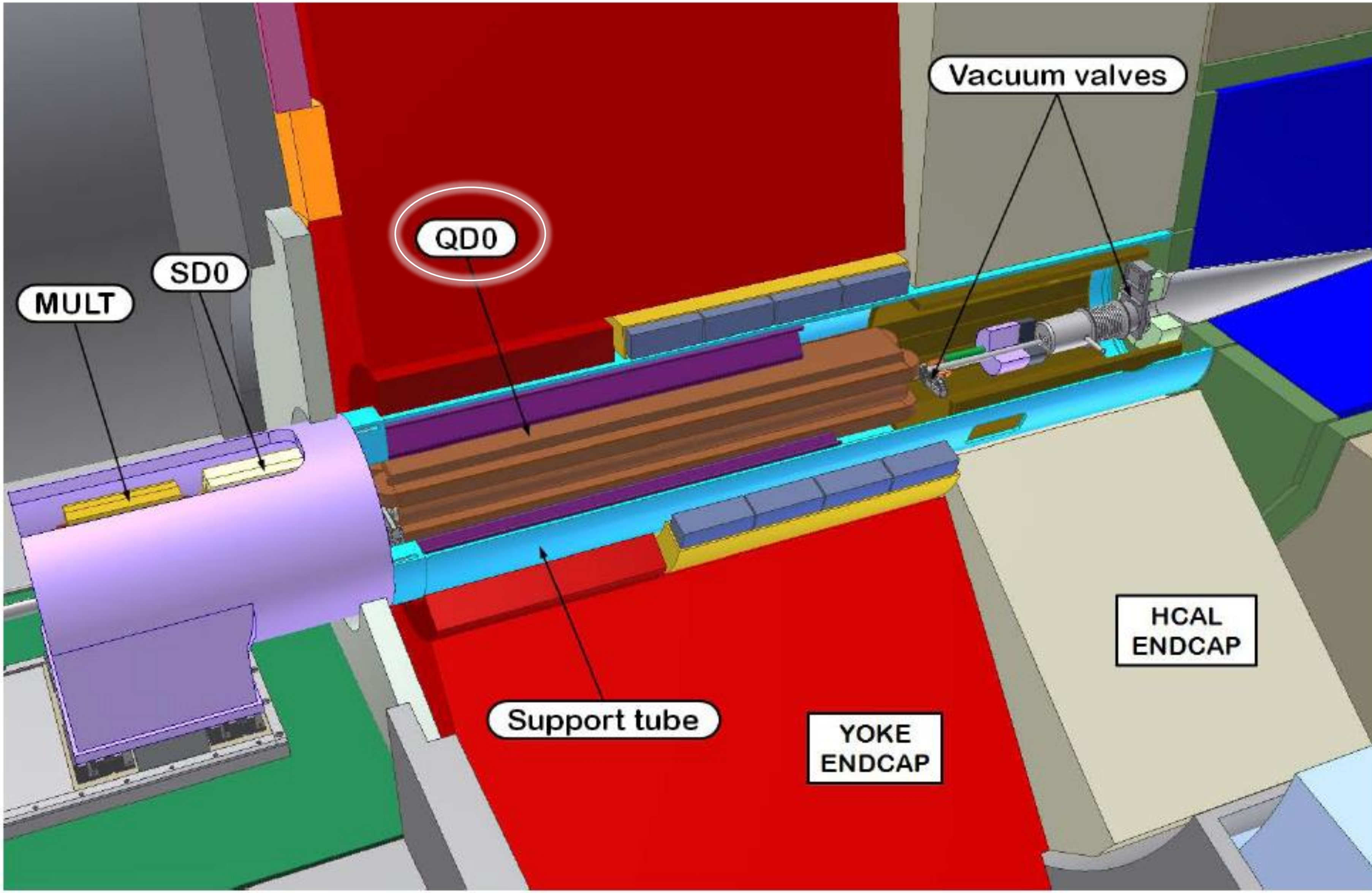
“CLIC/ILC QD0” Meeting 23 October 2013

Outline:

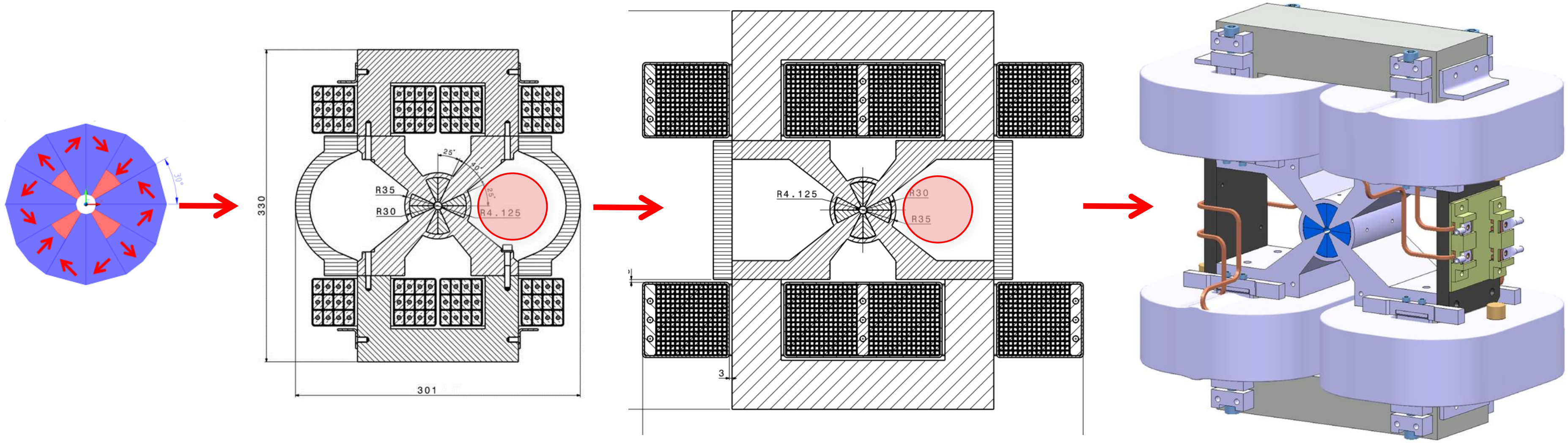
1) CLIC QD0 status

2) A hybrid QD0 for ILC ? (basic conceptual design)

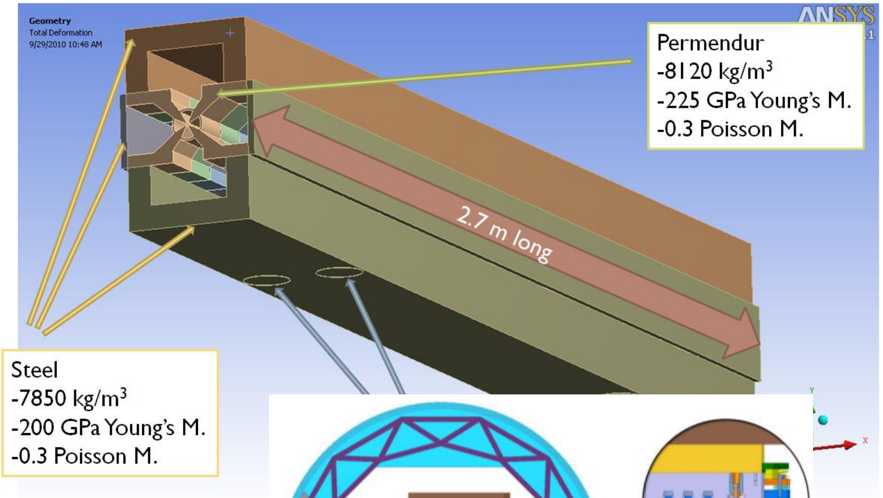


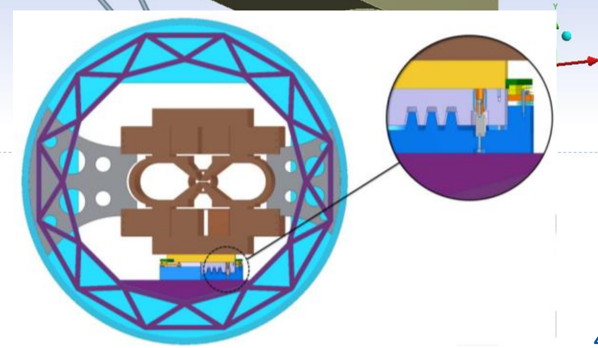
CLIC QDO (3 TeV; L=3.5 m) typical layout*

