Different structures for different dipoles

Common collars, separate collars, austenitic stainless steel versus aluminium collars, vertical versus horizontal iron yoke gap, bladders and keys, etc., etc.

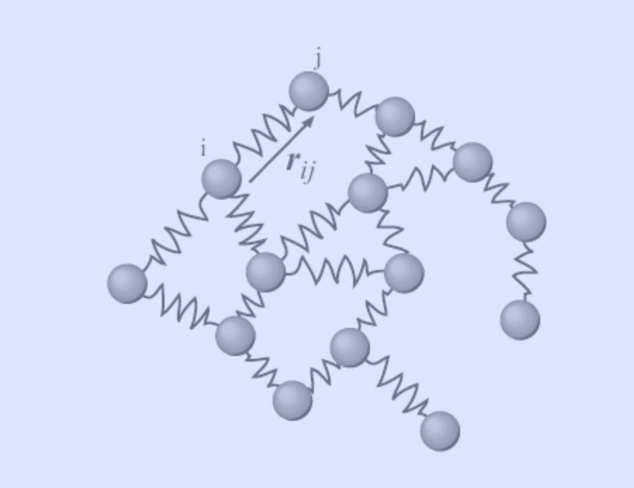
Is there a logic?

Diego Perini

17.11.2022

Summary

- Let’s focus on coils
- Support structure to limit stresses and deformations
- Different structures for different applications
- Longitudinal section
- Present and near future, the 12 T robust dipoles
- Conclusions

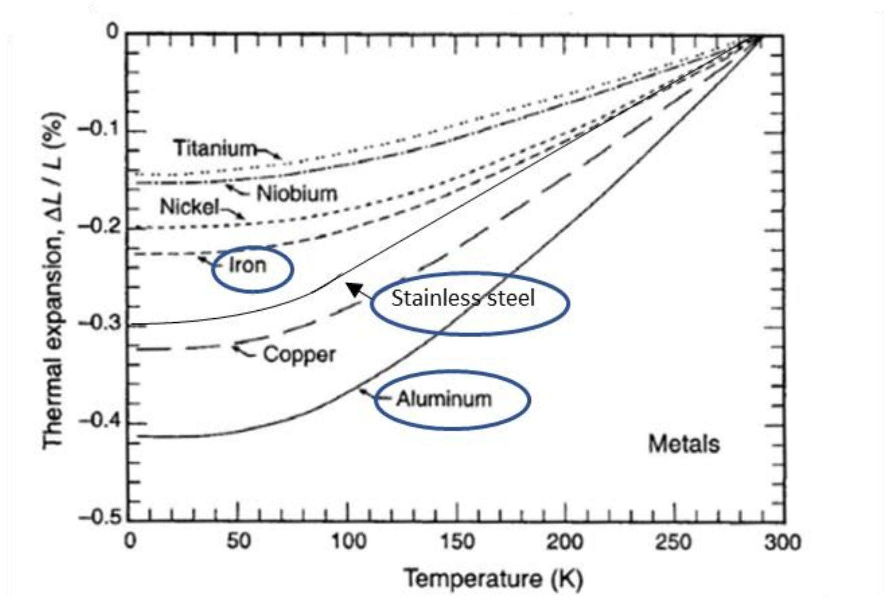


Disclaimer

- This presentation will describe dipoles, with cosθ coils and up to two layers.
- In presentations, one always starts with the magnet cross sections and often stops there.
- But the majority of the quenches are located in the ends or in the transition regions.
- Cross section are 'easy' to compute and understand.
- The ends are a 'grey area' where one must use common sense and experience. 3D FEM computations are evolving and there are more and more valid simulations, but the precision is still much lower than the 2D simulations. So, for the time being, common sense is still the main design tool.
- In this presentation you will see many cross sections, but at least, there will be a few slides describing the 'grey area' regions.

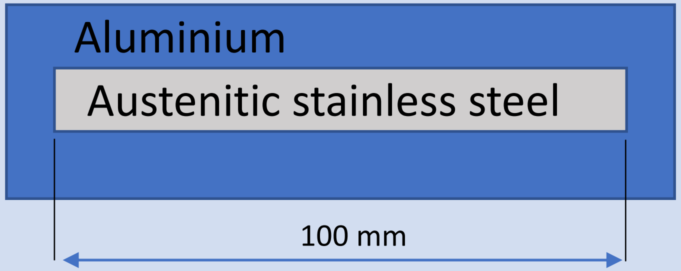
Assembly and cool down of a dipole

- Magnets are assembled at room temperature.
- And are powered at cryogenic temperature.
- The tolerances of the different pieces can modify the contact forces between them. The real structure after assembly will not be in nominal situation but in a state close (hopefully) to it.
- The differential contraction of the different materials generates, during cool down, extra contact forces between the pieces of the structure. These forces add (or subtract) to those created during the assembly.
- The size variations due to tolerances are of the same order of magnitude as the variations due to thermal contraction.



Integral contraction of different materials

Iron laminations	~ 2 mm / m
Aluminium collars	~ 4 mm / m
Aust. stainless steel collars	~ 3 mm / m



Size of the aluminium slot: 100 ± 0.05 mm
Size of the austenitic stainless steel piece: 100 ± 0.05 mm

Differential contraction (alum.) – (a. s. steel) 0.1 mm
At cold: just in touch or interference up to 0.2 mm

Nominal FEM can be different from real structure

Not all the structures are feasible – better to say it clearly

- In nominal conditions (FEM simulations) all structures work fine. It is always possible to find a set of parameters in the µm range satisfying our requirements.

- The manufacturing of components and the assembly of the magnet make the difference: some theoretically good structures can be assembled only 'far from nominal conditions'. So they are bad structures.

- The challenge in the design of a SC magnet is to find an easy to manufacture, stable and reproducible solution. The basic question is how to foresee and master tolerances and random actions in the assembly processes. It is important to compare different solutions with analysis of the variations due to tolerances.

- A tolerance $\pm$ 0.01 mm anywhere, in the drawings of all the parts, is not the right solution. Something like that can not be built in small or large series.

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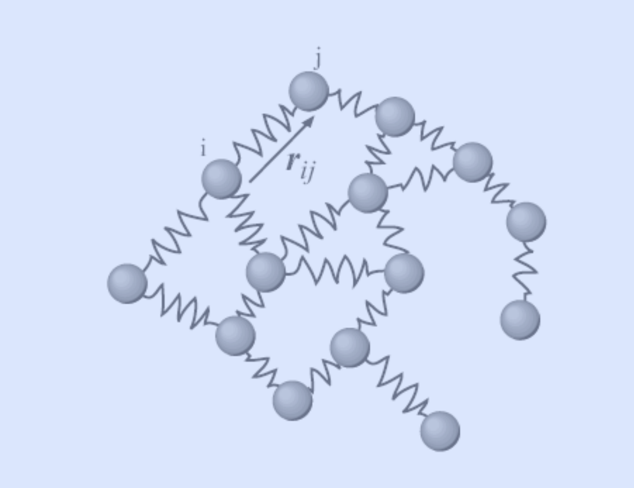
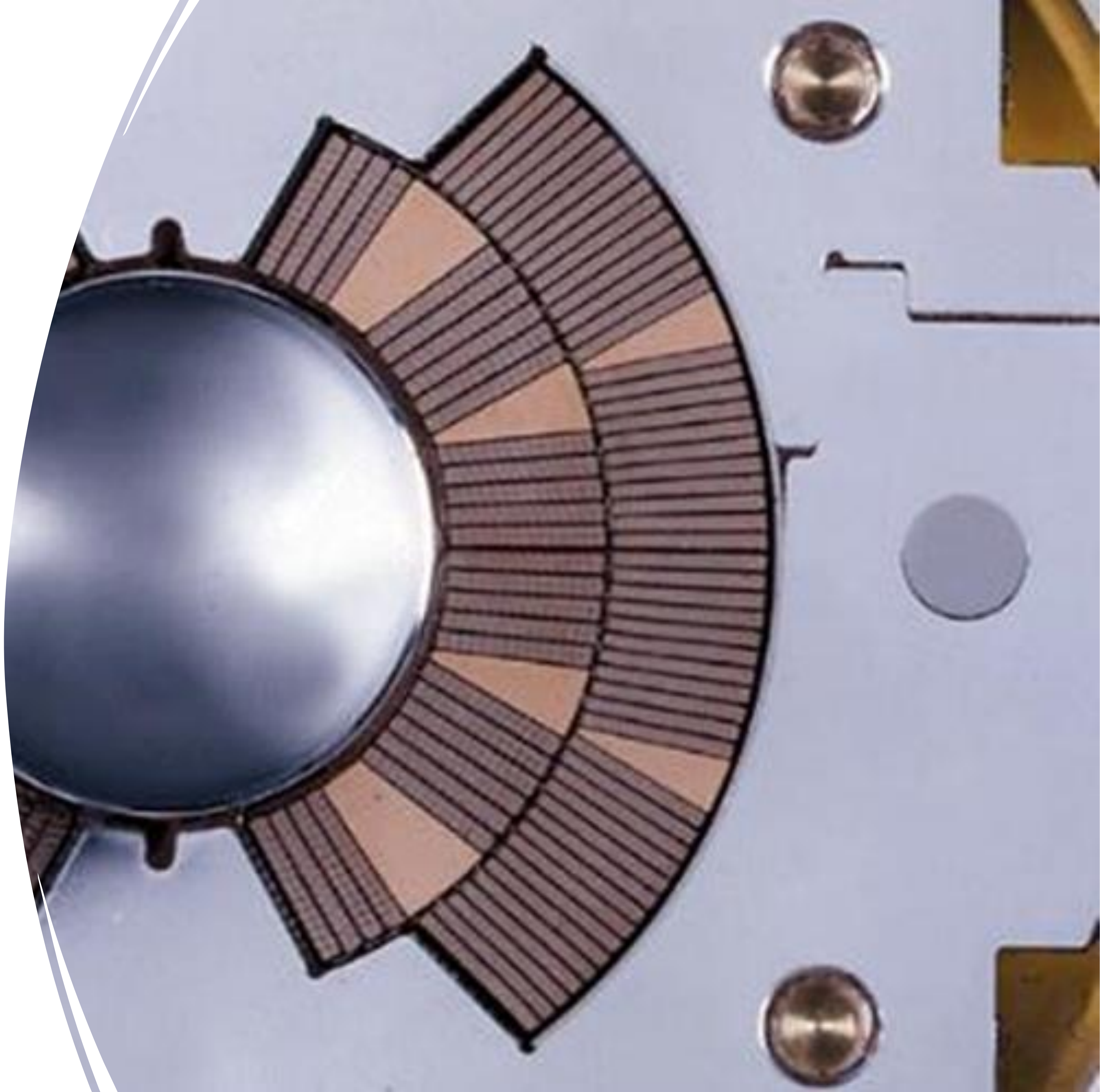
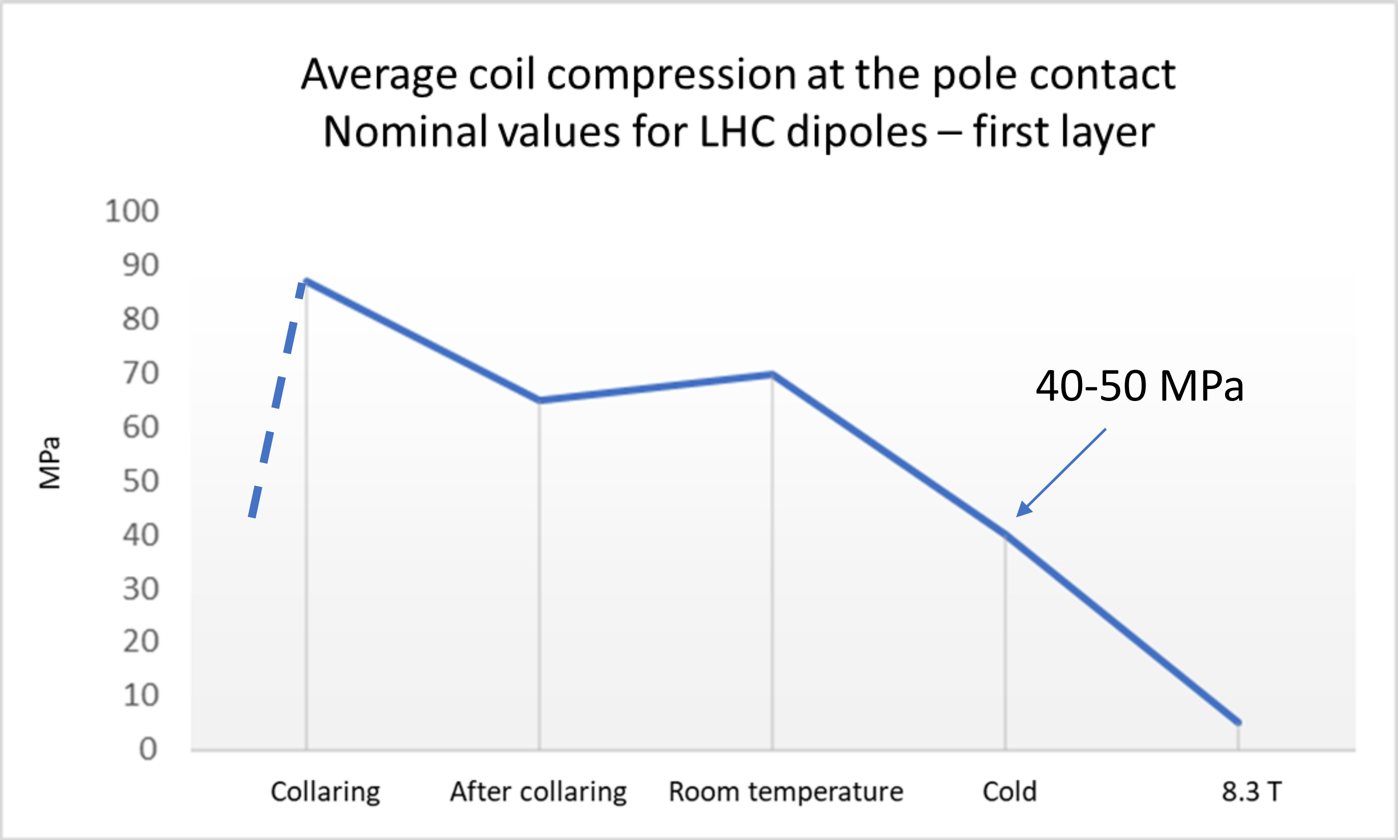


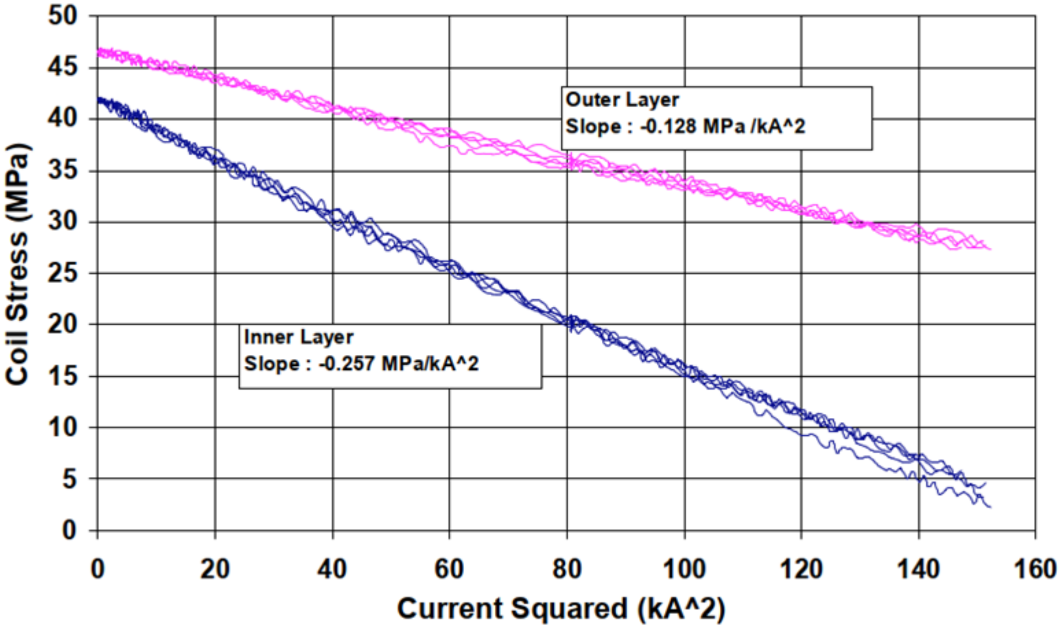
Functionalities of a coil support structure

- ❑ Retain the coils in position during powering.
  - Avoid sudden micro movements
  - Limit deformations
- ❑ Keep the coil under compression in all conditions (assembly, cool down, powering)
  - Avoid cracks in the insulation
  - Avoid cracks in the conductor
- ❑ Limit the compression to reasonable values to avoid damages of the superconductor (in particular Nb_3Sn)



As an example, compression in the coils of LHC dipoles





Coil stress during excitation – magnet MBSMS11.V1

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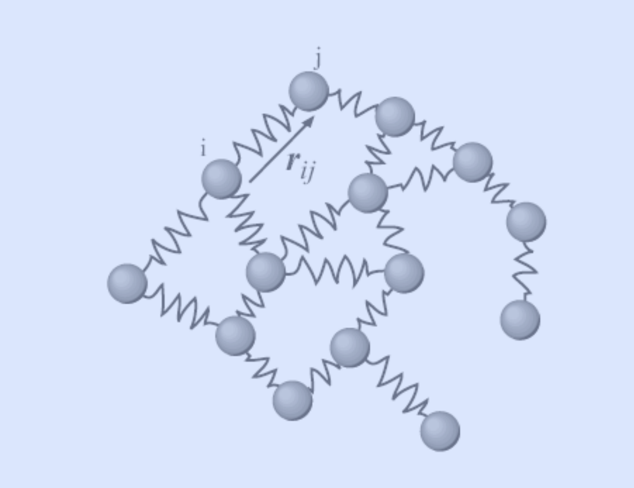
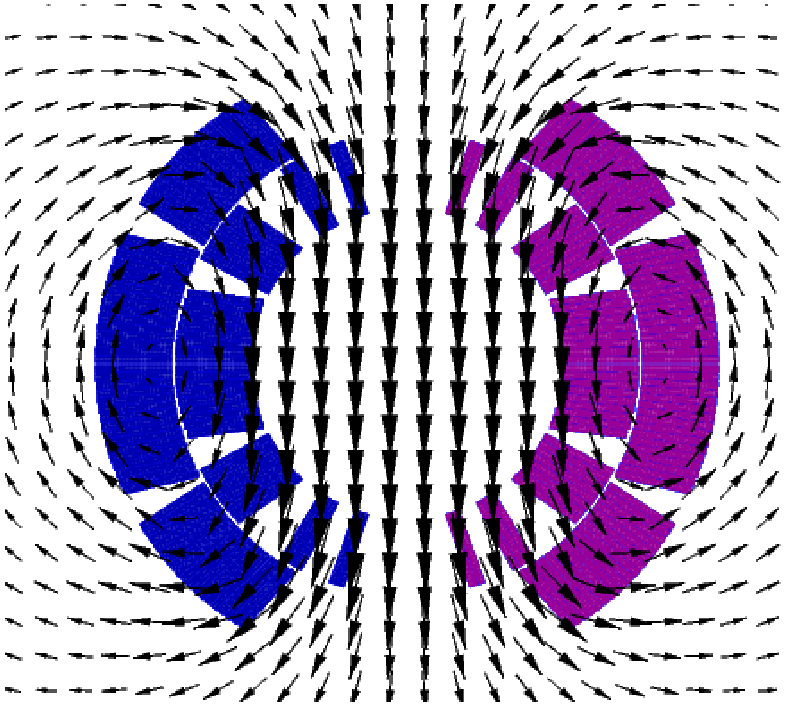
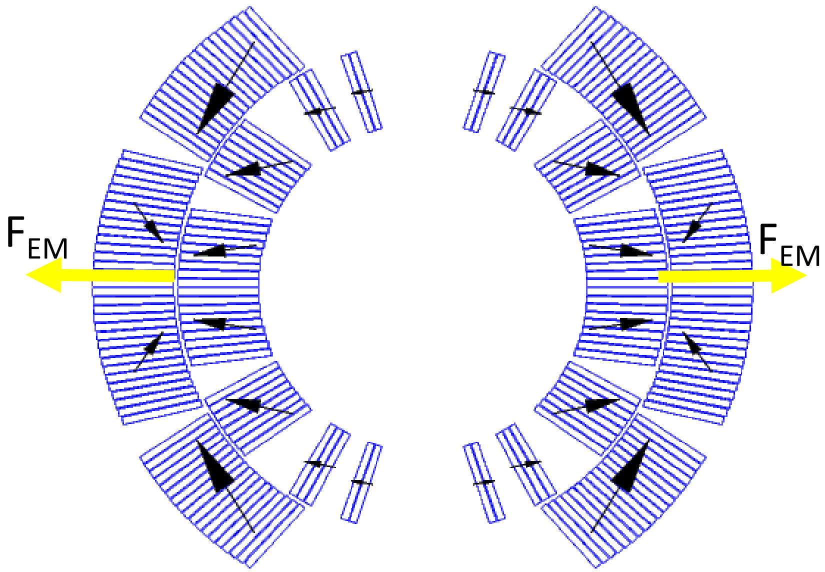


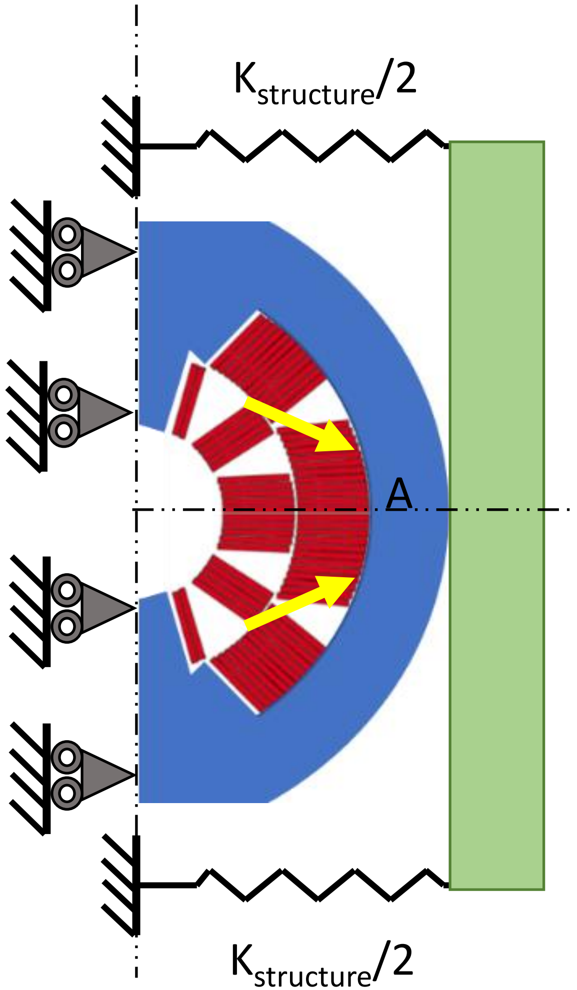
Deformation and stress in the coils



LHC Dipoles, field direction



LHC Dipoles, forces in the blocks
F_{EM} = resulting total force
F_{EM} = 2 x 1.7 MN/m @ 8.3 T



(Total coil deformation) = (Deformation inside the cavity) + (Deformation of the cavity)

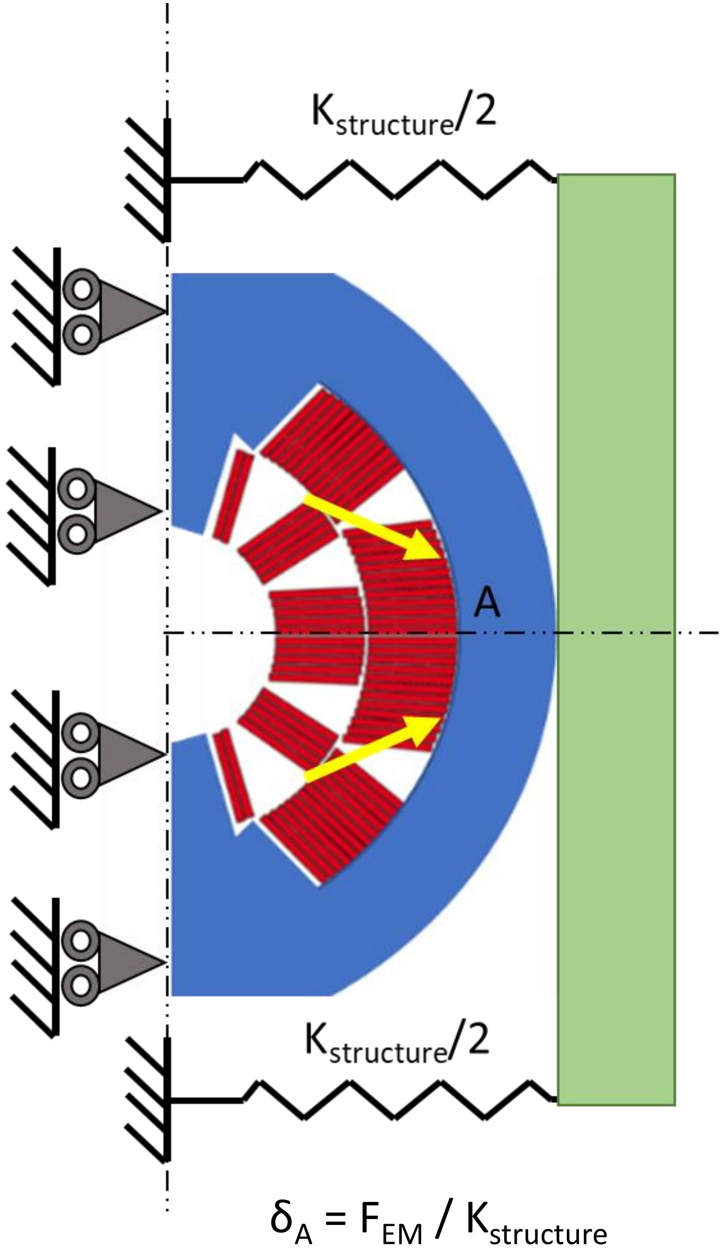
Stresses are related to deformations

Goals of the mechanical design:

- Manage coil stresses and deformations

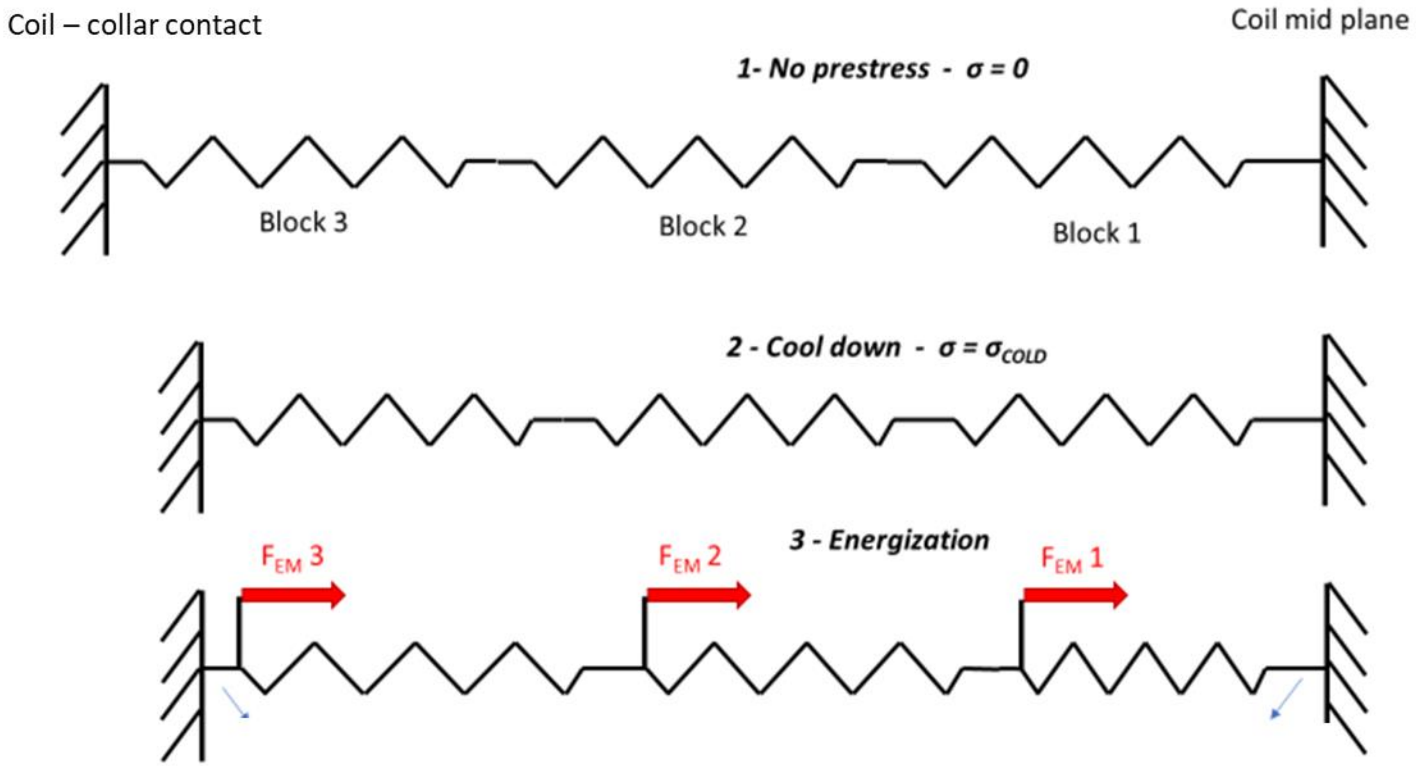
How to obtain this:

- Maximize $K_{structure}$ within reasonable size and weight of the magnet



An ‘high’ $K_{structure}$ can be obtained in many different ways

Azimuthal electromagnetic forces and azimuthal stresses



First layer coil

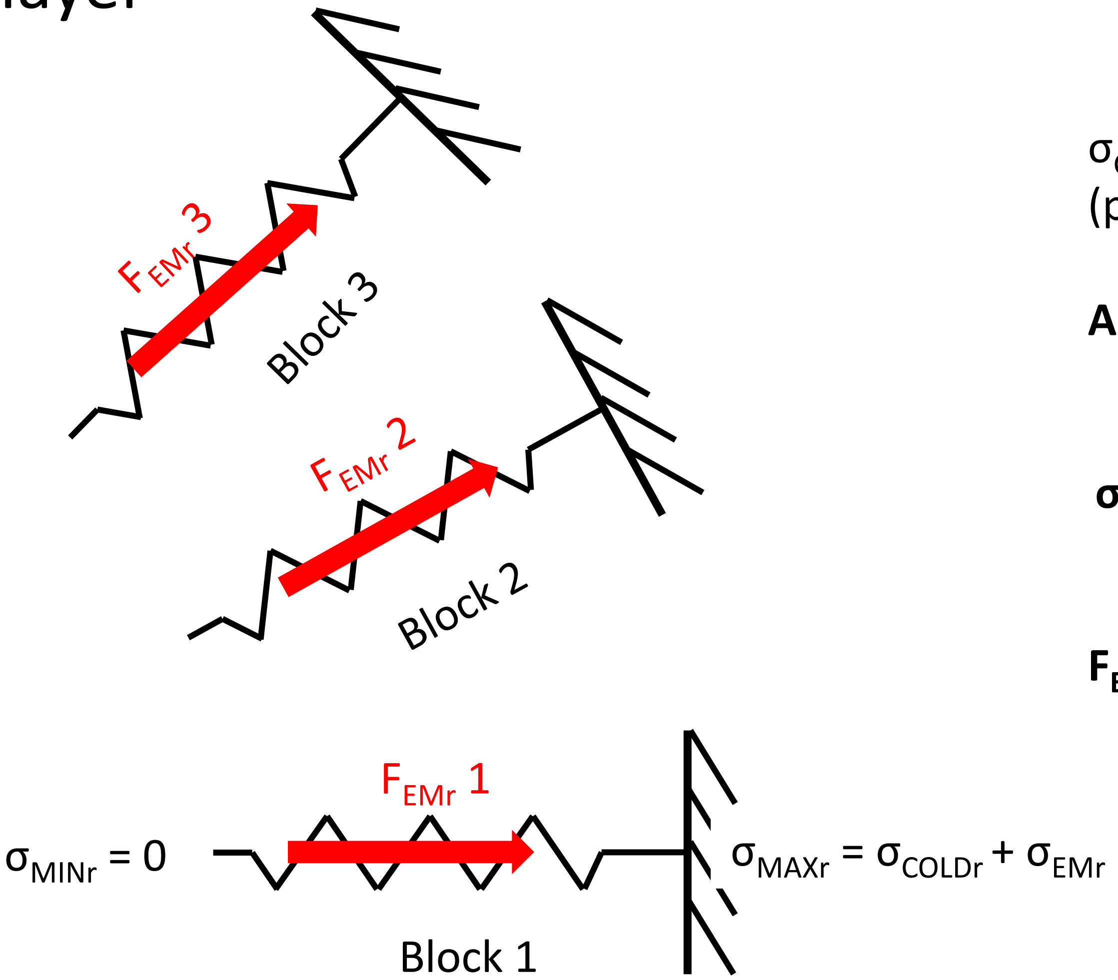
- Straight, springs in series.
- Radial containment infinitely rigid.
- Azimuthal F_{EM}.

$$\sigma_{EM\theta} = \Sigma(F_{EM\theta})/A_{COIL} \quad (F_{EM} = K' B^2)$$

- ➢ These stresses are independent from the Young's modulus of the coil. Just due to the azimuthal electromagnetic forces.
- ➢ This is an average on the cable width. True for small cables and/or large bore diameter.

Radial electromagnetic forces and radial stresses

First layer



σ_{COLD} Is related to the surrounding structure (prestress, relative shrinkage of structural parts).

$\mathbf{A_{block} = Th_{cable} \times N_{cable}}$

$\mathbf{\sigma_{EMr} = F_{EMr}/A_{block}}$ $\mathbf{(F_{EMr} = K' B^2)}$

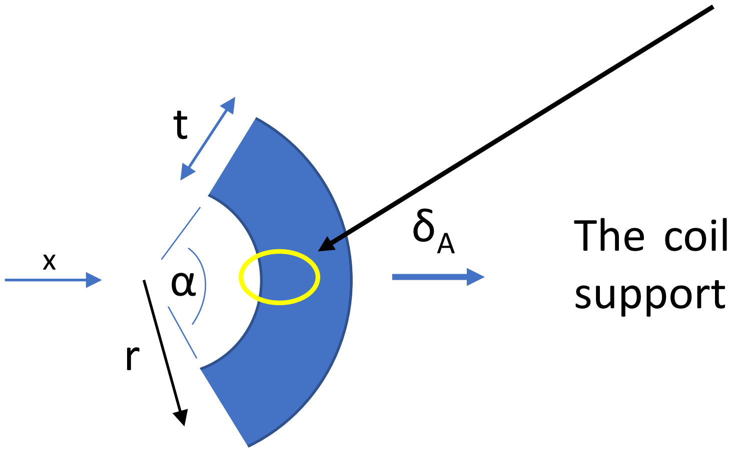
$\mathbf{F_{EMr}\,1 >> F_{EMr}\,3}$

Not in this seminar
A block coil is in the straight part very similar to the block 1 here on the left.

Effect of the deformation of the surrounding structure

Since the radial containment is not infinitely rigid. The horizontal deformation of the coils generates additional stresses. Further compression in the midplane, inner radius ($\Delta\sigma$)

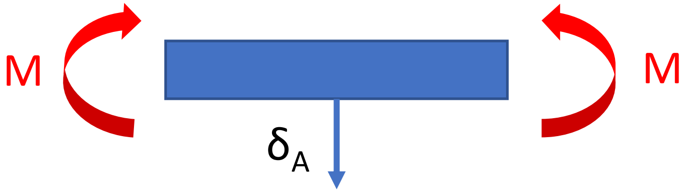
$$\boldsymbol{\sigma_{TOT\theta} = \sigma_{EM\theta} + \Delta\sigma}$$



The coil sees a displacement δ_A due to the support structure deformation.

In first approximation the coil cavity deforms as follows:

$\delta x(\theta) = \delta_A \cos\theta \quad [-\alpha/2,\alpha/2]$



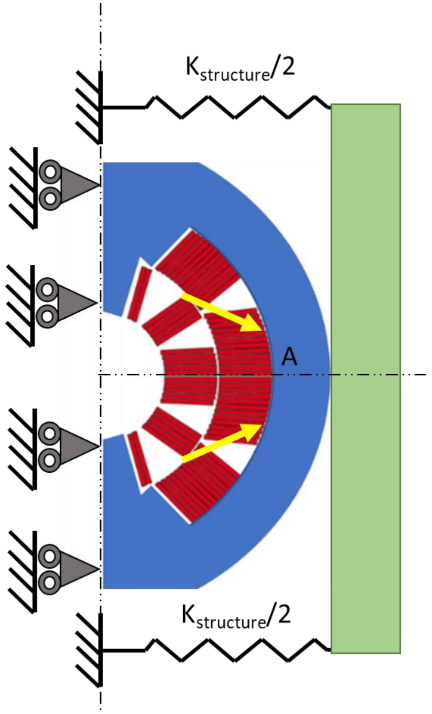
$$\Delta\sigma = \frac{(4\,\delta_A\,E\,t)}{(r^2\,\alpha^2)} = \frac{K\,\delta_A\,t}{r^2}$$

This is equivalent to a torque M applied to the extremity of the coils (upper and lower pole) generating a displacement δ_A of the midplane of the coils. For simplicity I consider straightened coils.

Knowing δ_A one can compute M and the related stress gradient. The gradient is larger for large cables and small apertures.

- δ_A is function of the rigidity of the surrounding structure.
- M for a given δ_A, is function of the coil Young's modulus E.