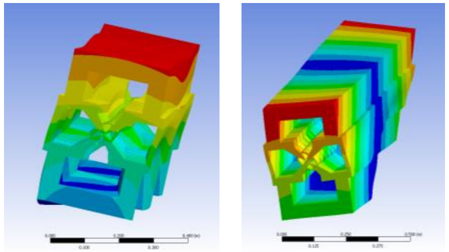
CLiC QD0 design in one slide



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

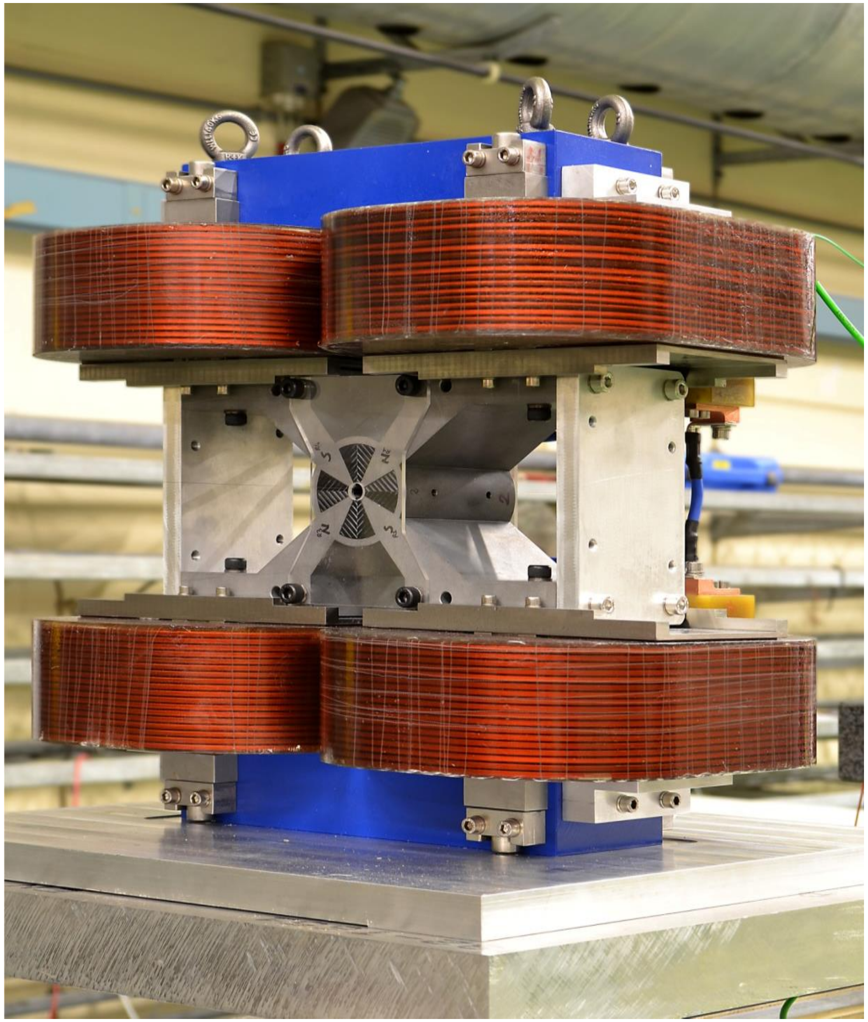






Mode	1st	2nd	3rd	4th
Freq [Hz]	190	260	310	366

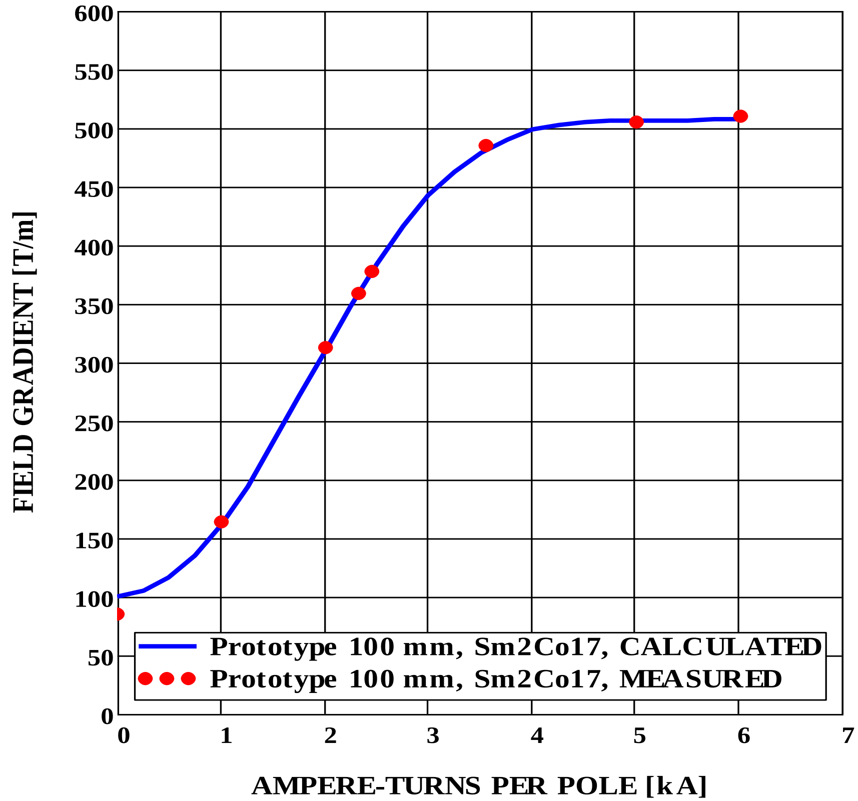
- A **short QD0 prototype** (for CLiC 3TeV layout) **was built** at CERN in 2010-2011.
- **Objective**: validate the Hybrid Magnet design proposed:
  PM blocks - Permendur core structure - coils for tunability (low current density).
- **Two** campaign of measurements were done in 2012 in two different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

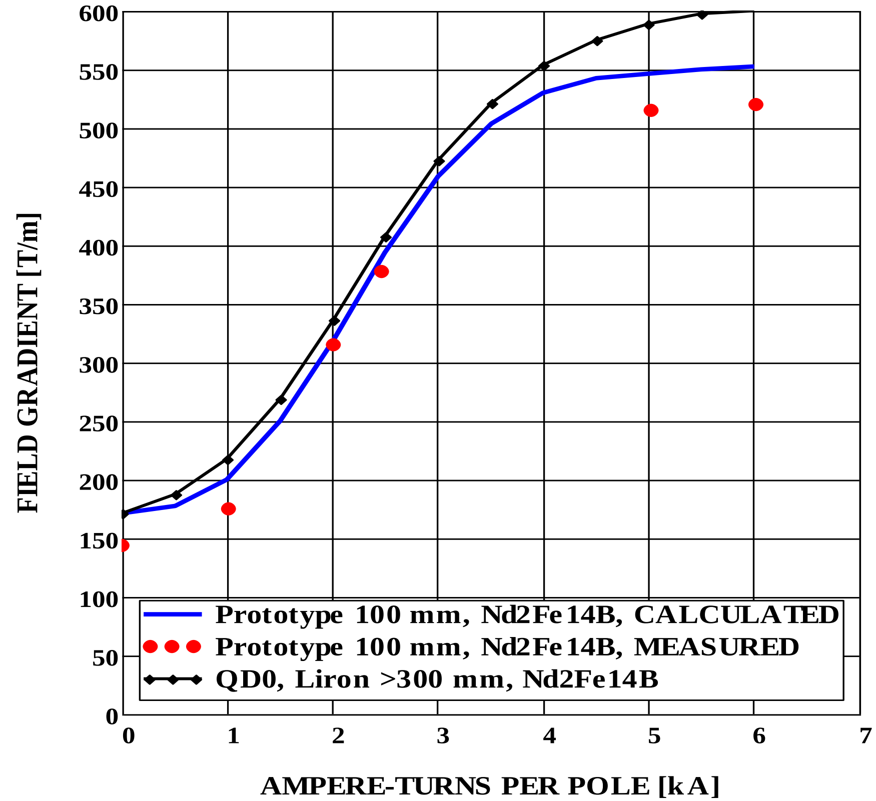


- QD0 equipped with **$Nd_2Fe_{14}B$** blocks (measured in January 2012)
- QD0 equipped with **Sm_2Co_{17}** blocks (measured in August 2012).
- ***"Vibrating Wire"*** MM method was used (the only available due to the small magnet radius).