	Tevatron	Hera	RHIC	SSC	LHC	12 T Nb_3Sn
Nominal field (T)	4.5	5.3	3.5	6.7	8.3	12
Bore diameter (mm)	76	75	80	50 (40)	56	50 - 56
1st layer cable size (not insulated) (mm)	7.2	10	9.7	12.3	15.1	18 - 21
2nd layer cable size (not insulated) (mm)	7.2	10	-	11.7	15.1	18 - 21
Bore / 1st layer c. size	10.6	7.5	8.2	4.1 (3.2)	3.7	2.4 – 3.1



$$\Delta\sigma = \frac{(4\,\delta_A\,E\,t)}{(r^2\,\theta^2)} = \frac{K\,\delta_A\,t}{r^2}$$

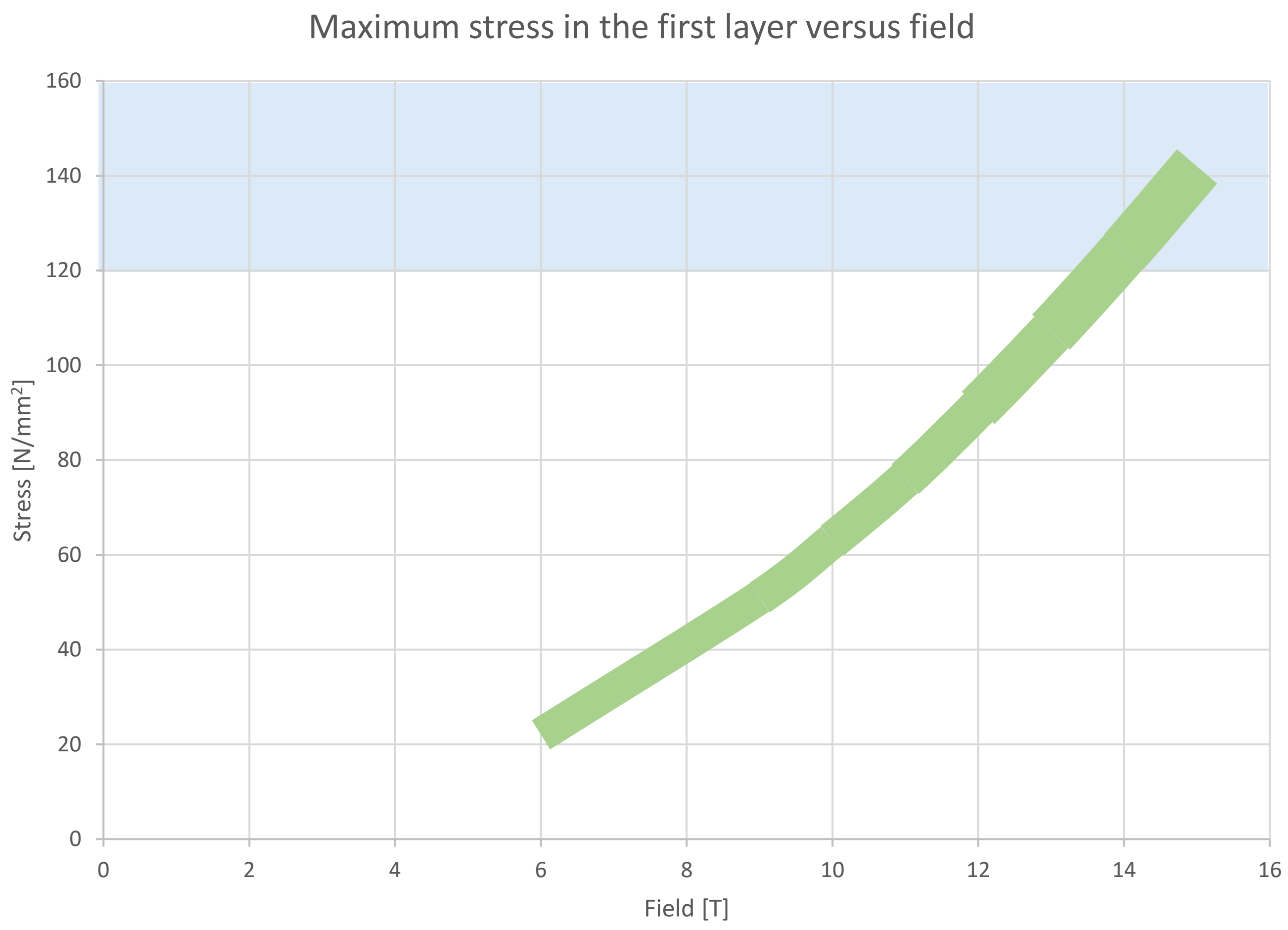
$\delta_A = 0.1$ mm

$\delta_A \leq 0.05$ mm

To generate high fields, we need small bores and large cables.

In terms of structures, we need something giving us $\delta_A \leq 0.05$ mm

Peak stress in the coil midplane for cosθ coils, two layers



- If we use the limit of 120 MPa as maximum admissible coil compression (nominal), 12 T – 13 T are at the edge of what we can realize with the configuration cosθ coils and 'standard' structures.
- We need a safety factor. Nominal is lower than the peak due to tolerances, uncertainties, etc.

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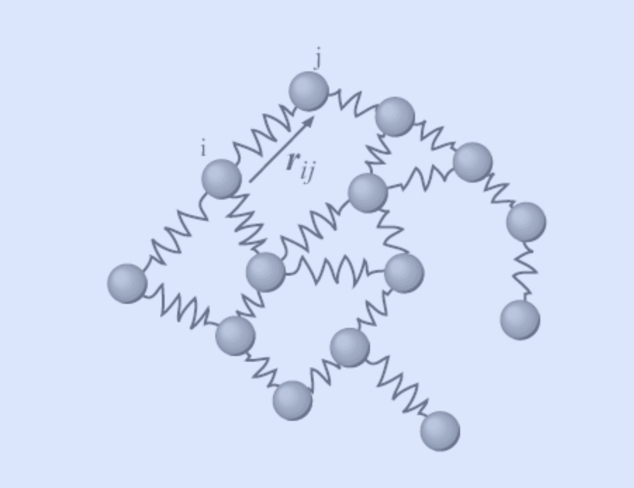
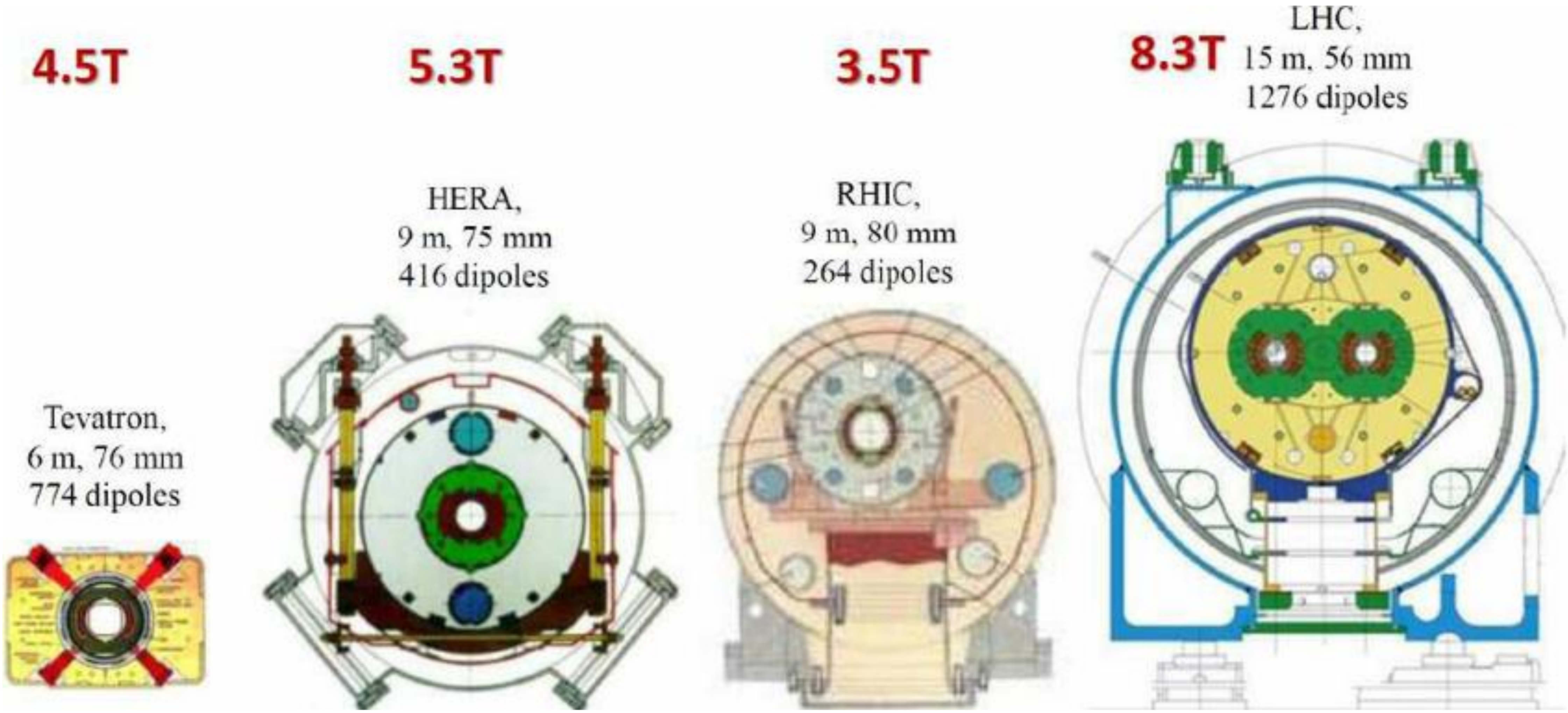
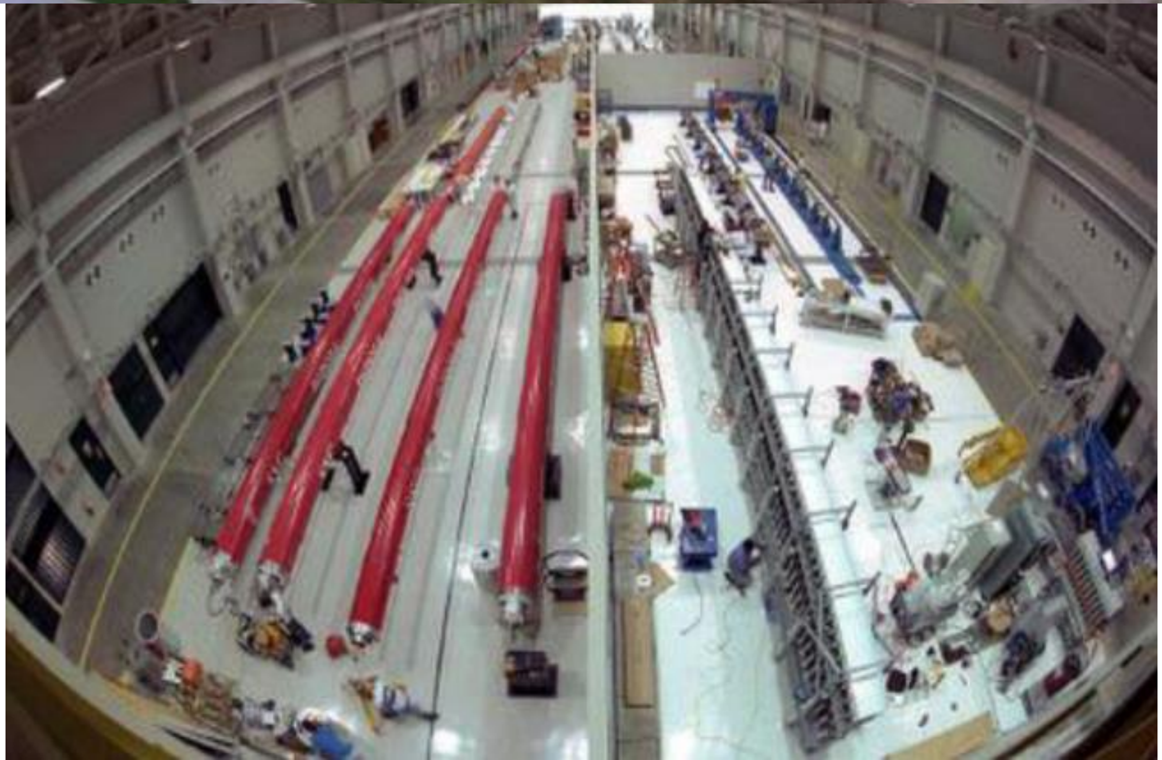


Accelerators operated so far with SC dipoles.

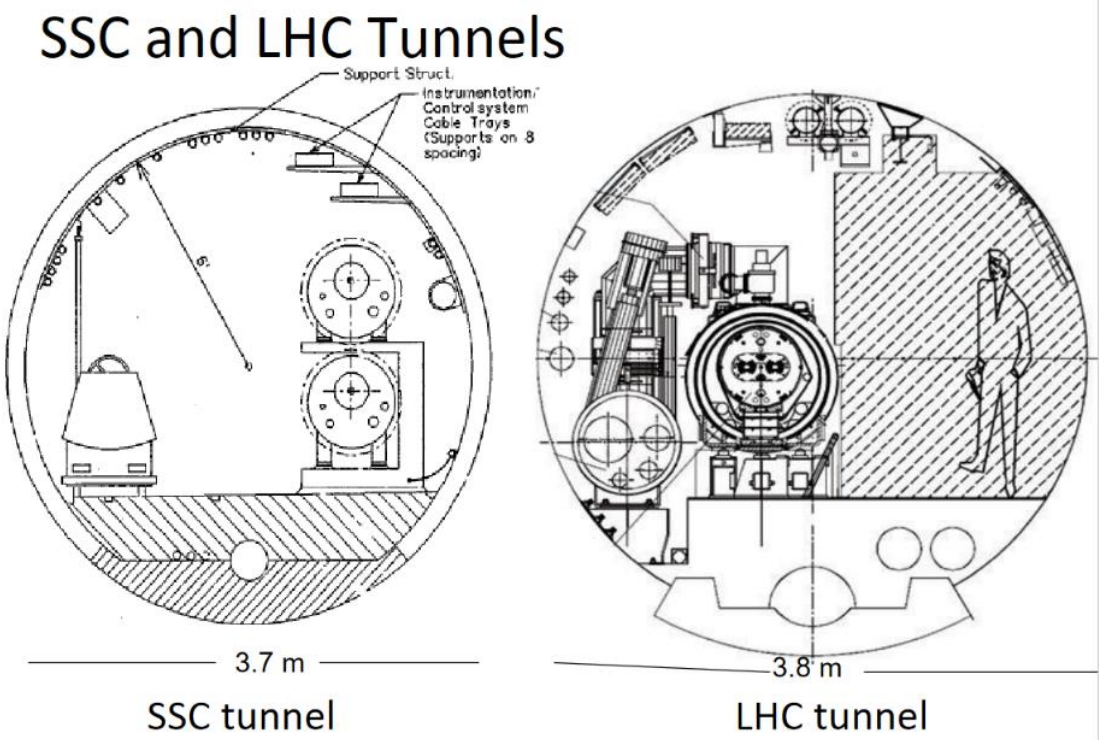


Courtesy V. Shiltsev, FNAL, Batavia, IL.



SSC. Project cancelled in 1993

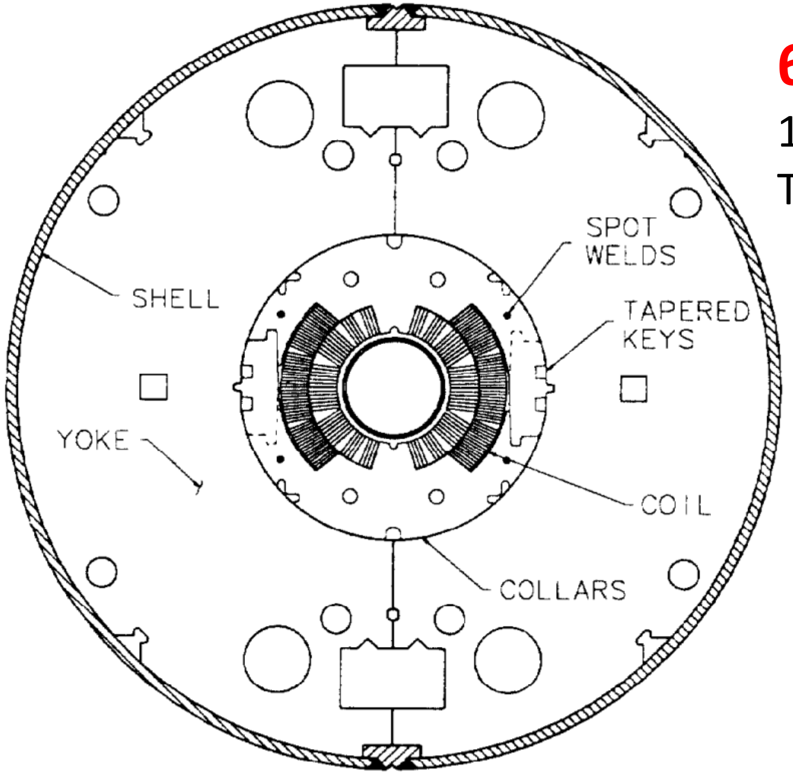
The planned ring circumference was 87.1 kilometres with an energy of 20 TeV per proton and was designed to be the world's largest and most energetic particle accelerator



Important contribution to the development of NbTi SC magnets.

In LHC magnets, there is a lot from HERA and SSC

SSC dipoles – steel collars



6.7 T

17 m, 50 mm

Tens of prototypes

Mechanical Design of the 2D Cross-Section of the SSC Collider Dipole Magnet*

J. Strait, J. Kerby, R. Bossert and J. Carson
Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510

G. Spigo and J.R. Turner
SSC Laboratory, 2550 Beckleymeade Ave., Dallas, TX 75237

Quench Performance of 50-mm Aperture, 15-m-Long SSC Dipole Magnets Built at Fermilab

J. Kuzminski, T. Bush, R. Coombes, A. Devred, J. DiMarco, C. Goodzeit, M. Puglisi, P. Sanger, R. Schermer, J. C. Tompkins, Y. Yu§, and H. Zheng
SSC Laboratory, 2550 Beckleymeade Avenue, Dallas, TX 75237 USA

T. Ogitsu
SSC Laboratory and KEK, National Laboratory for High Energy Physics, 1-1 Oho, Tsukuba-shi, Ibaraki-ken 305, Japan

R. Bossert, J. Carson, S. W. Delchamps, S. Gourlay, R. Hanft, W. Koska, M. Kuchnir, M. J. Lamm, P. Mantsch, P. O. Mazur, D. Orris, J. Ozelis, E. G. Pewitt, T. Peterson, J. Strait, and M. Wake¶
Fermi National Accelerator Laboratory, Batavia, IL 60510 USA

To be presented at the
Third Annual 1991 International Industrial Symposium
on the Super Collider (IISSC)
Atlanta Hilton and Towers
Atlanta, Georgia
March 13-15, 1991

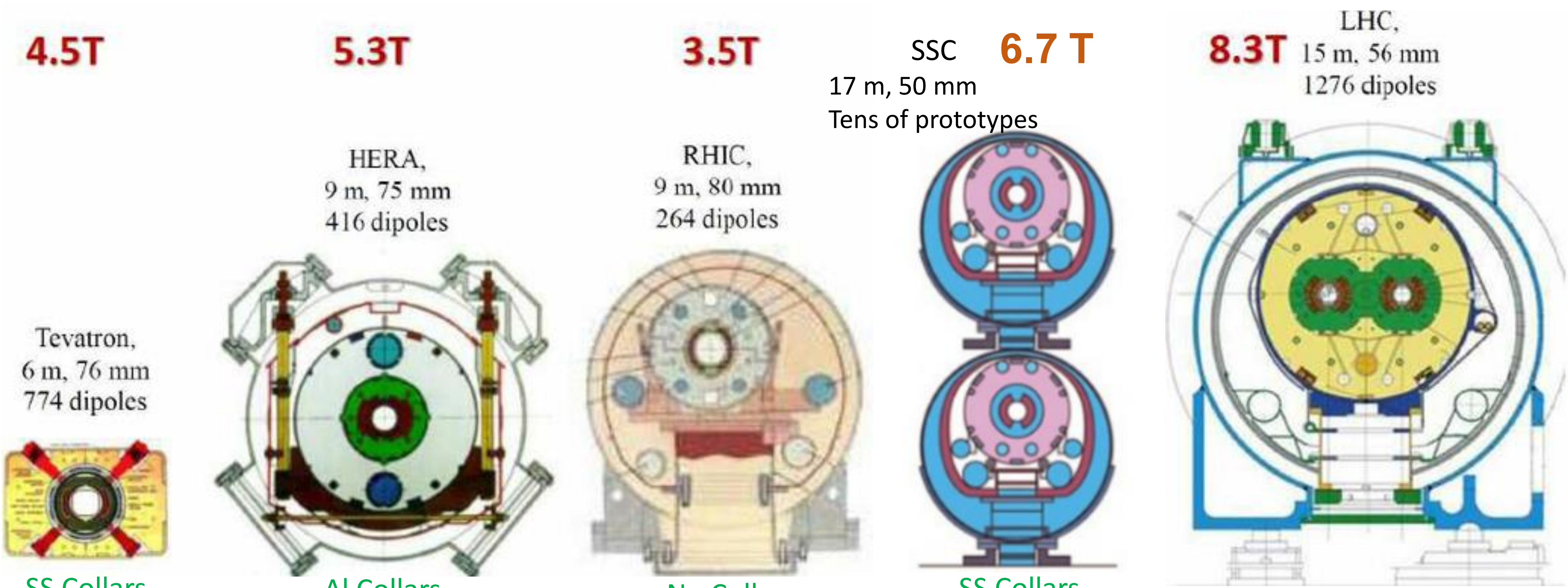
BNL - 45290

SSC 50 MM DIPOLE CROSS SECTION*

R.C. Gupta, S.A. Kahn and G.H. Morgan

Accelerator Development Department
Brookhaven National Laboratory
Upton, NY 11973 USA