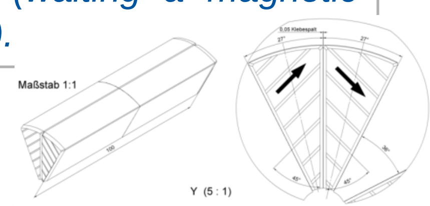
Main Parameter	***Value***
Required field gradient G	575 T/m
Prototype gradient expected	547 *(NdFeB)* ; 503 *(SmCo)* T/m
Magnetic length (full size QD0)	2.73 m
Magnet aperture *(required for beam)*	7.6 mm
Magnet bore diameter *(assuming a 0.30 mm vacuum pipe thickness)*	8.25 mm
Good field region(GFR) 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: <u>very good agreement</u> with the FEA computation.*
- ***$Nd_2Fe_{14}B$** blocks: <u>a difference of ~ -6% is visible.</u>*
  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).

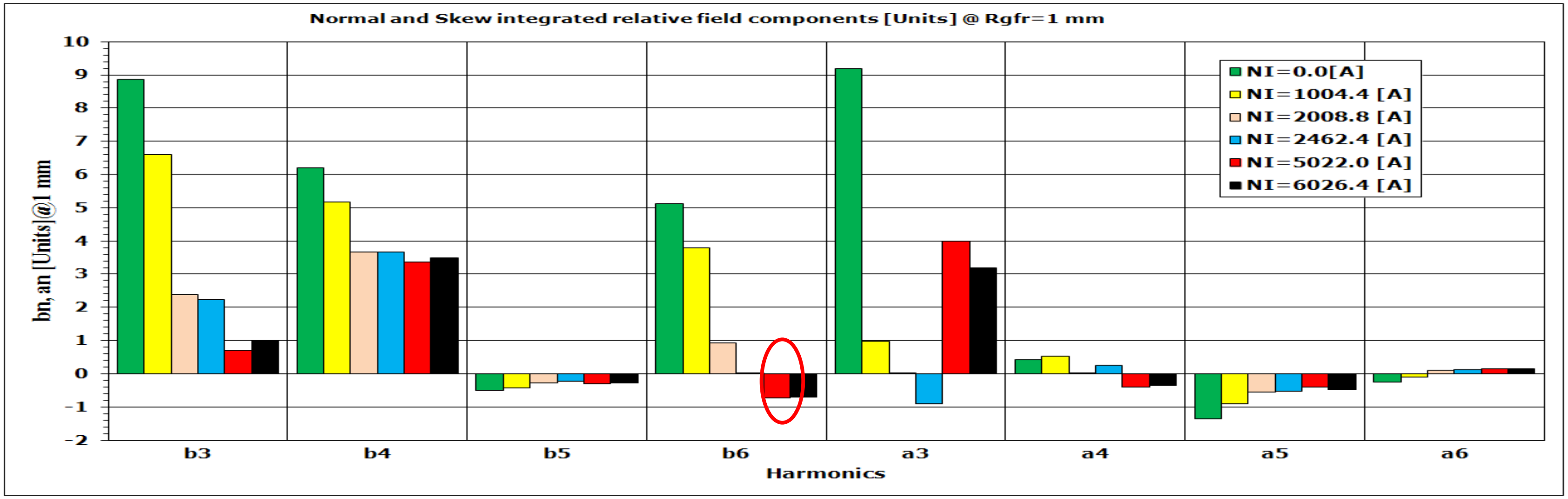


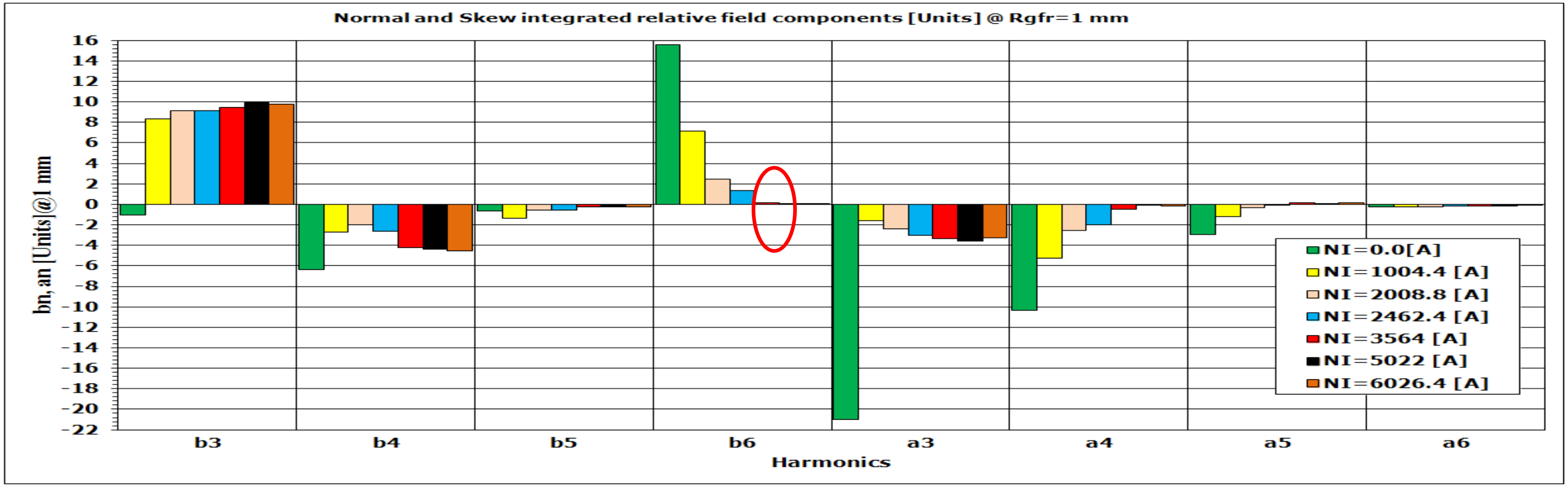
Helmholtz coil

3D Helmholtz coil

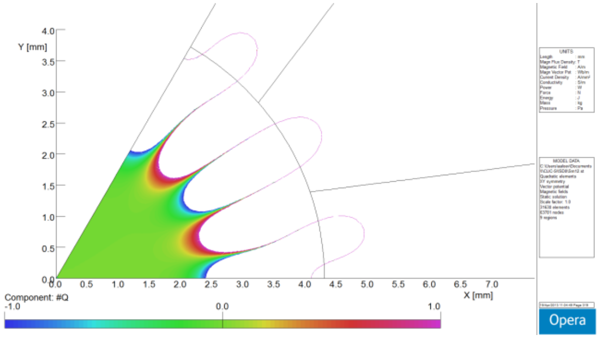
Prototype FIELD QUALITY (given as magnetic harmonic content, multipoles) versus the magnet powering: $Nd_2Fe_{14}B$ (upper graph), Sm_2Co_{17} (lover graph).

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

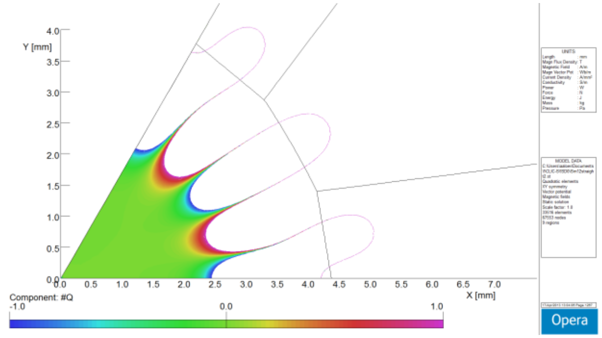




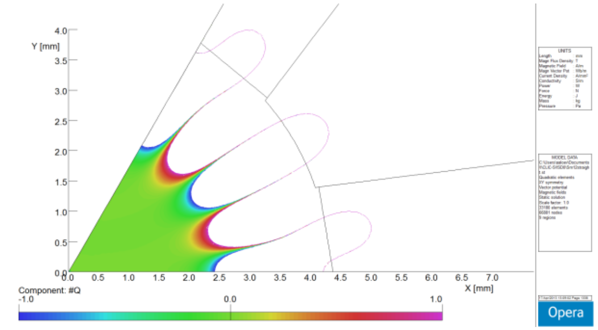
Field quality tuning: ex. SD0



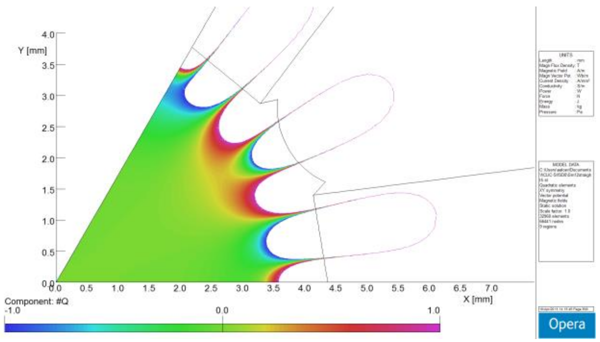
Opt.1 S-grad 222 020 T/m^2



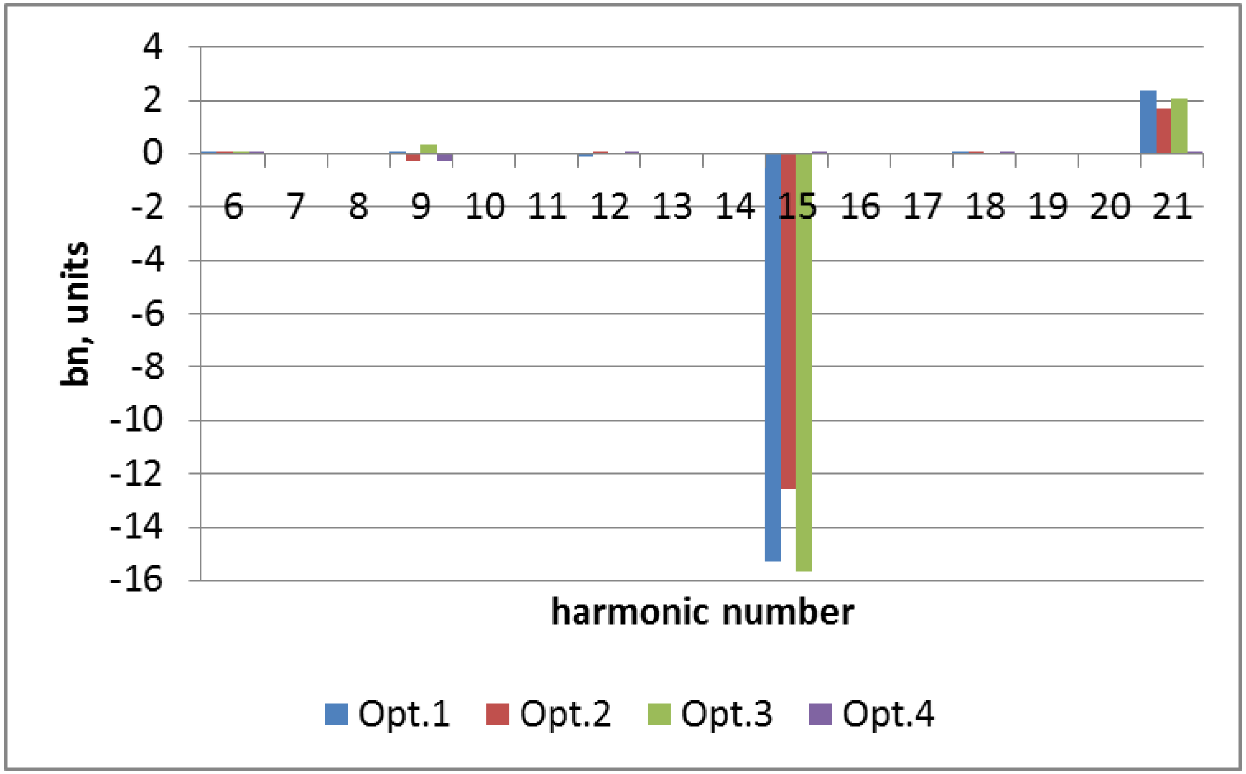
Opt.2 S-grad 220 349 T/m^2



Opt.3 S-grad 221 247 T/m^2



Opt.4 S-grad 215 785 T/m^2



Outline:

1) CLIC QD0 status

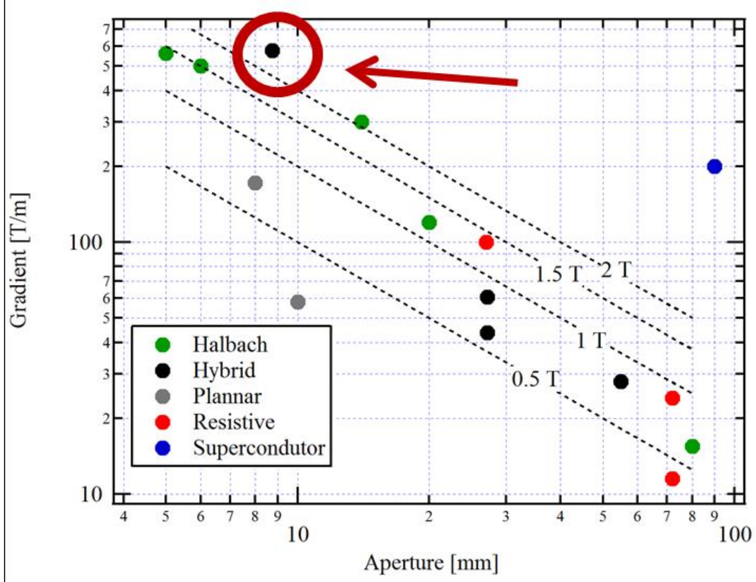
2) A hybrid QD0 for ILC ? (basic conceptual design)

State of the art

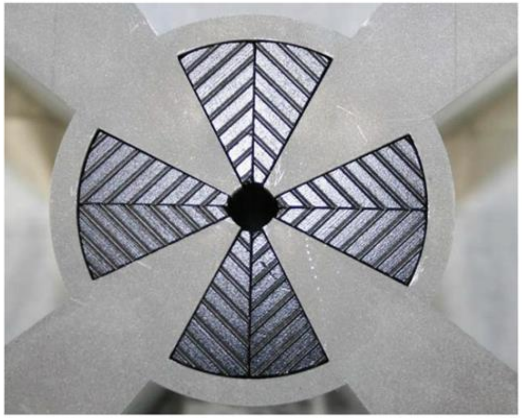
A Light for Science

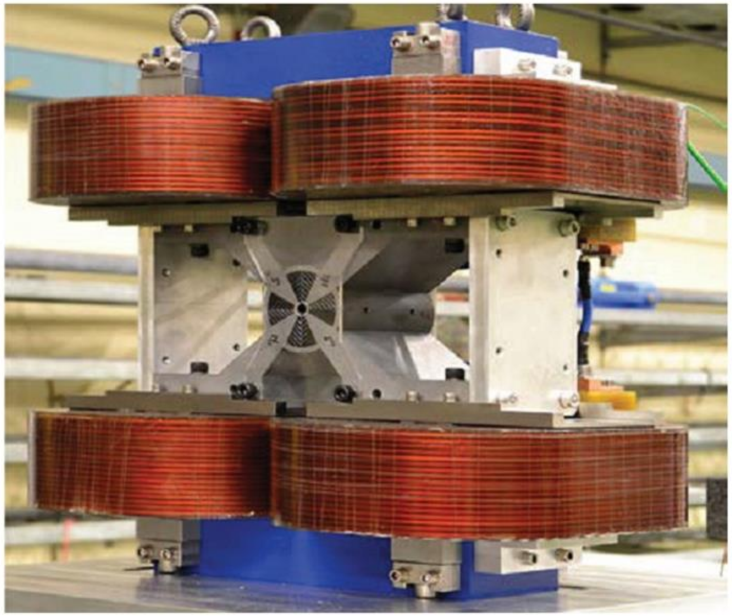
CLIC final focusing

- Iron dominated, Coils + PM
- Gradient 525 T/m
- Aperture 8.25 mm
- Tuning range 80 %