Accelerator dipoles built so far in pre-series or series



SS Collars

Al Collars
Vertical gap

No Collars
Horizontal gap

SS Collars
Hor. and vert. gap

SS Collars Hard, last minute change
Vertical gap

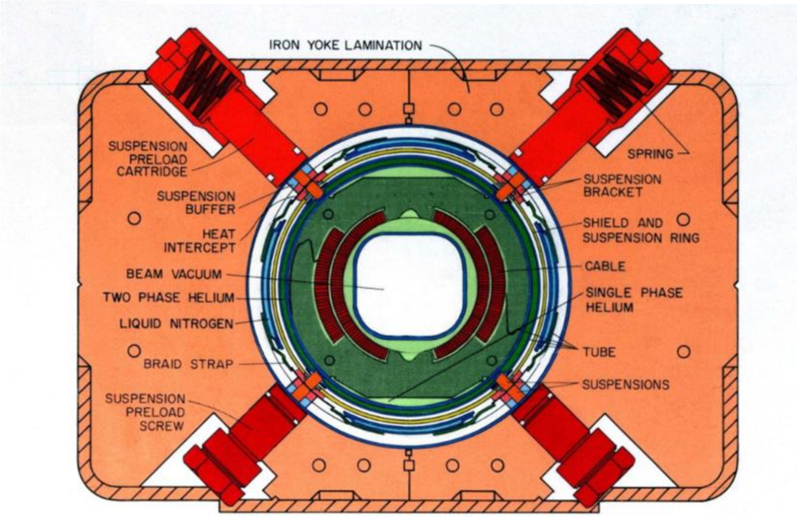
~4.5 K, single aperture (one in one)

~2 K, double aperture (two in one)

Electromagnetic forces are proportional to the square of the field

Stored energy is proportional to the square of the bore diameter

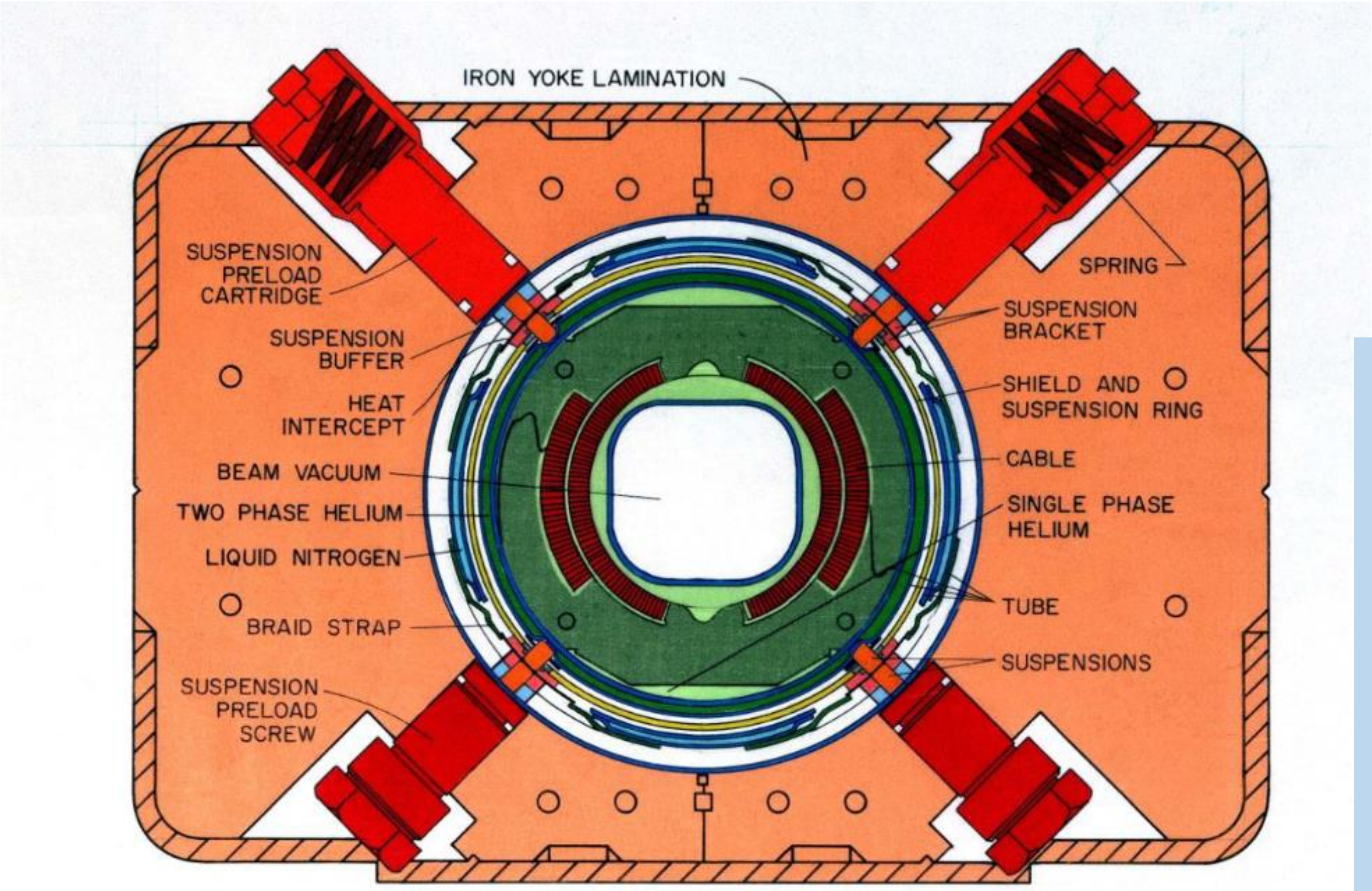
Tevatron dipoles. Warm iron.



Accelerator Science and Technology Breakthroughs, Achievements and Lessons from the Tevatron*

V. Shiltsev, FNAL, Batavia, IL 60510, USA#

To Fermilab staff who made the Tevatron collider a great success.

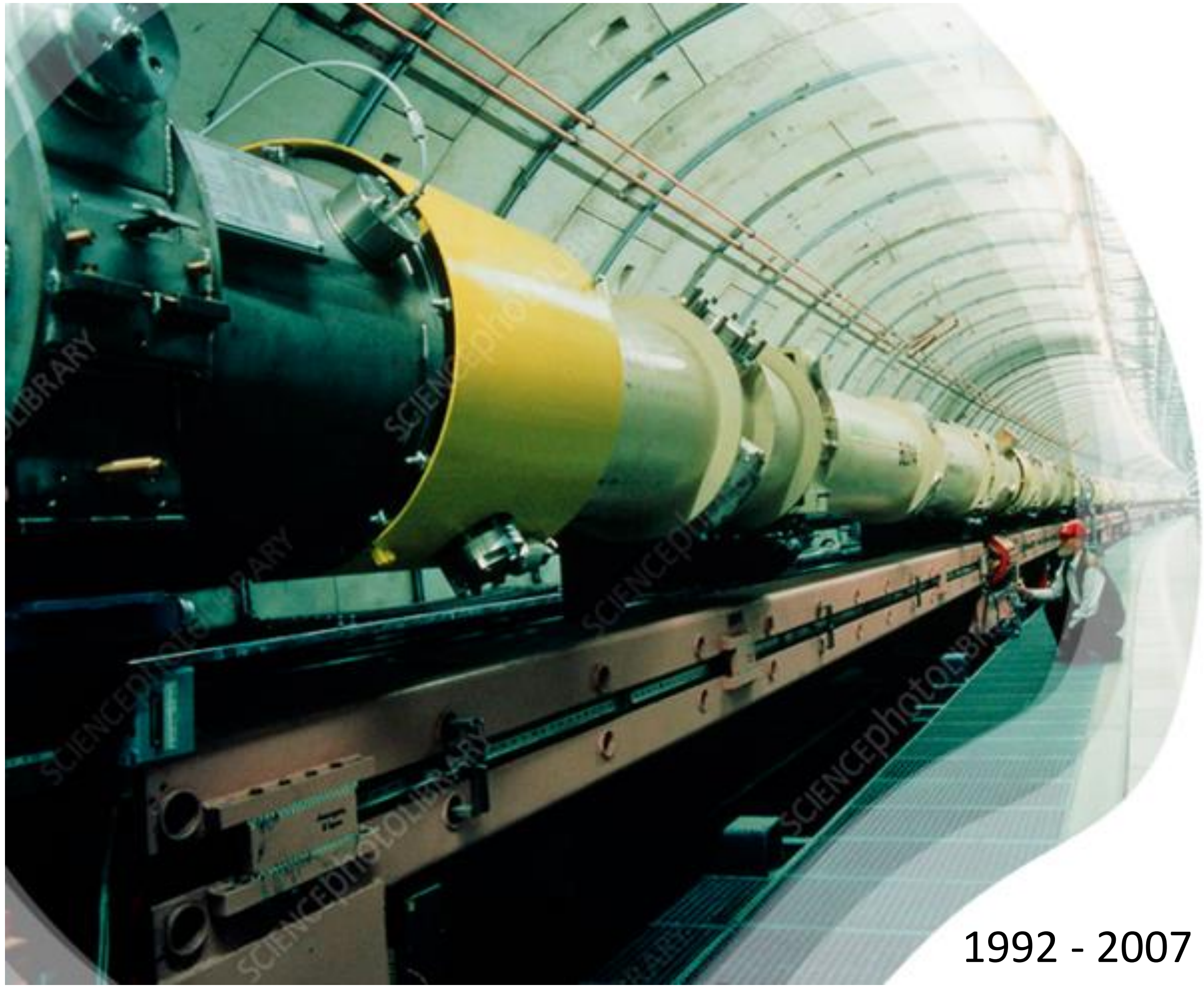


Protons – antiprotons.
Common vacuum beam with electrostatic separator.

Magnets were Designed in mid 1970's.

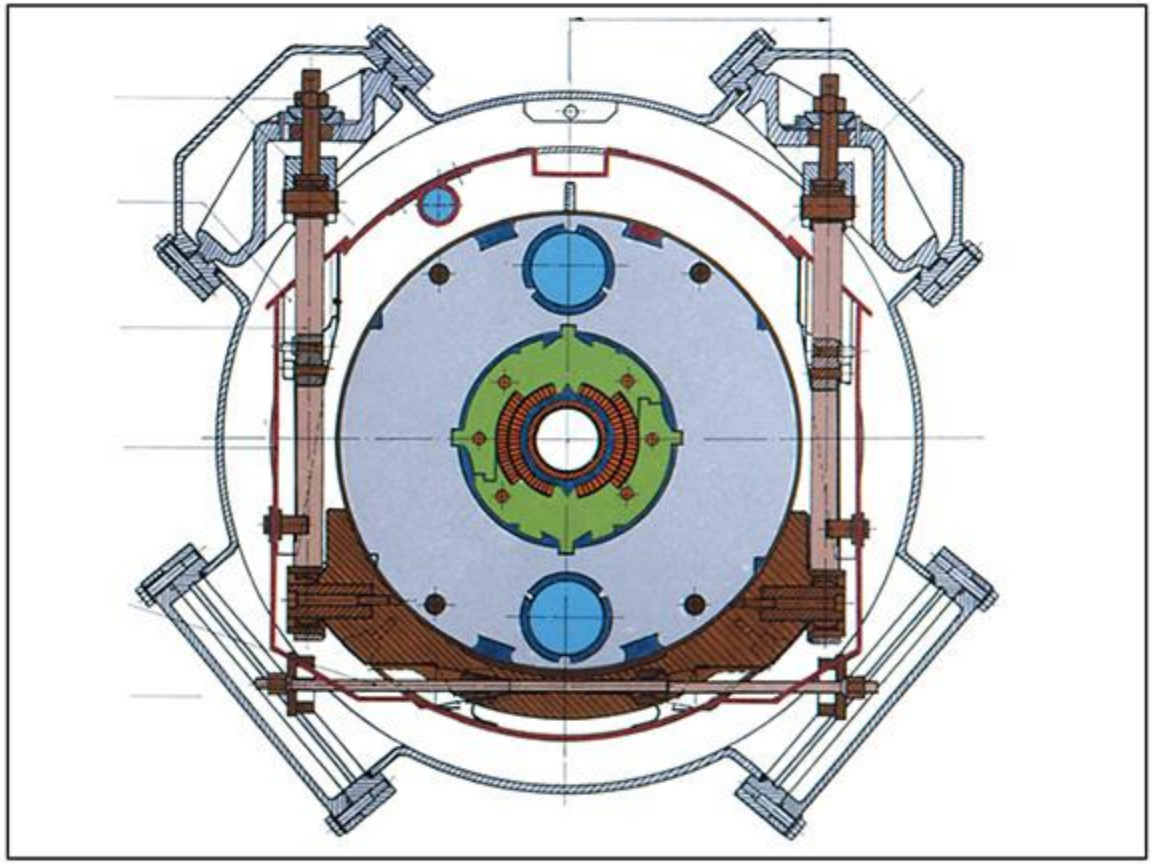
Creep of supports after 20 years (degraded field quality).
Shimmed in situ to fix the problem.

HERA Dipoles. Aluminium collars.



1992 - 2007

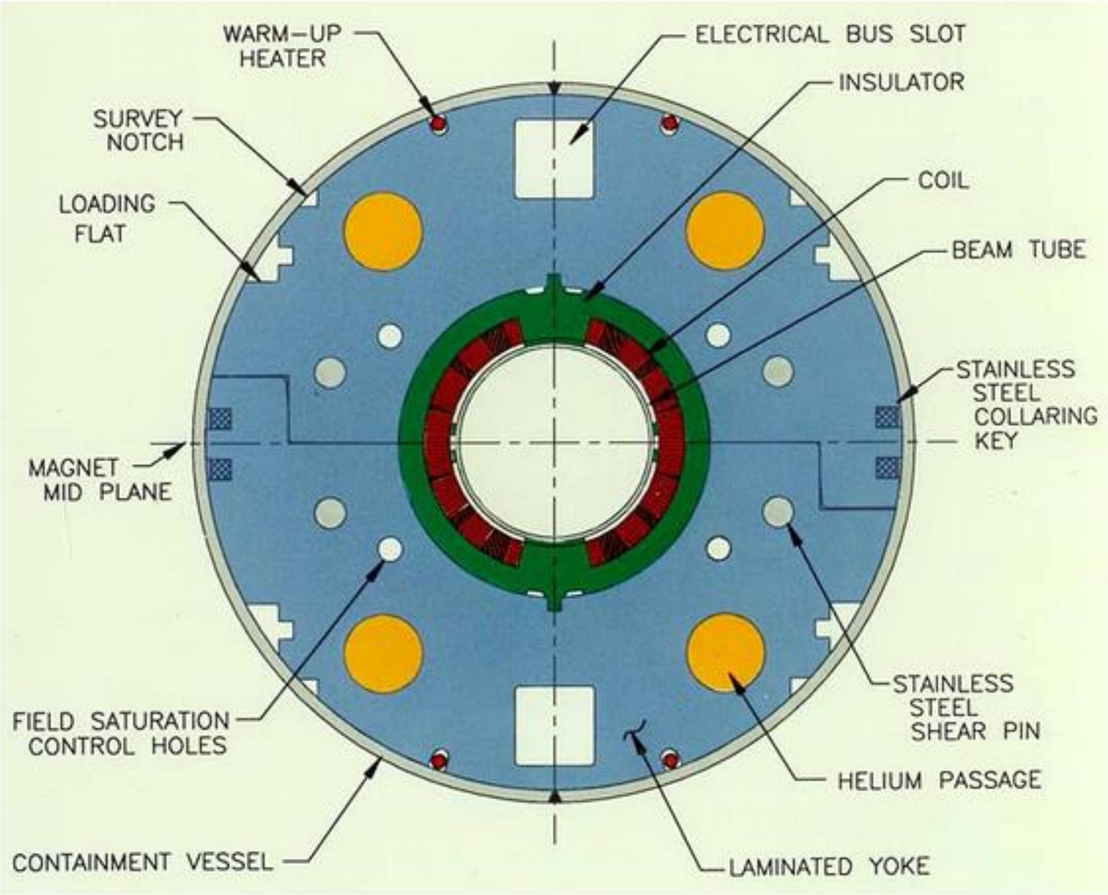
HERA accelerator at DESY (Deutsche Elektronen Synchrotron), Hamburg. HERA (Hadron Electron Ring Accelerator) consists of two accelerator rings installed in a 6.3-km circumference tunnel. In the upper ring run protons while in the lower ring run electrons in opposite direction. At two points on the ring the beams cross, providing proton/electron collisions.



DESIGN OF SUPERCONDUCTING DIPOLE FOR HERA

H. Kaiser
Deutsches Elektronen-Synchrotron DESY
2000 Hamburg 52, West Germany

RHIC dipoles. The elegance of a cost optimized solution.