M. Modena, CERN, IPAC 2012



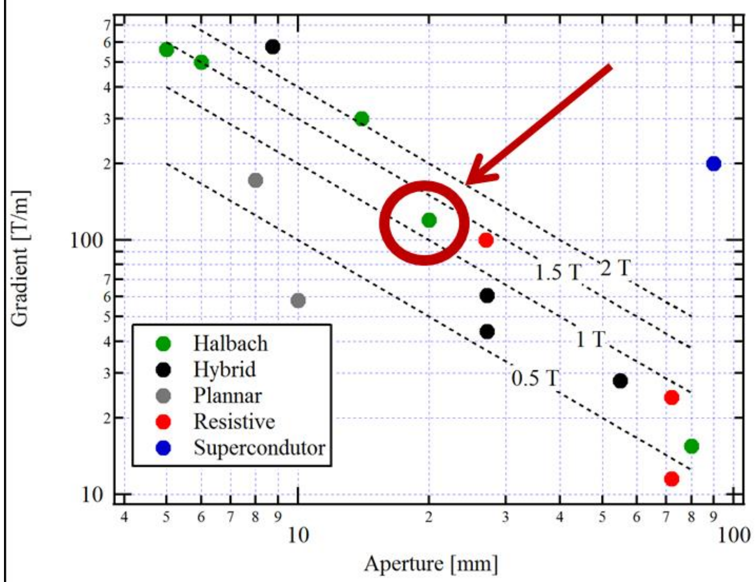


State of the art

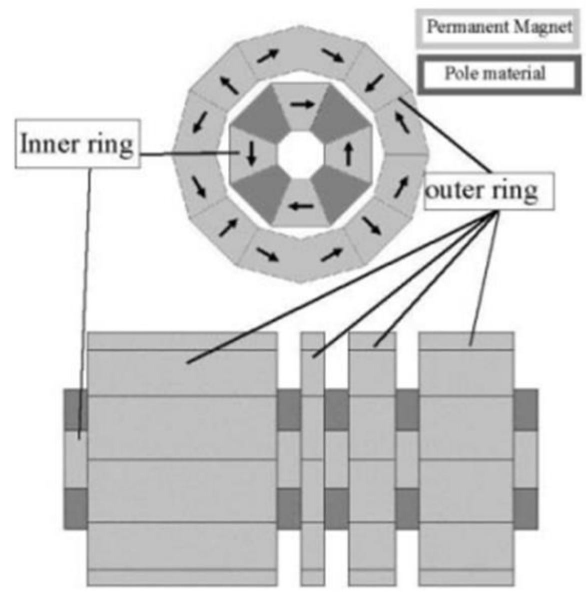
A Light for Science

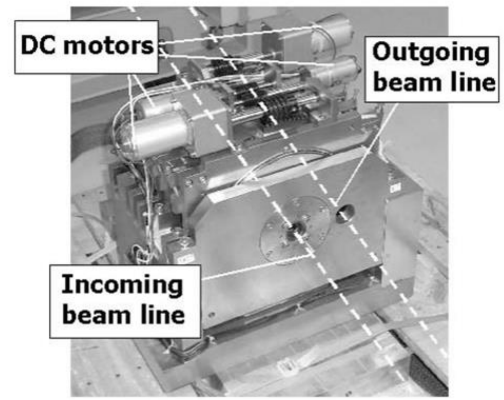
ILC final focusing

- PM
- Gradient 120 T/m
- Aperture 20 mm
- Tuning by 7 T/m steps



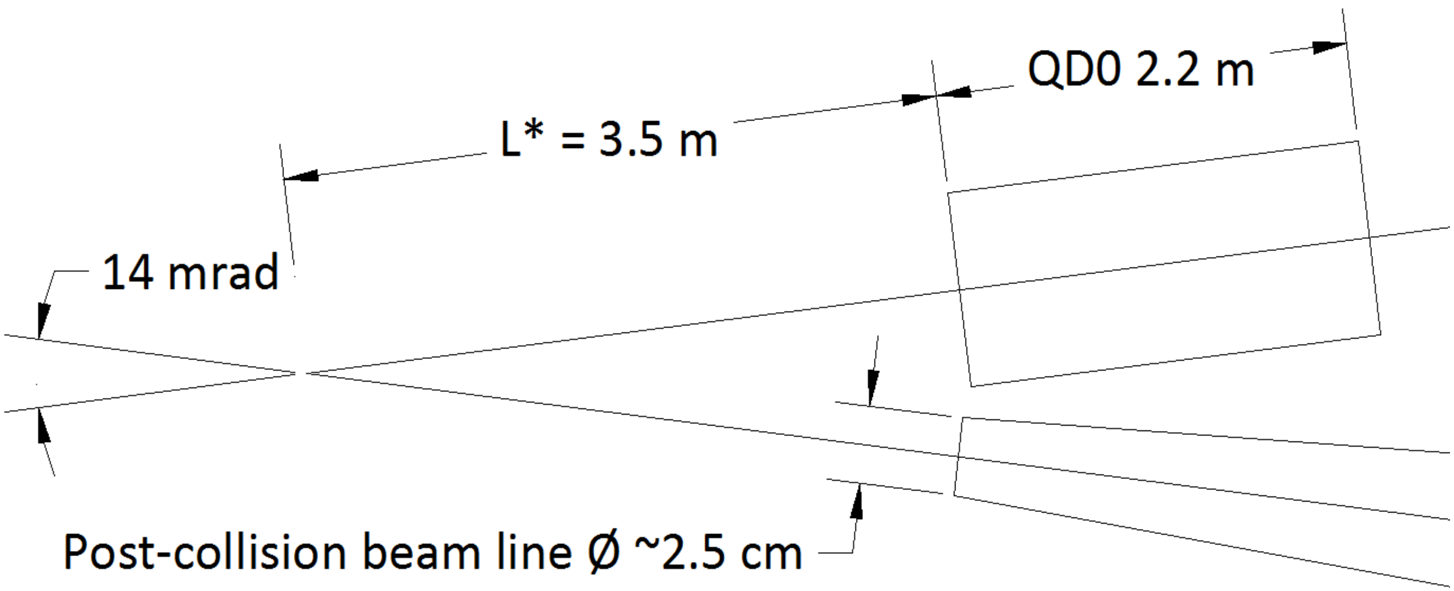
Y. Iwashita, Kyoto U., EPAC 2006



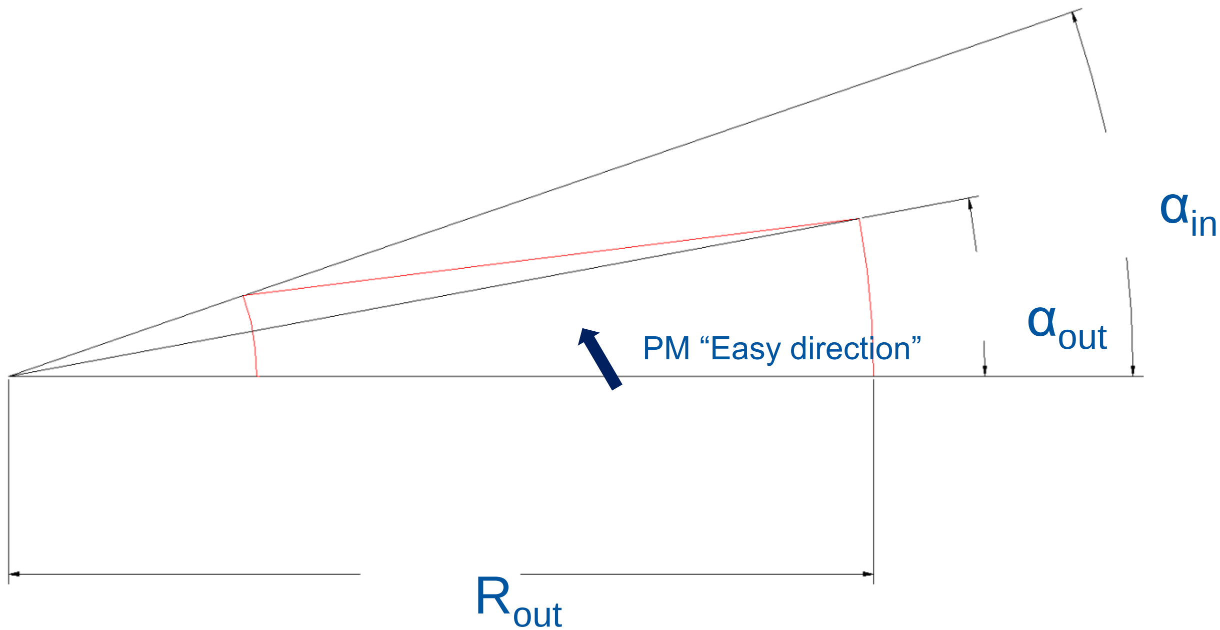


Basic ILC QD0 parameters *(R.Tomas Garcia: private communication, 8 May 2013):*

- Crossing angle: 14 mrad
- L* = 3.5 m
- QD0 full aperture: 2 cm
- QD0 total length: 2.2 m
- QD0 gradient: 124 T/m
- Post Collision Line vacuum pipe radius at 3.5 m: ~ 12.5 mm



Examples of the optimization done on 3 parameters (α_{in}, α_{out}, ↑$_{easy\ dir;}$) (R out=30 mm).
The sets of values that maximize field quality are 32° for both α_{in}, α_{out}, and 55 ° for the easy dir. (1st Table)

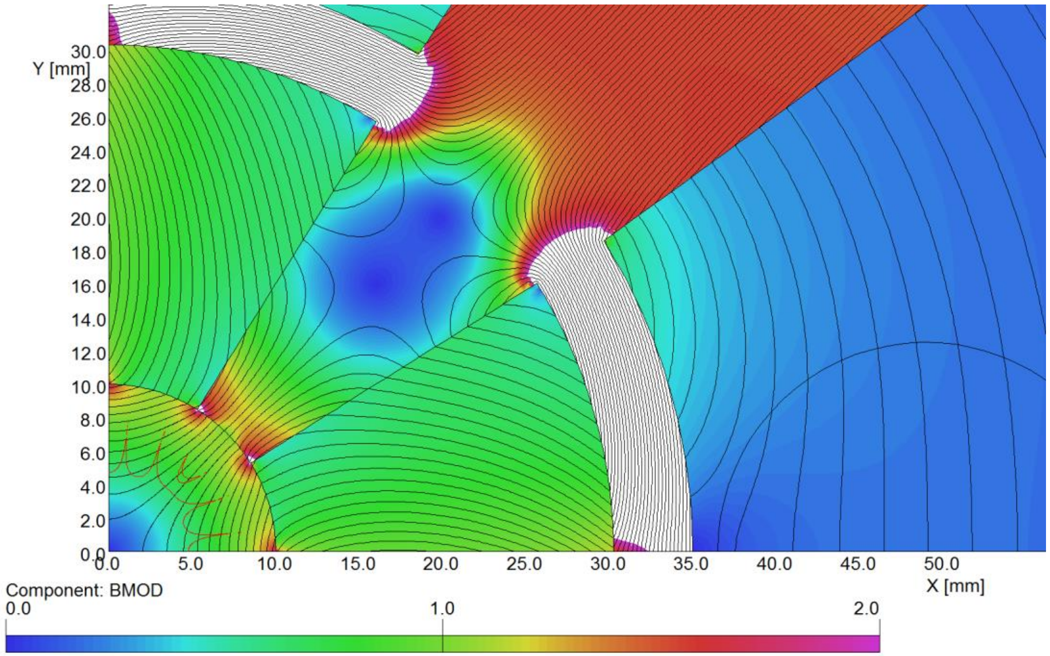


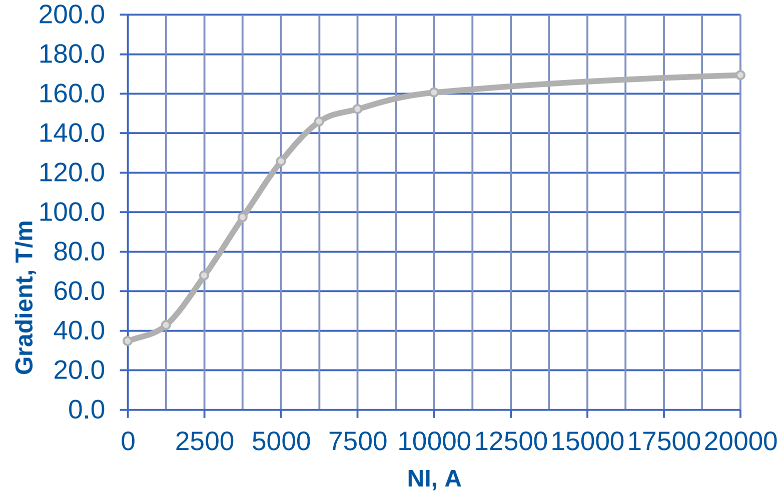
outer angle	inner angle	easy direction	Gradient, T/m	b6, units	b10, units	b14, units	b18, units	abs(b6)
32	32	55	-125.6883919	-0.018011928	0.021495857	0.001156133	-5.42639E-06	0.018011928
14	33	37	-109.7656866	0.035278019	0.020945055	0.000970438	-1.71047E-06	0.035278019
28	28	32	-128.8464878	-0.069765144	-0.102218168	0.001223987	7.28026E-06	0.069765144

outer angle	inner angle	easy direction	Gradient, T/m	b6, units	b10, units	b14, units	b18, units
33	13	32	-142.2927103	40.41430891	0.020803327	0.001981567	-0.000987569
33	13	34	-142.2817507	40.80280099	0.024709188	0.002024723	-0.000996354
33	12	30	-142.2787609	41.64605989	0.039128861	-0.002075543	0.000436098

We have tried to "scale" our QD0 design taking into account the geometric condition but also starting an optimization of the main parameter toward a wider field quality range for the asked tunability.