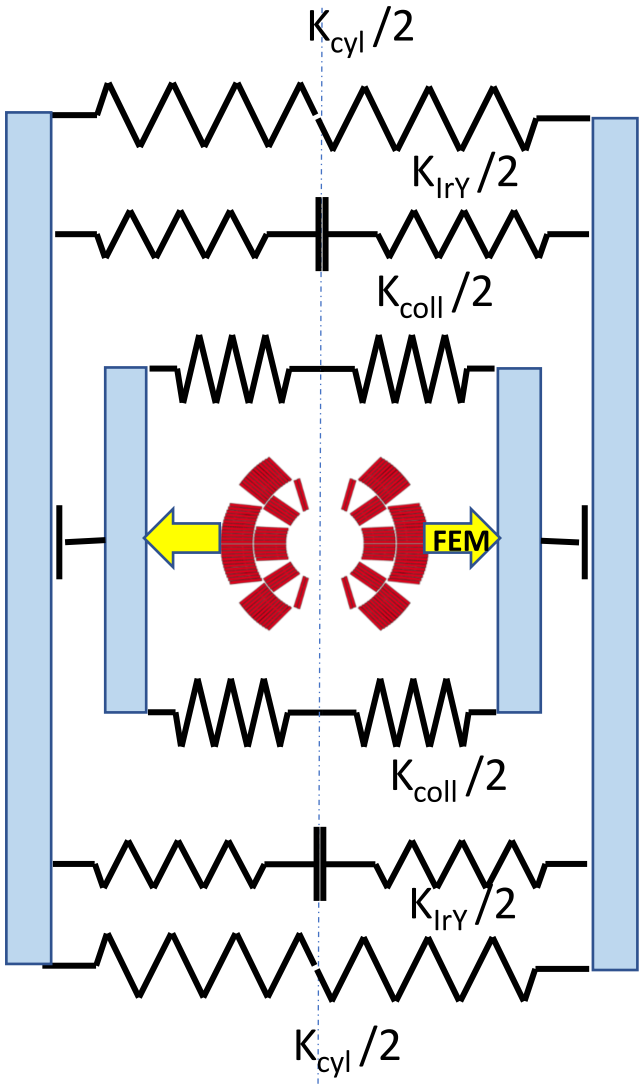


CONSTRUCTION AND TESTING OF ARC DIPOLES AND QUADRUPOLES FOR THE RELATIVISTIC HEAVY ION COLLIDER (RHIC) AT BNL*

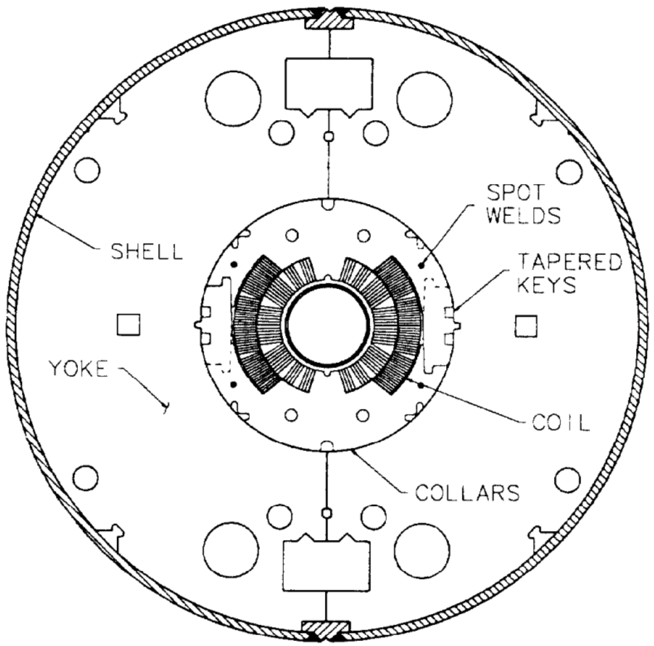
P. Wanderer, J. Muratore, M. Anerella, G. Ganetis, A. Ghosh, A. Greene, R. Gupta, A. Jain, S. Kahn, E. Kelly, G. Morgan, A. Prodell, M. Rehak, W. Sampson, R. Thomas, P. Thompson, E. Willen
Brookhaven National Laboratory, Upton, New York 11973-5000 USA

The dipoles provide a 3.45 T field in a cost-effective design. Key features include the use of NbTi Rutherford cable, a single-layer coil, and cold iron as both yoke and collar. The magnets operate in forced-flow helium at a nominal temperature of 4.6K.

Single aperture, aluminium or steel collars – open or closed gaps

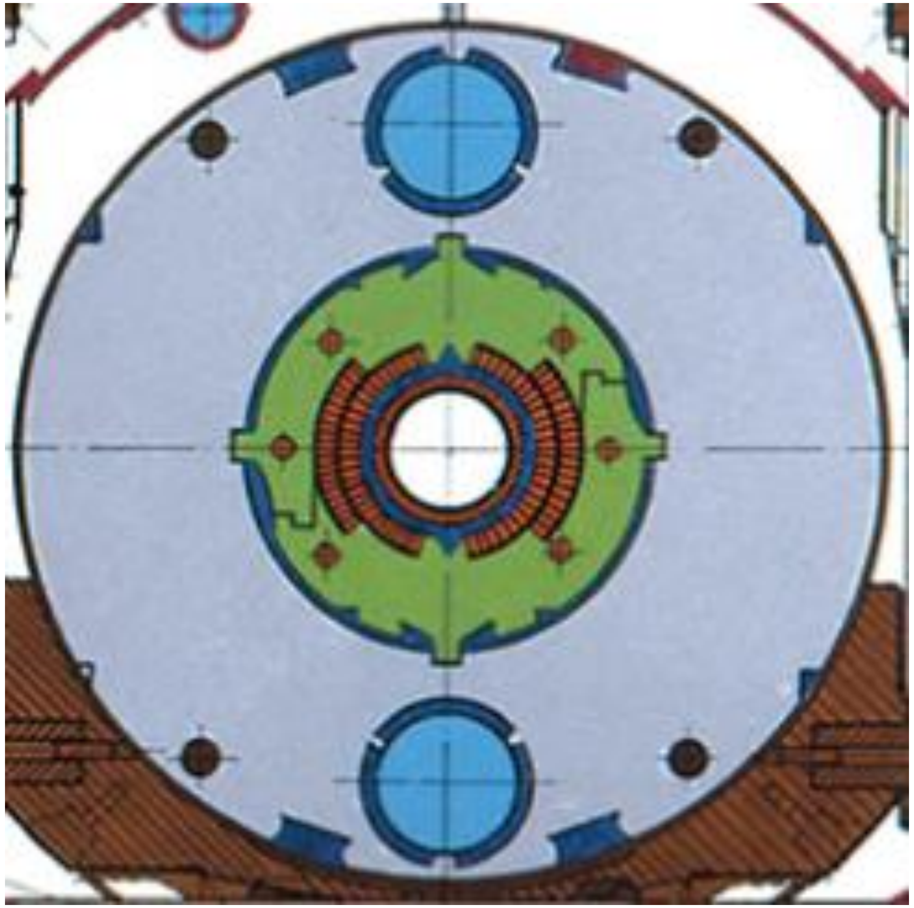


SSC: 6.7 T – 50 mm bore



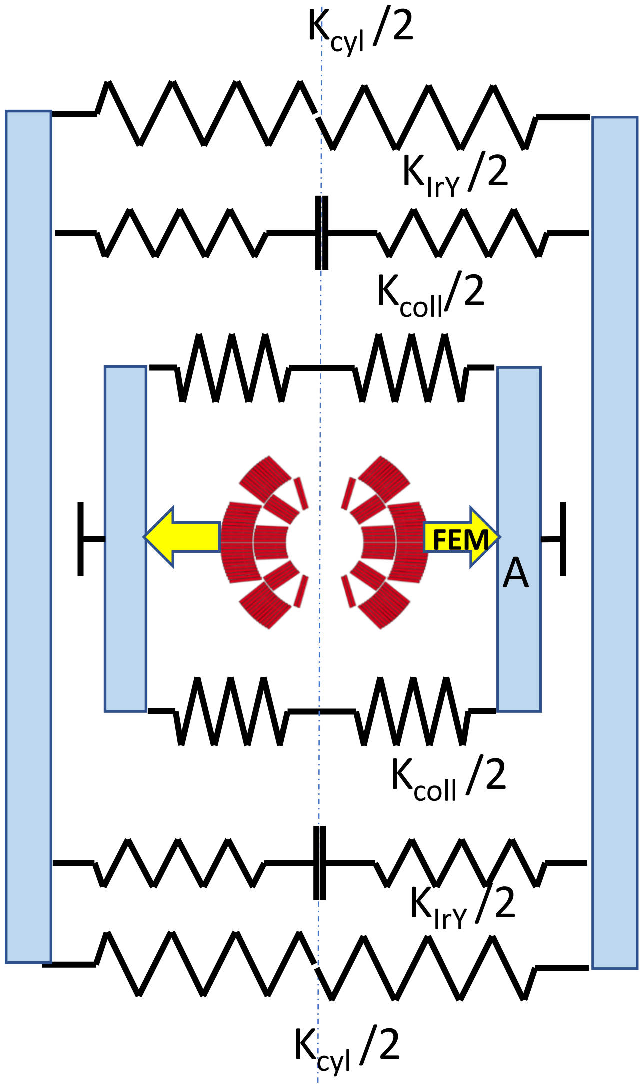
At cold, contact between austenitic stainless steel collars an iron. Thin collars (low K_{Coll}), high preload of K_{irY} and K_{cyl}.

HERA: 5.3 T – 75 mm bore



At cold, ~0.1 mm radial gap between aluminium collars and iron. Thick collars, moderate horizontal preload. The iron does not contribute to limit the coil deformation.

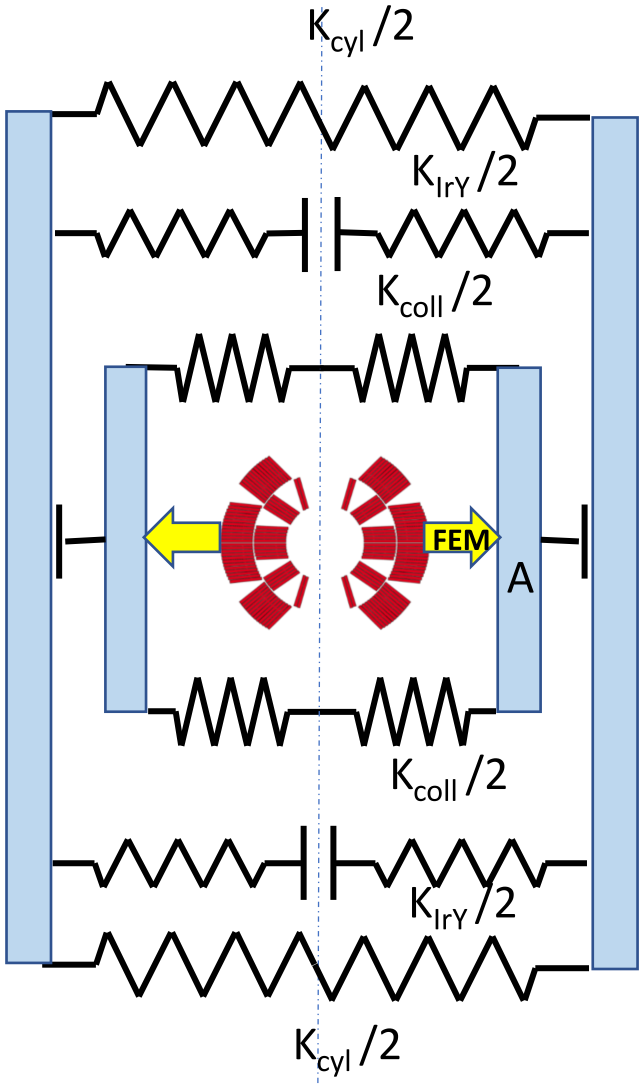
Effect of open gaps on the global stiffness of a structure



Open collar – Iron yoke gap

$\delta_A = F_{EM} / K_{Coll}$

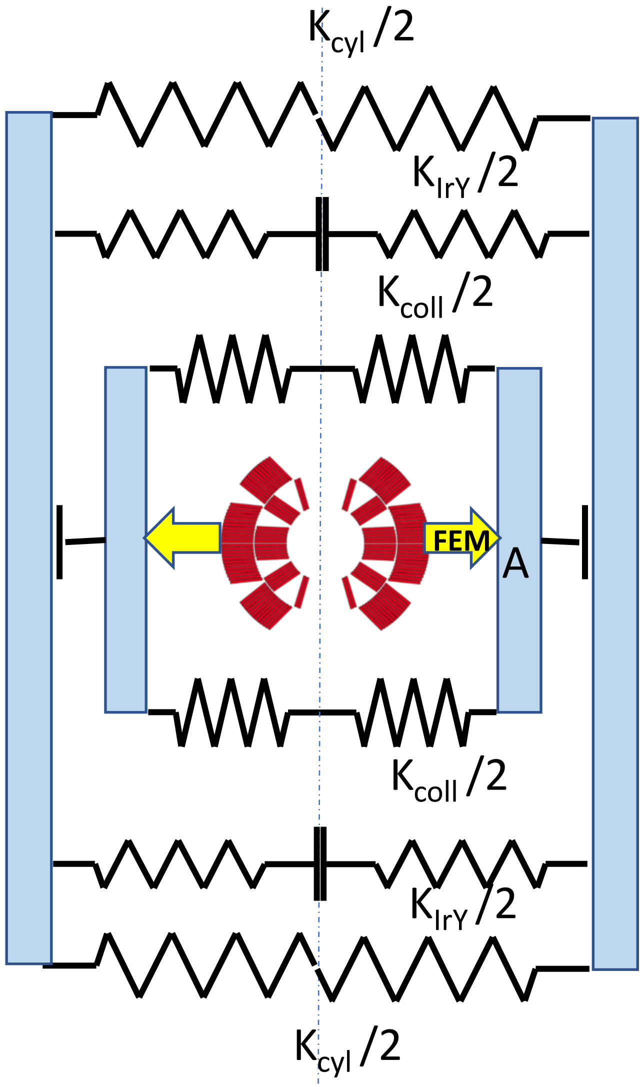
A possible design choice for low fields



Open Iron yoke gap

$\delta_A = F_{EM} / (K_{coll} + K_{cyl})$

I think this is not an option



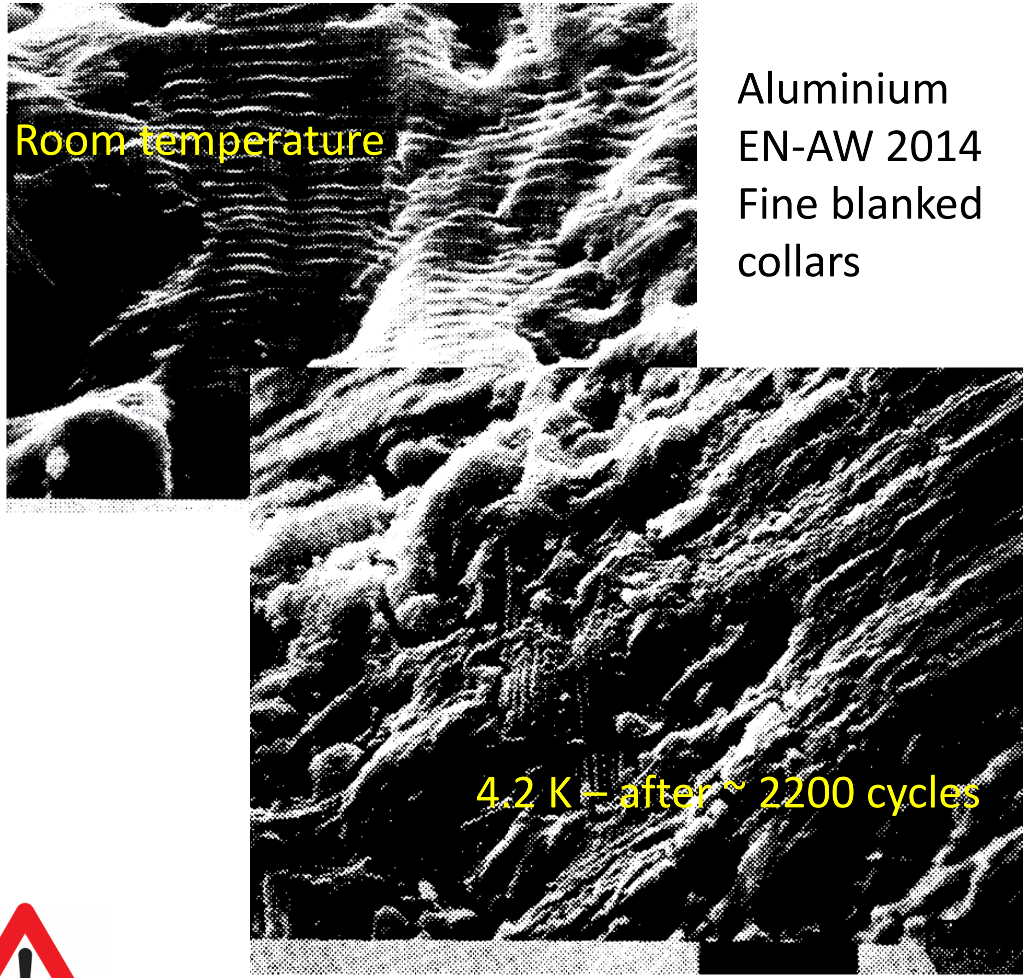
All gap closed

$\delta_A = F_{EM} / (K_{coll} + K_{IrY} + K_{cyl})$

The design choice for high fields

Aluminium or austenitic steel grades for structural components some facts

- Young's modulus of aluminium grades is about one third of the Young's modulus of austenitic stainless steel grades (deformations of collars and coils)
- Density of aluminium grades is about one third of the density of austenitic stainless steel grades (cost of raw material strips)
- Thermal contraction coefficient of aluminium grades is larger than the thermal contraction coefficient of austenitic stainless steel grades (coil prestress, contacts between iron yoke and collars / pads)
- Relalive magnetic permeability of some austenitic steel grades is not 1 and can vary with temperature (field quality)
- Creep of aluminium grades under high loads (stress concentration areas, for example holes for collaring rods).
- Cold brittleness of some aluminium grades (stress concentrations)
- Oligocyclic (low number of cycles but high stresses) fatigue limit of aluminium grades can be very low (stress concentrations in the holes for collaring rods and powering cycles from injection to collision level)



Aluminium
EN-AW 2014
Fine blanked
collars

LHC note 253

Measurement of the Resistance to Stress Cycling at 4.2 K of LHC Dipole Collars

N. Galante, J. Gilquin, G. Patti, R. Perin, D. Perini

LHC Dipoles. Different options and a last minute change.