*(thanks to **A. Aloev** for the FEA calculation!).*



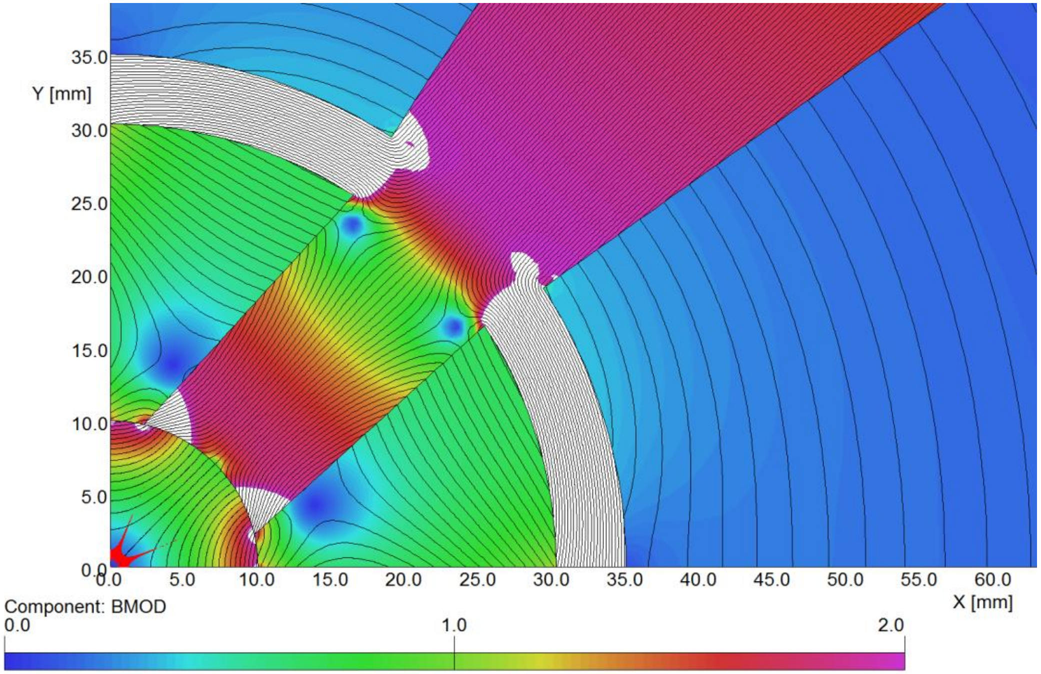


"red line" inside the aperture: area where ΔG/G ≤1 unit (good field region)

NI	A	0	1250	2500	3750	5000	6250	7500	10000	20000	40000
Gradient	**T/m**	**34.7**	**42.8**	**67.8**	**97.3**	**125.7**	**145.8**	**152.2**	**160.6**	**169.4**	**174.9**
b6	units	61.2472	45.2059	19.9428	6.8605	-0.0183	-3.3895	-4.2944	-5.3982	-6.4427	-7.0075
b10		0.1978	0.1510	0.0769	0.0386	0.0215	0.0173	0.0173	0.0182	0.0201	0.0217
b14		0.000192	4.51E-04	8.62E-04	1.07E-03	1.16E-03	1.16E-03	0.001148	0.001123	0.001086	0.001056
b18		0.003501	2.58E-03	1.14E-03	3.89E-04	-4.59E-06	-1.98E-04	-0.00025	-0.00031	-0.00037	-0.0004

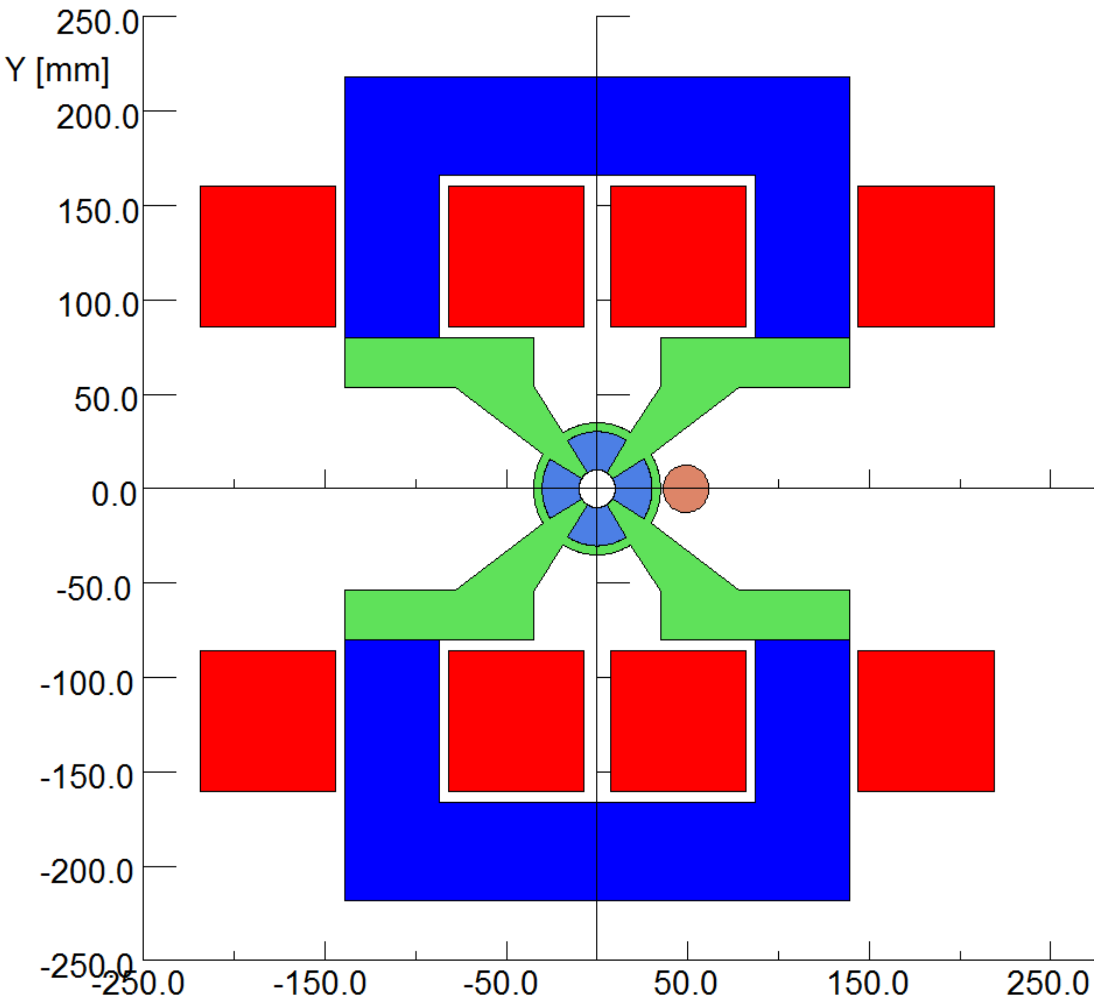
Main multipoles estimation at r = 3 mm; 5000 NI is the nominal working point (G:125 T/m)

In this slide the MAXIMUM GRADIENT configuration (~ 142 T/m)
Poles are wider, saturation appear in some areas, field quality is deeply affected (even in these IDEAL CALCULATION To not forget!)



"red line" inside the aperture: area where ΔG/G ≤1 unit (good field region)

NI	A	1250	2500	3750	5000	6250	40000
Gradient	**T/m**	**44.14719**	**75.58737**	**111.0874**	**142.2917**	**155.2365**	**171.4439**
b6	units	58.93988	54.76554	48.30059	40.41387	36.75506	32.13193
b10		0.216246	0.14742	0.072838	0.023252	0.013356	0.011051
b14		0.001752	1.04E-03	0.000633	6.08E-04	6.24E-04	5.96E-04
b18		0.000583	5.37E-04	0.000473	3.95E-04	3.59E-04	3.13E-04



A basic sketch for the hybrid QD0 adapted to the ILC parameters:

- As for CLIC case, this solution minimize vibrations.
- Coils are sized to a current density of J ~ 0.9 A/mm (→ no water cooling).
- Overall dimension are in the range of 500 x 500 mm.

Other solutions , for ex. minimizing the cross-section, could be studied.

In that case some coils cooling system will be necessary.

Some conclusions:

- CLIC QD0 baseline (for L*=3.5 m) is an hybrid quadrupole design.
- A short prototype of the magnet was successfully built to validate the concept.

- We have recently started a hybrid magnet design study for the ILC (i.e. CLIC QD0 design scaled to ILC geometry and strength)

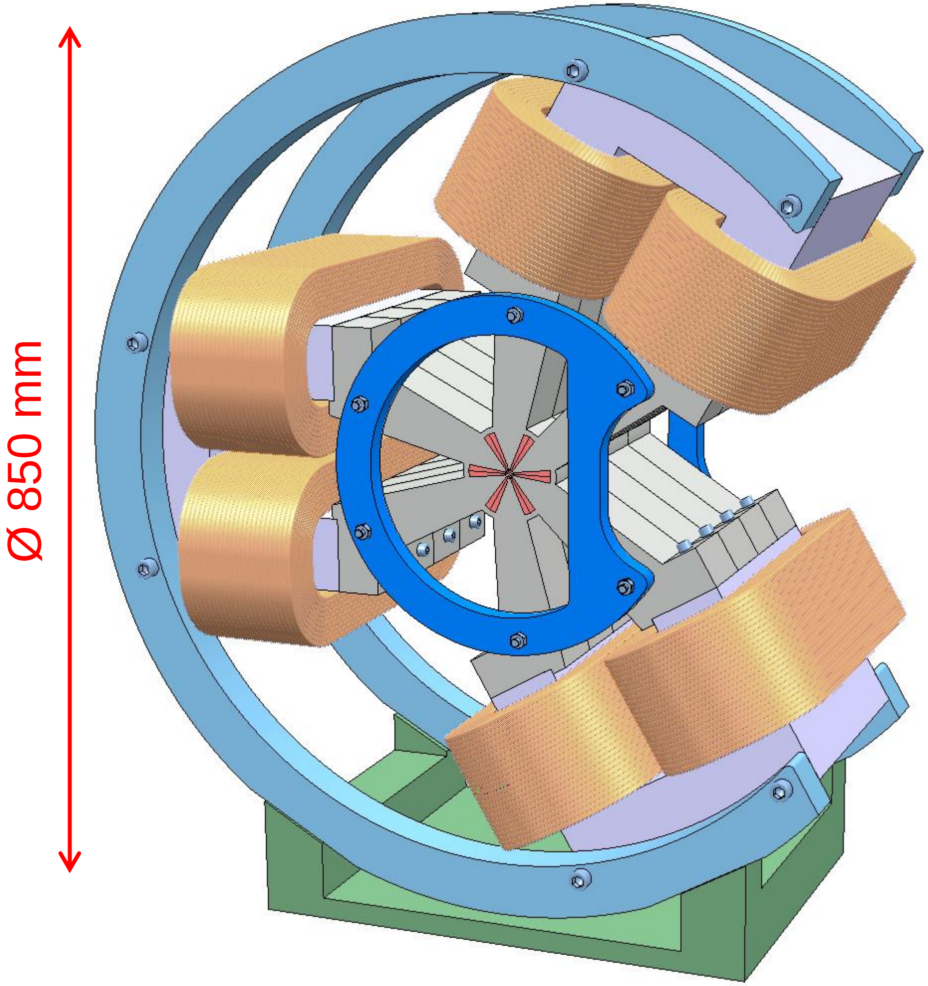
- Field quality aspects are also take into account in the study, that shows possible optimization paths for the magnet performances.

- In order to proceed with the study, we should discuss and have inputs about boundary conditions imposed by the ILC experiments and accelerator .
- Among them:
    a. QD0 cross-section limitation
    b. tunability required
    c. field quality requirements
    d. vibrations limitation requirements

- The study for an anti-solenoid system should be also evaluated.

Thanks

Extra slides

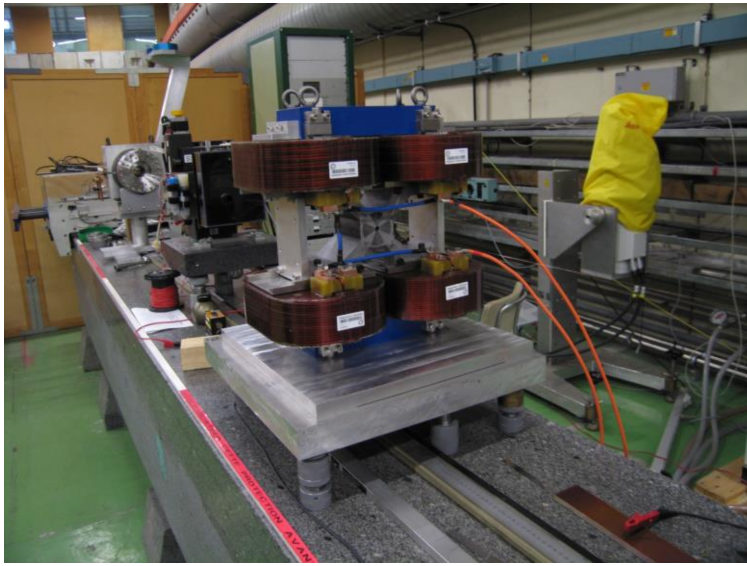


- ***Main requirements & boundary conditions:***
  - Tunability of ~ -20 %
  - Minimized vibrations (magnet should be actively stabilized)
  - Integration with the Post Collision vacuum pipe needed.

- Compactness is less critical respect to QD0. Magnet is placed outside the Detector onthe Accelerator Tunnel border.

- **Prototype key aspects:**
  - The proposed design should permit us to investigate the very precise assembly of several (4 or 5) longitudinal sections, each equipped with PM.
  - Manufacturing (with highest precision) of each Permendur sector, PM insert, “C” shape return yokes
  - Measuring, Assembly and sorting of PM blocks
  - Assembly of the sectors (magnetic forces between blocks impact? PM blocks are very fragile!)
  - Magnetic measurements
  - Final alignment

The “Single Stretched Wire”, “Vibrating Wire” and “oscillating wire” MM Systems



Rotated Vibrating Wire (RVW)

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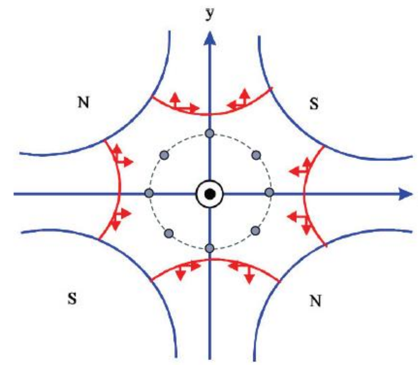
4/35 **Basic idea**

Measure multipoles:

1. *by means of a vibrating wire*
2. *by measuring in different positions on a circle*

through a simple mathematical model relating oscillation and field components



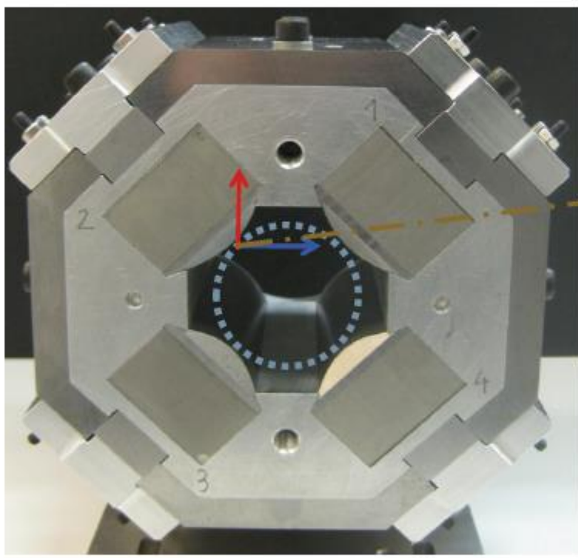
The “Rotated Vibrating Wire” MM System

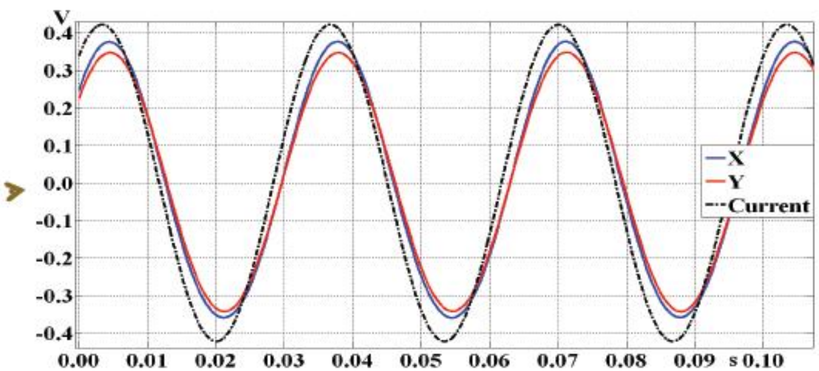
Rotated Vibrating Wire procedure

Università degli Studi del Sannio

10/35 **How to measure multipoles by vibrating wire?**

On each position there are two components of the wire displacement





Moving a wire on a circle
fed by a sinusoidal current (in order to increase the measurement significativity)