LHC Project Note 288 – April 2002

Comparative Study of Different Designs of the Mechanical Structure for the LHC Main Dipoles

P. Fessia, D. Perini, R. Vuillermet, C. Wyss / LHC-MMS

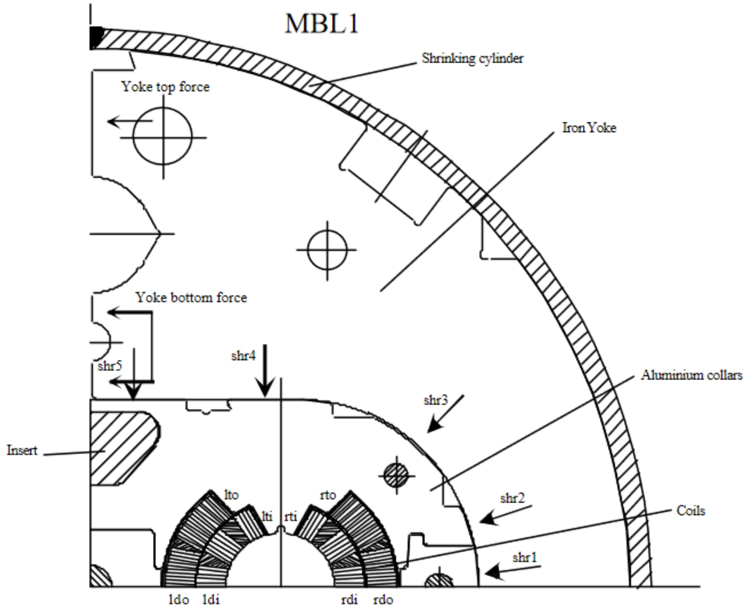


Fig.1.: MBL1 model; (male collar 25 369 mm^2+ female collar 18 764 mm^2 ,total surface = 44 133 mm^2)

The great dilemma of the end of last millennium ☺

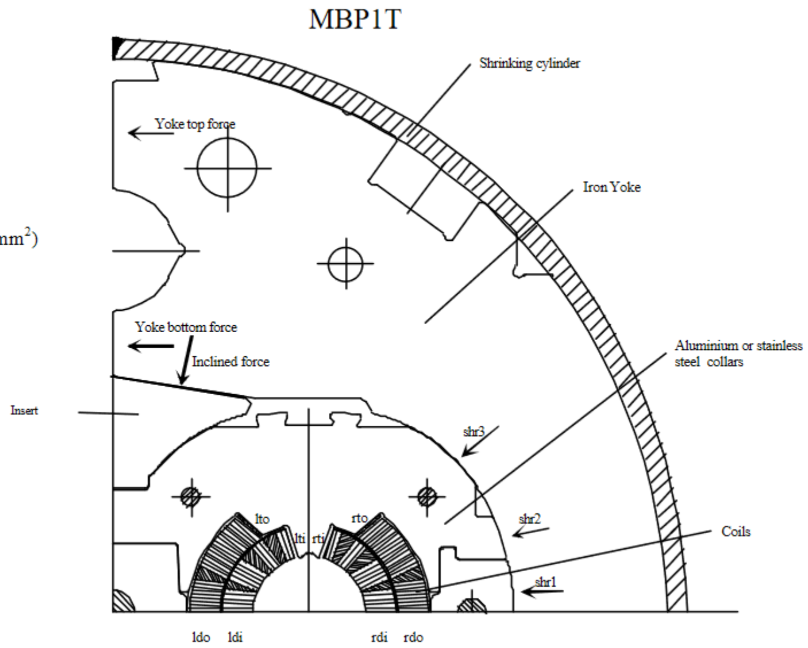


Fig.2.: MBP1T model; (male collar 26 316 mm^2+ female collar 18 764 mm^2 , total surface = 45 080 mm^2)

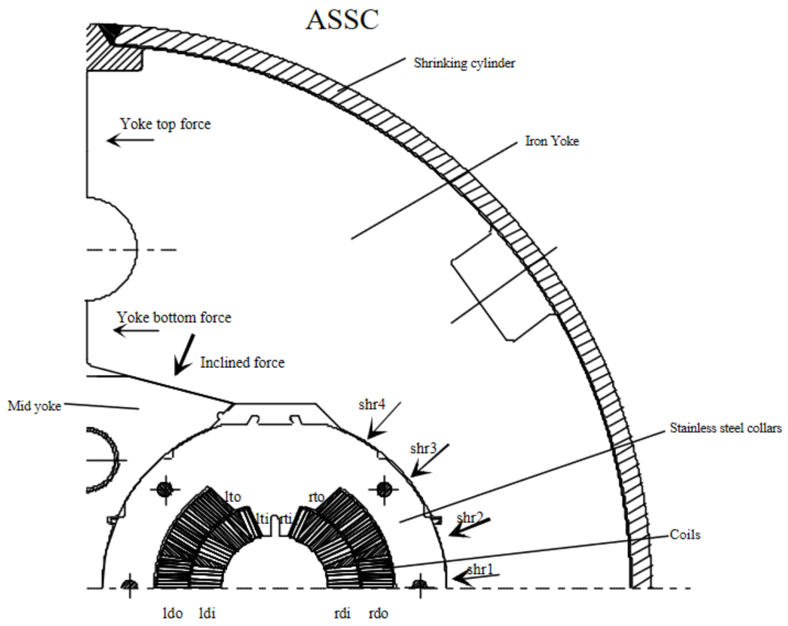
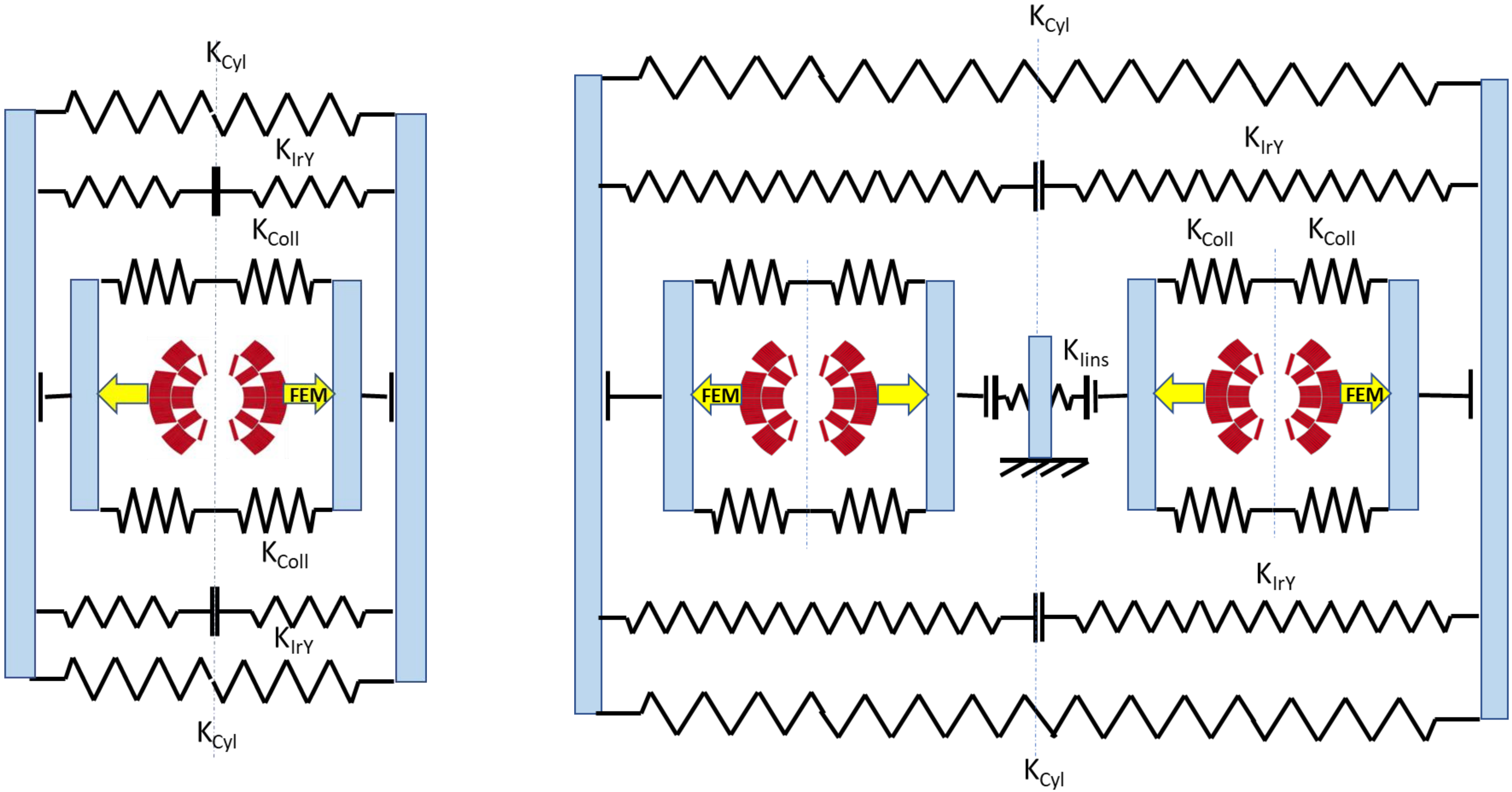


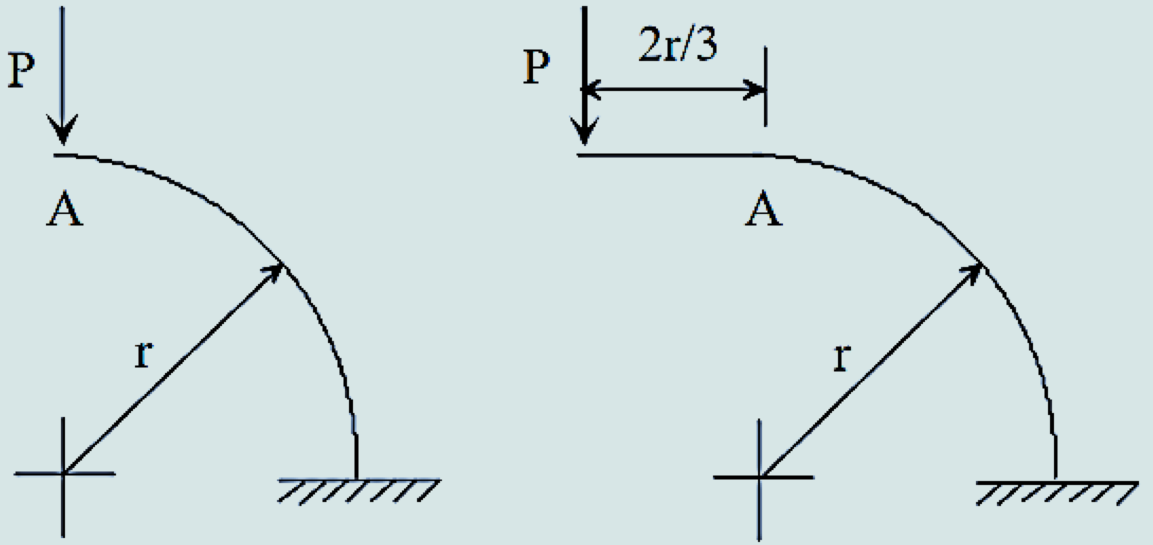
Fig.3.: ASSC model; (2 male collar 17 116 mm^2+ 2 female collar 13 068 mm^2, total surface = 30 184 mm^2)

Single and double aperture - vertical iron gap

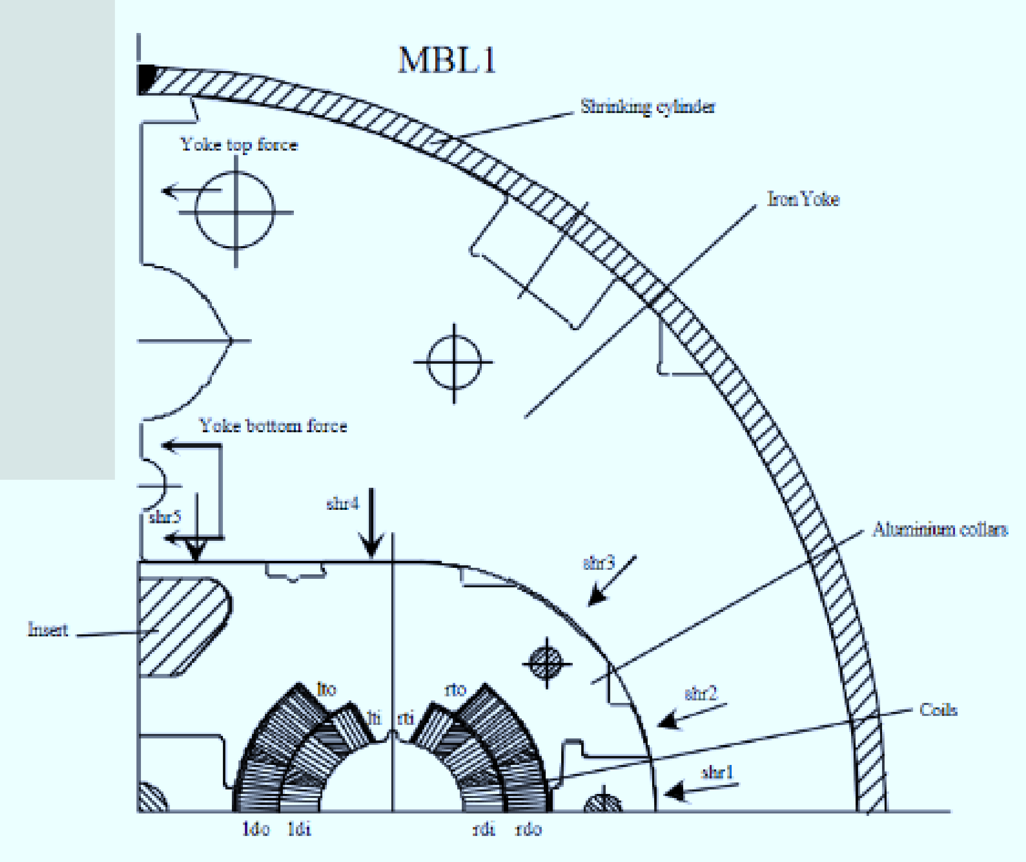
lack of symmetry in the rigidity around the coils of a double aperture



Qualitative example of iron yoke ‘flexibility’ in a single and double aperture dipole

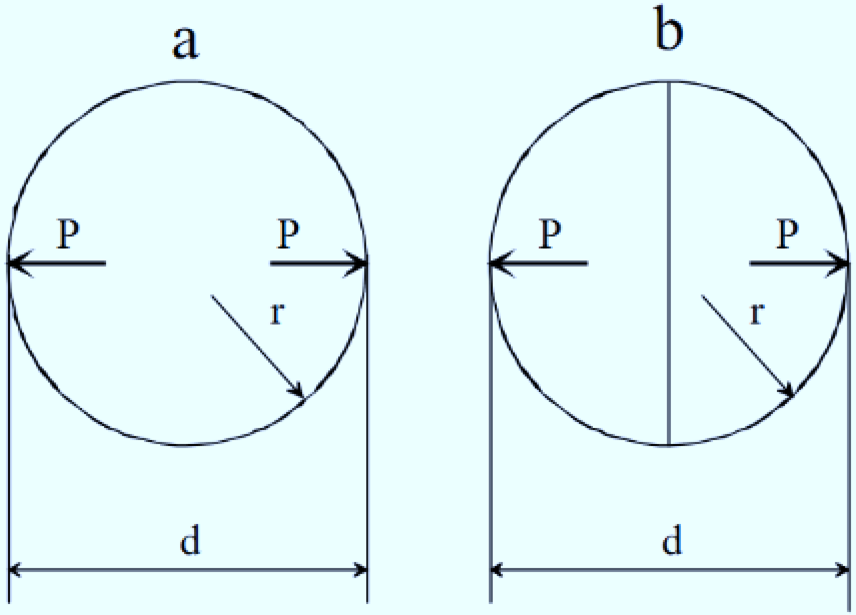


$$\text{Case a)}: \frac{P}{\delta} = K = 1.273 \cdot \frac{E \cdot J}{r^3} \qquad \text{Case b)}: \frac{P}{\delta} = K = 0.343 \cdot \frac{E \cdot J}{r^3}$$



Common collars and separate collars

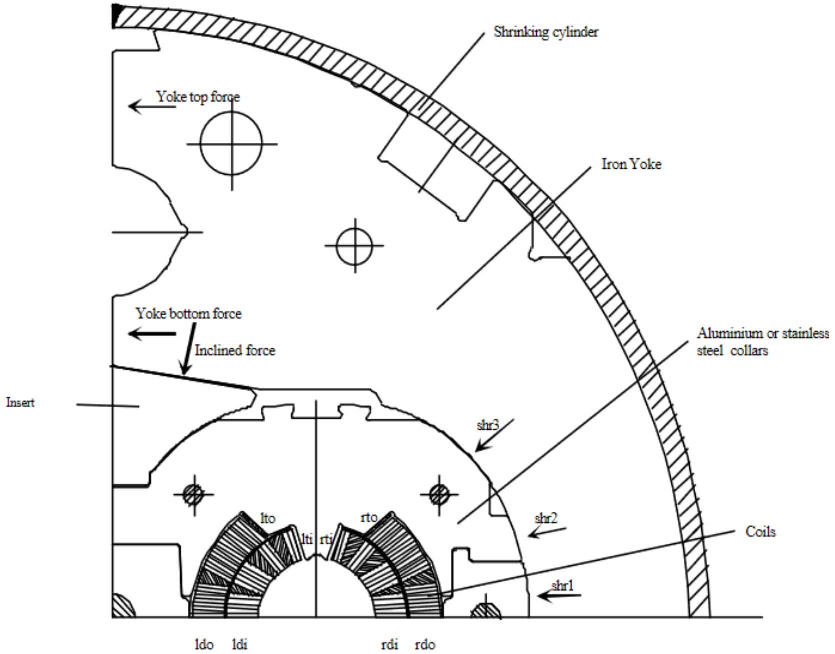
- Separate collars give a more 'symmetric' configuration
- Separate collars give a more rigid configuration
- Separate collars means more pieces to align



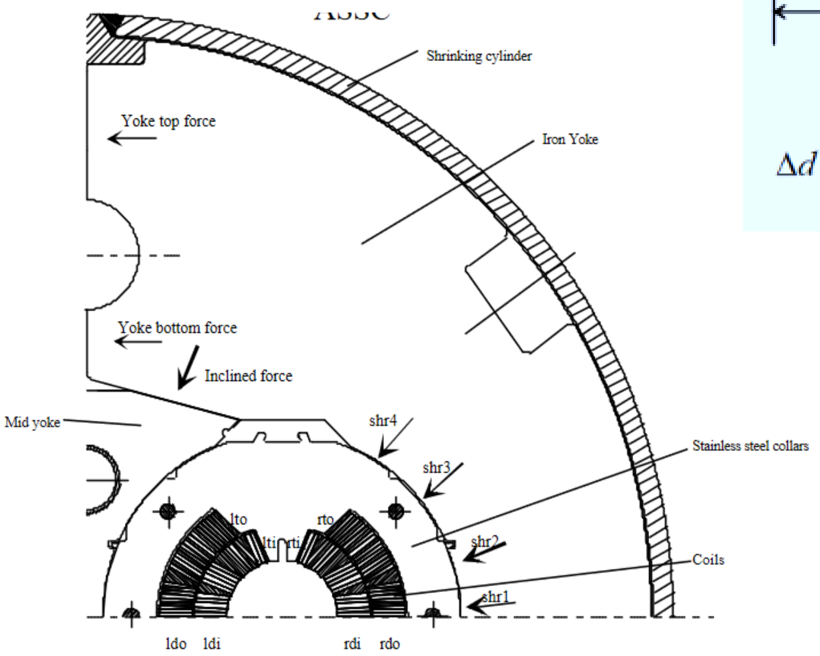
$$\Delta d = 0.149 \cdot \frac{Pr^3}{EJ}$$

$$\Delta d = 0.023 \cdot \frac{Pr^3}{EJ}$$

Qualitative example: the ring plus support as in case b deforms about 7 times less than the ring alone of case a



Close to case a



Close to case b

Some considerations about the assembly process

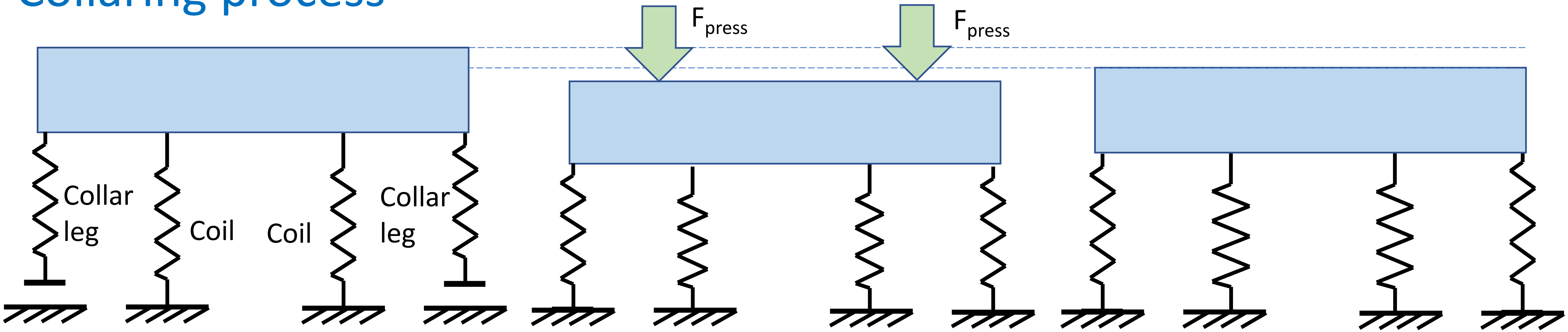
1) Collared coils

- Collaring
- Yoking

2) Bladders and keys

So far, the bladder and keys option has never been used for an accelerator type dipoles. It will be tested in the framework of the HFM project (FalconD – single aperture. 12 T short model – double aperture)

Collaring process



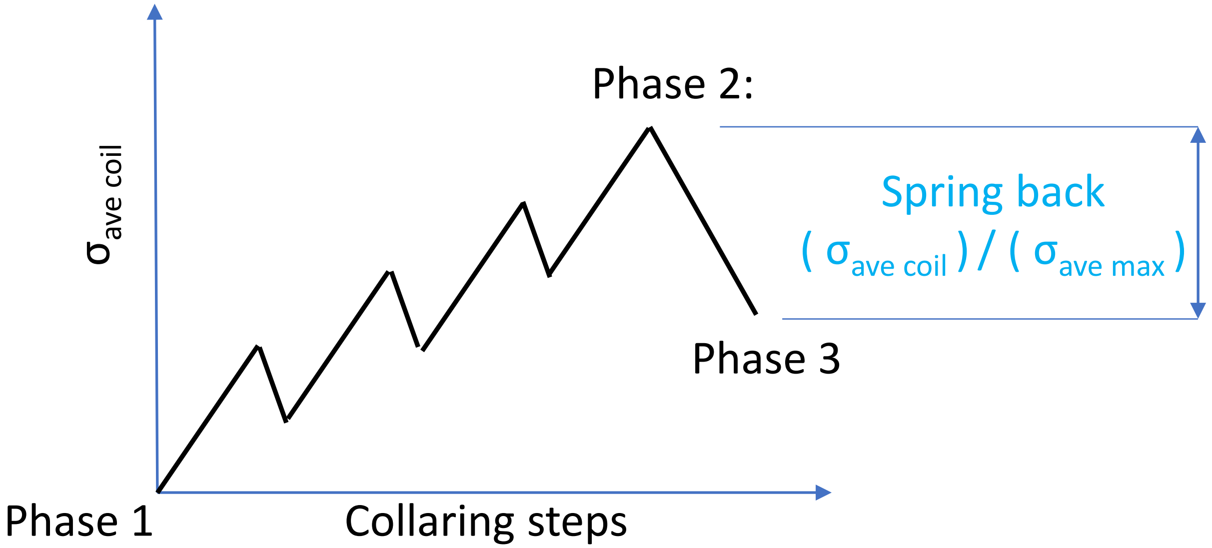
Phase 1: no pression

Phase 2: ready for insertion of keys or rods

In the coils $\sigma_{ave\ max} = F_{press} / A_{coil}$

Phase 3: press release

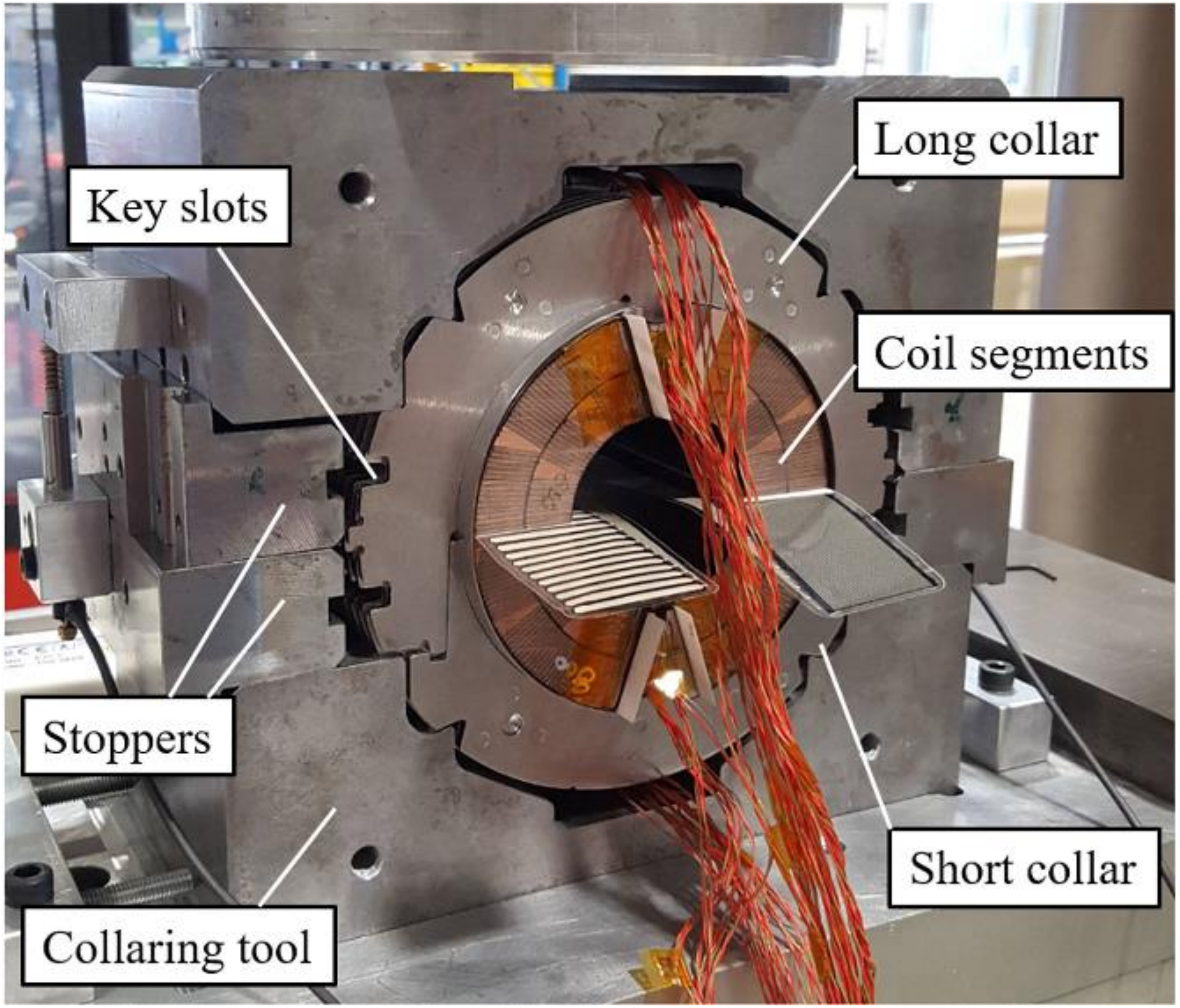
$\sigma_{ave\ coil}\ A_{coil} = \sigma_{ave\ collar}\ A_{collar}$

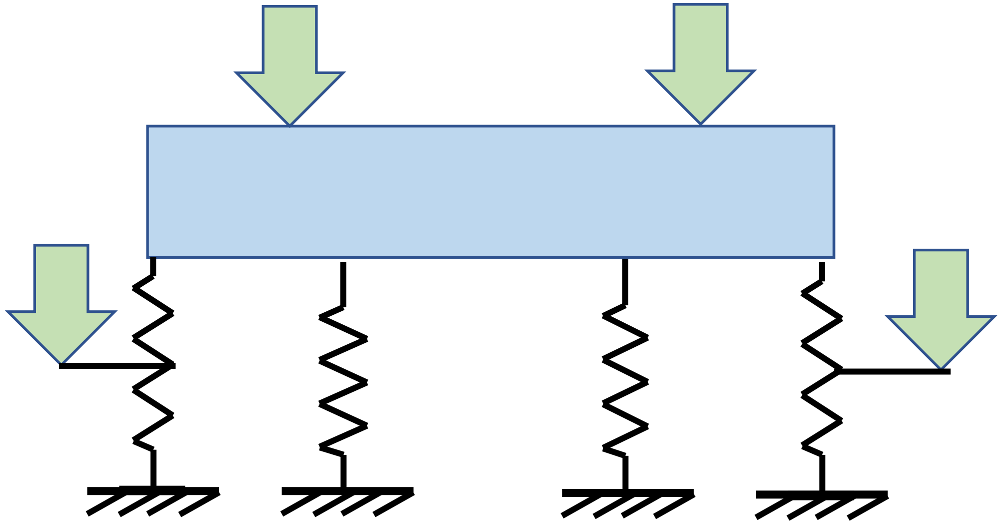


In this simple scheme, the spring back is function of coil size, collar size, coil E and collar E.

BUT

The way the press forces is applied can improve the situation.


Long collar
Key slots
Coil segments
Stoppers
Short collar
Collaring tool



ABOUT THE MECHANICS OF SSC DIPOLE MAGNET PROTOTYPES

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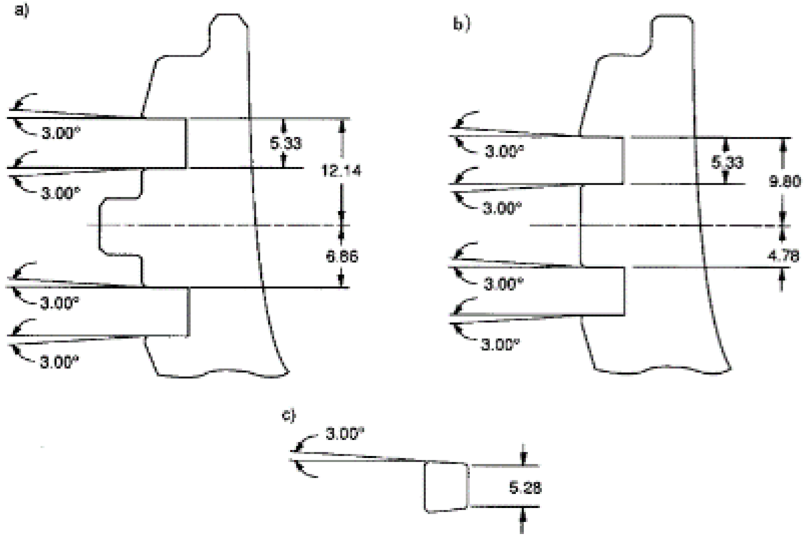


Figure 3. Collar key and keyway designs for most recent BNL 4-cm-aperture, 17-m-long collider dipole prototypes: a) round collar keyway, b) anti-ovalized collar keyway, c) key (the key design is common to the two types of collars).

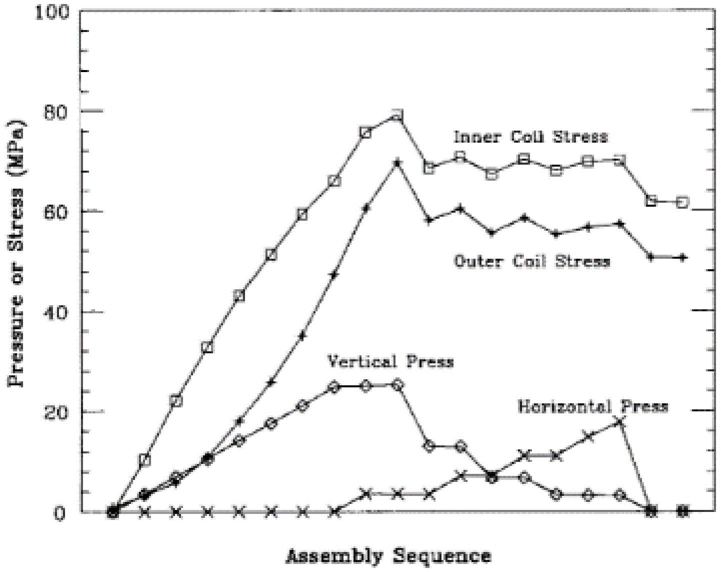
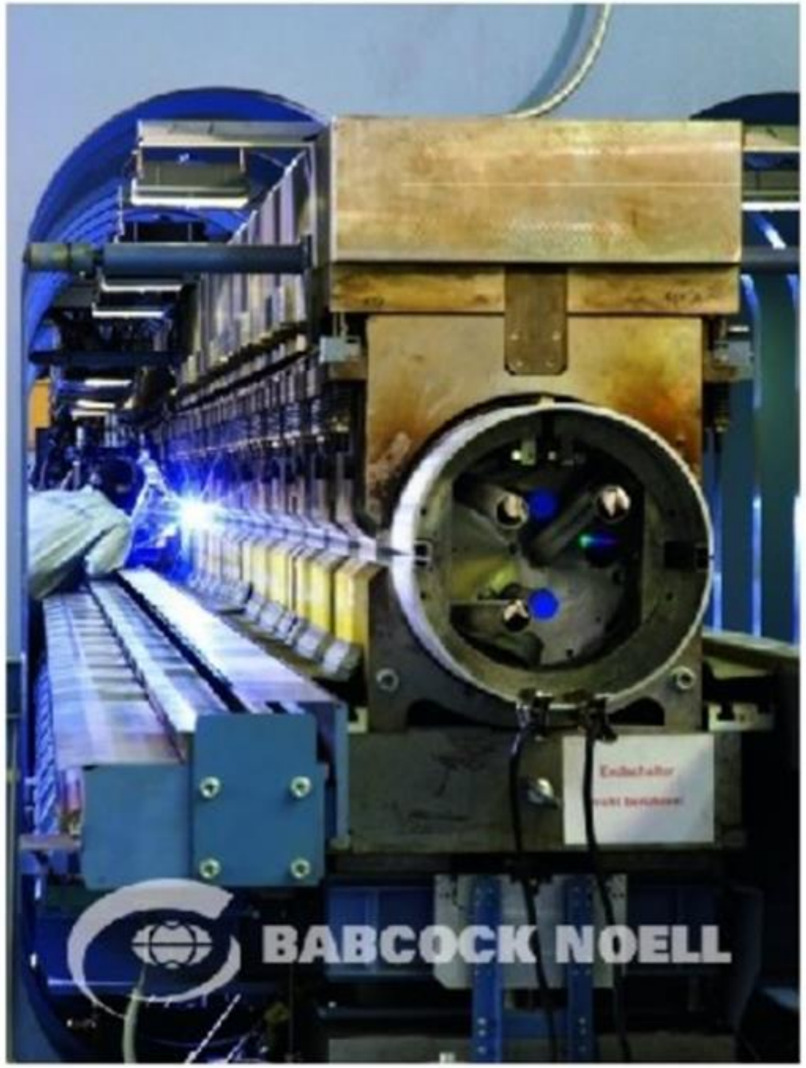


Figure 10. Collaring pressures and coil stresses during the collaring of BNL 4-cm-aperture, 17-m-long collider dipole magnet prototype DC0204. The stress data are averaged over the four coil quadrants.

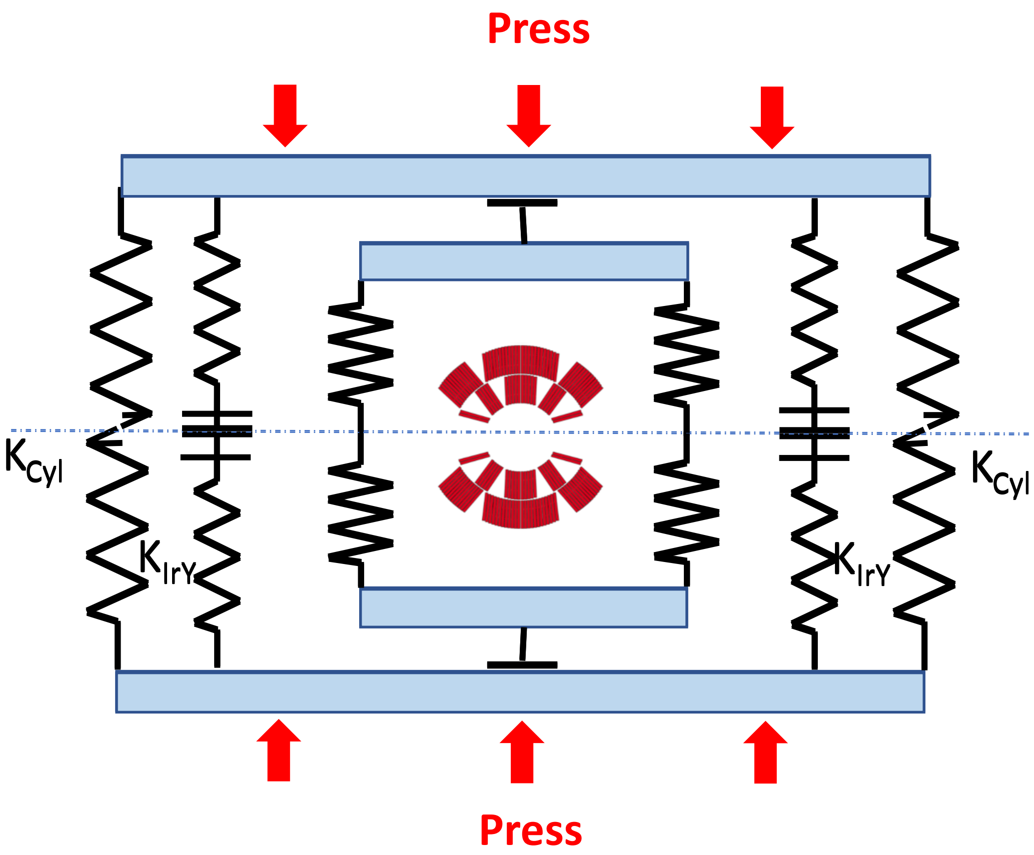
Yoking – welding of external cylinder



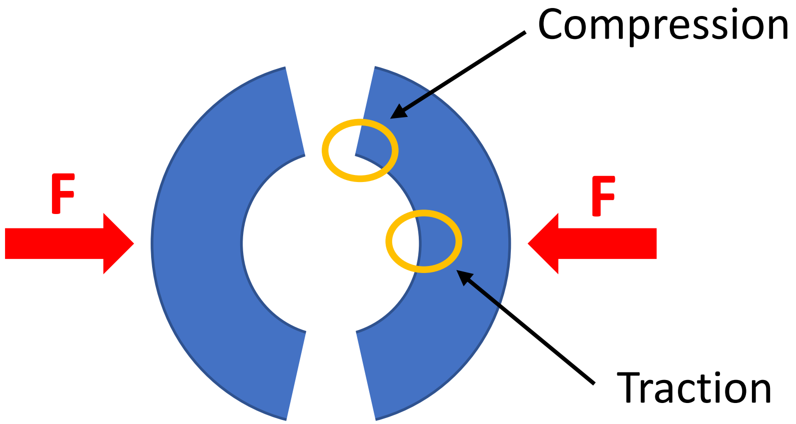
With stainless steel collars the iron gap is closed at room temperature under a press. The external cylinder is welded. The weld shrinkage generates the compressive force between the two half yokes.

Horizontal interference between collars and iron yoke. Compression at the contact between coils and pole in the inner radius

Effect of horizontal interference



- Compression is added at the top inner corner of the coil. This is the first place to loose the contact with the collars at energization.
- Traction is added at the coil midplane inner radius. This is the place where the compression is maximal at energization.

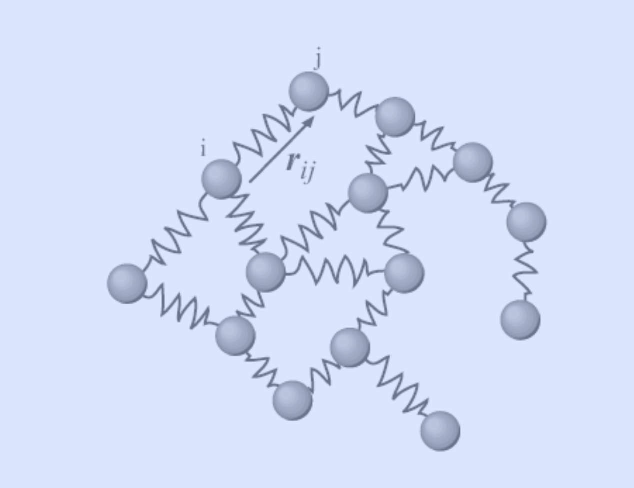


A moderate horizontal interference can help to control stresses in the coils. Easier to implement in case of single apertures.

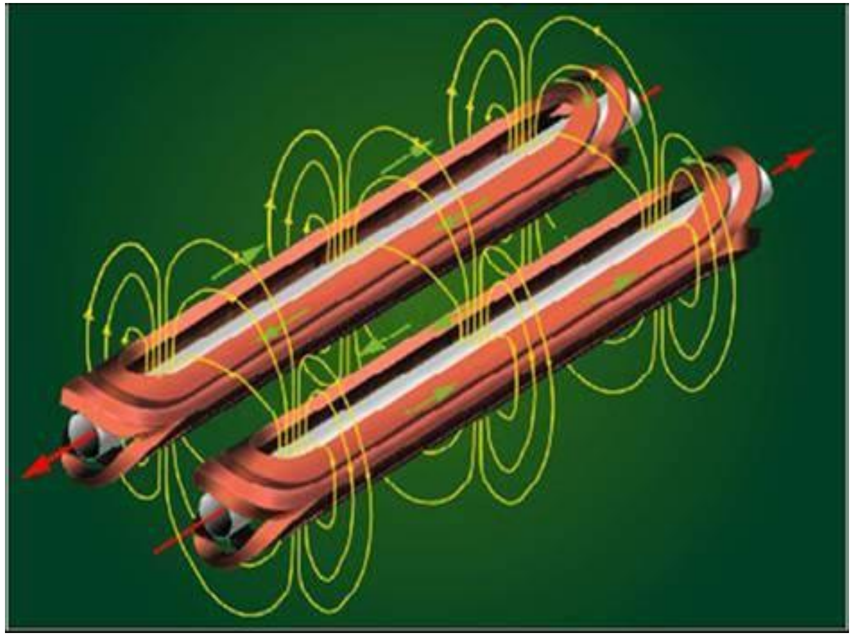
$$\Delta\sigma = \frac{4\,\delta_A\,E\,t)}{(r^2\,\theta^2)} = \frac{K\,\delta_A\,t}{r^2}$$

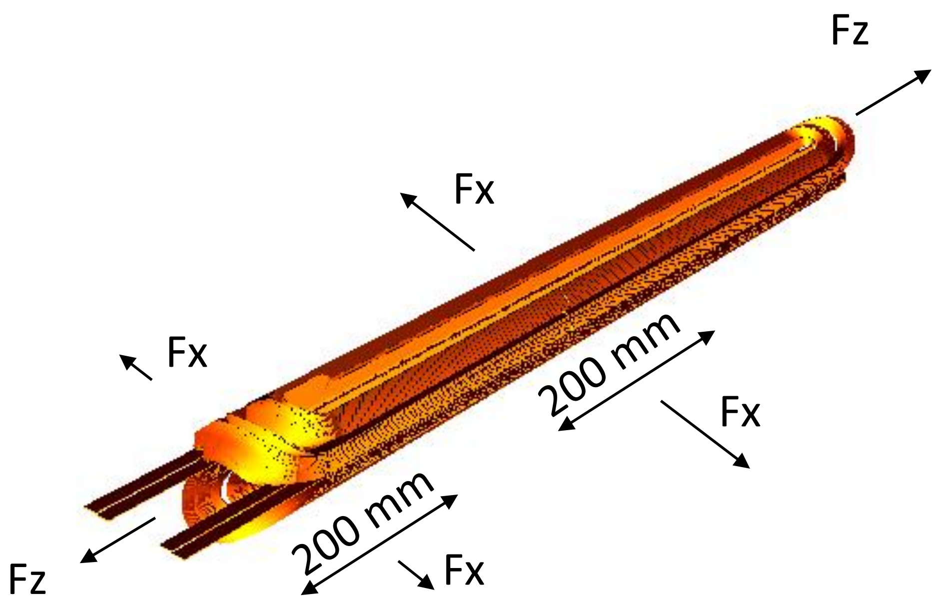
Summary

- Let’s focus on coils
- Support structure to limit stresses and deformations
- Different structures for different applications
- Longitudinal section
- Present and near future, the 12 T robust dipoles
- Conclusions

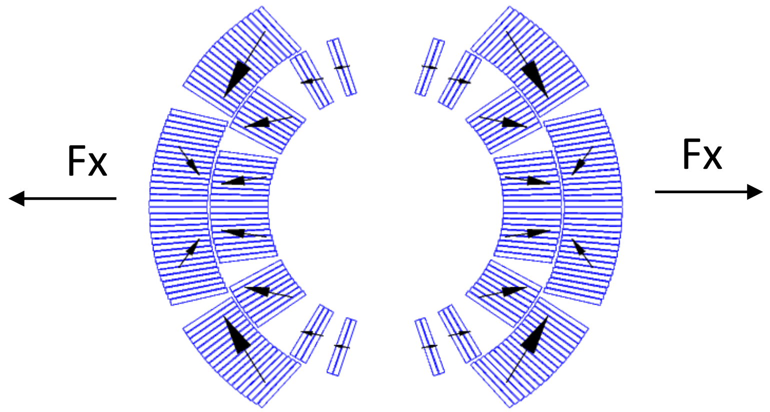


Longitudinal forces





Resulting forces of a 12 T dipole, 50 mm diameter bore

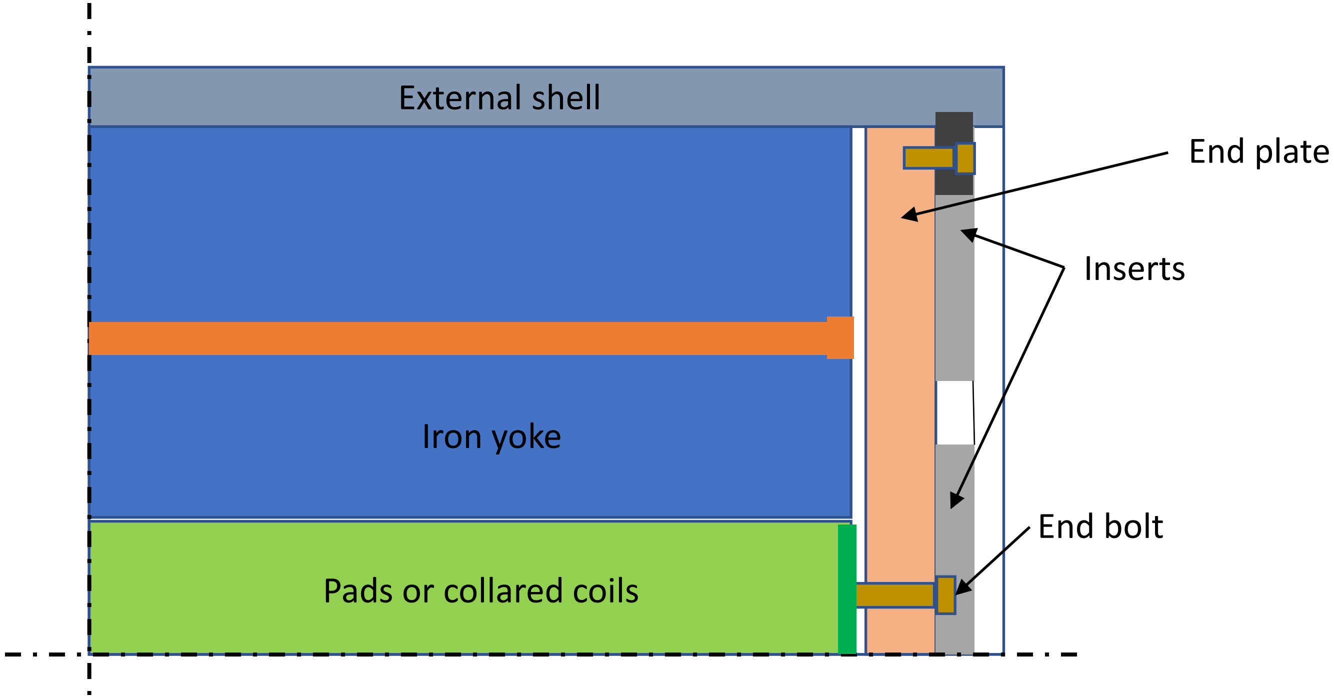


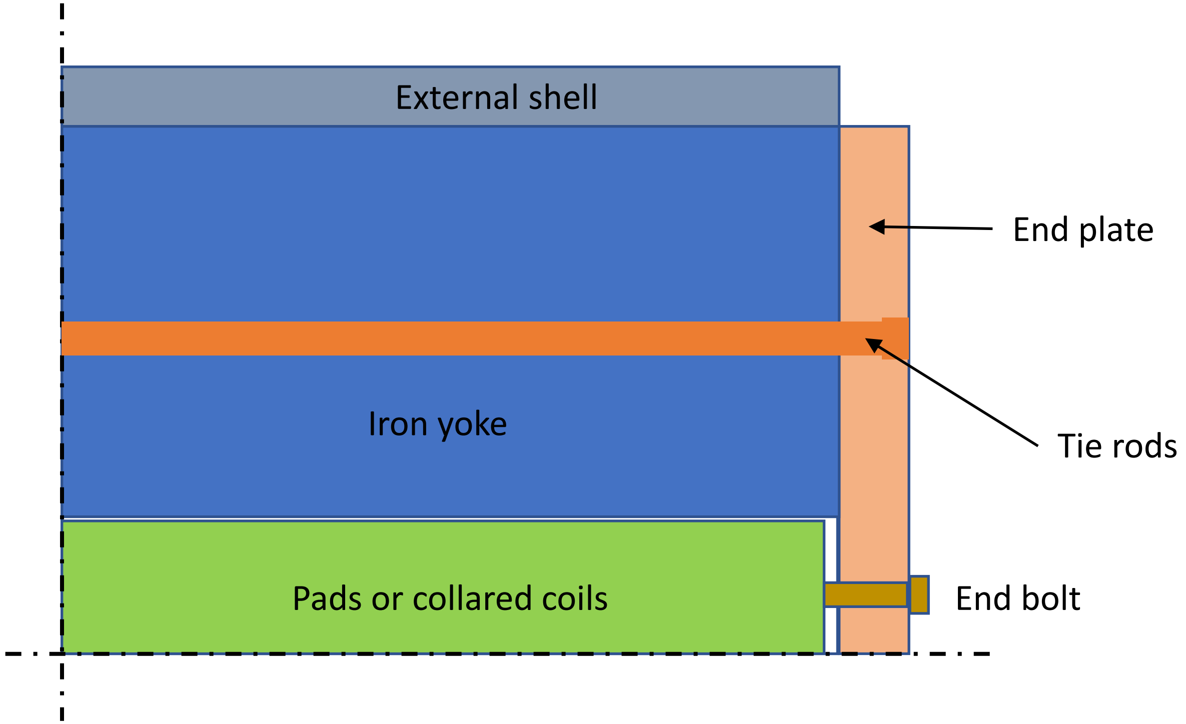
In 200 mm of straight part:
Fx = 1350 kN
Fy = 0
Fz = 0

In 200 mm of ends:
Fx = 440 kN
Fy = 0
Fz = 520 kN

Less azimuthal prestress in the ends respect to the straight parts. Decreasing compression profile. Longitudinal containment of Fz.

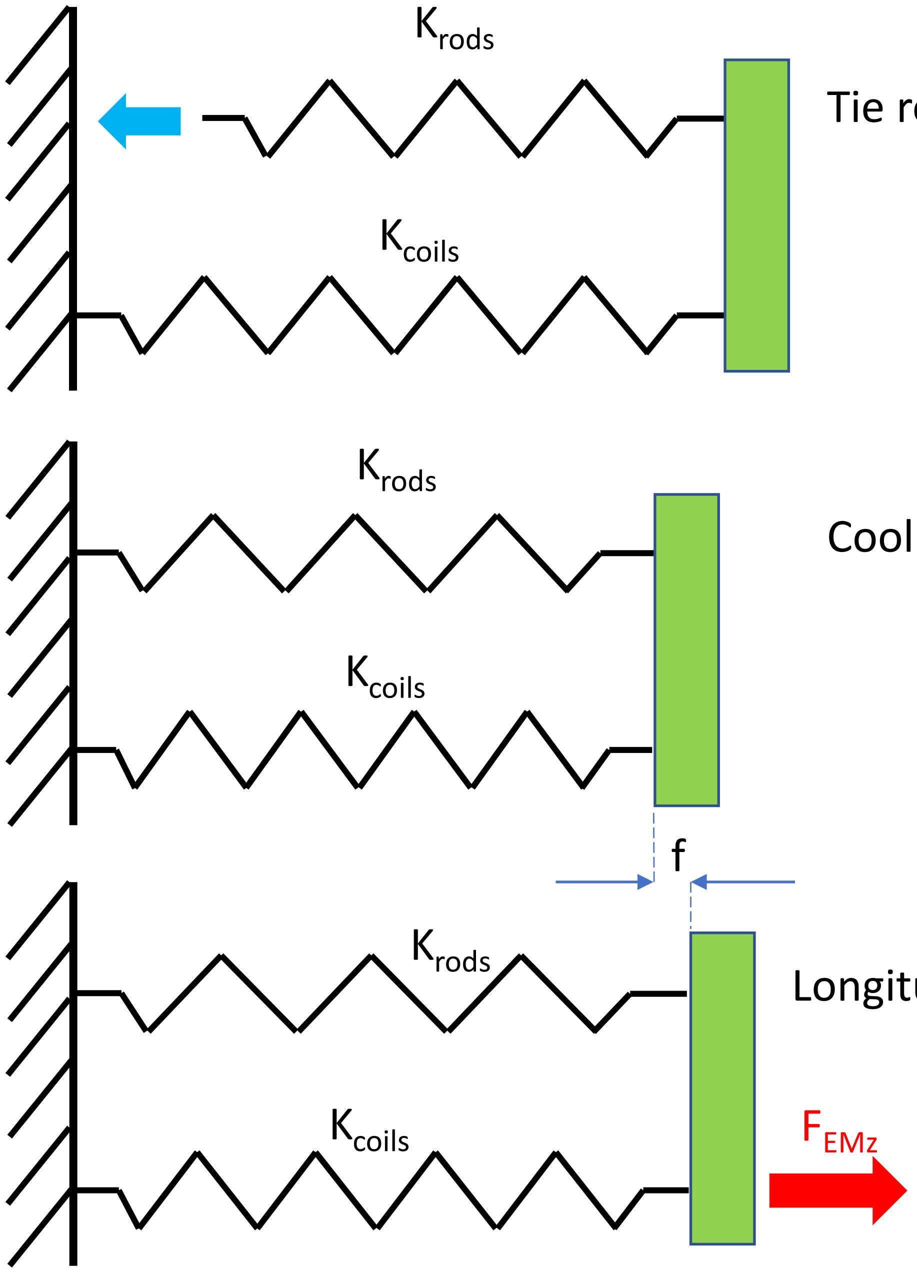
Longitudinal containment
Tie rods (simpler) or external shell (more parts)





The two configurations can give very different results. Particularly in case of long magnets.

Theoretical situation without friction



Tie rods pre-load

Cool down

Longitudinal EM forces

$K_{rods} = (E \times A)/l$

E: Young's modulus of rod material
A: Surface of the rods
l: length of the rods and of the coils

Elongation due to electromagnetic forces (z component)
In case of no friction

$f \times K_{equ} = F_{EMz}$ Independent from tie rod pre-load

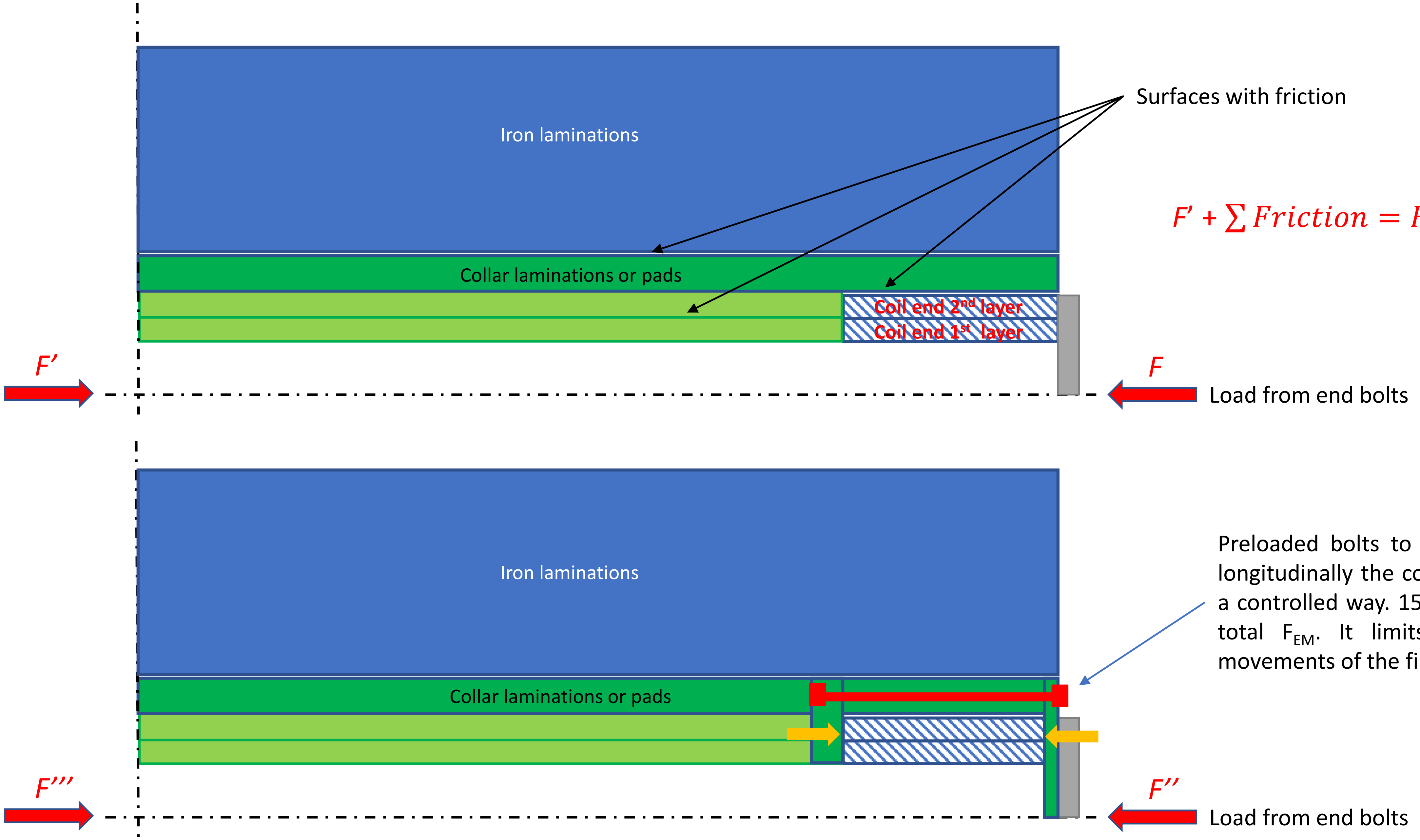
$f = Const \times l$

$l = 1.5$ m for a short model
$l = 10 - 15$ m for accelerator magnets

Long tie rods are less rigid. Heads have larger displacements in long magnets.

The external shell is equivalent to a rod with a very large surface

End cage working principle – longitudinal compression of first turns.



$$F' + \sum Friction = F$$

Preloaded bolts to compress longitudinally the coil ends in a controlled way. 15%-20% of total F_{EM}. It limits relative movements of the first turns.

Summary

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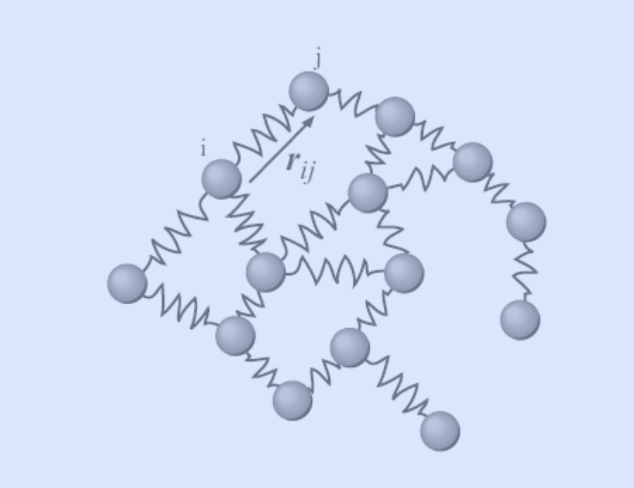
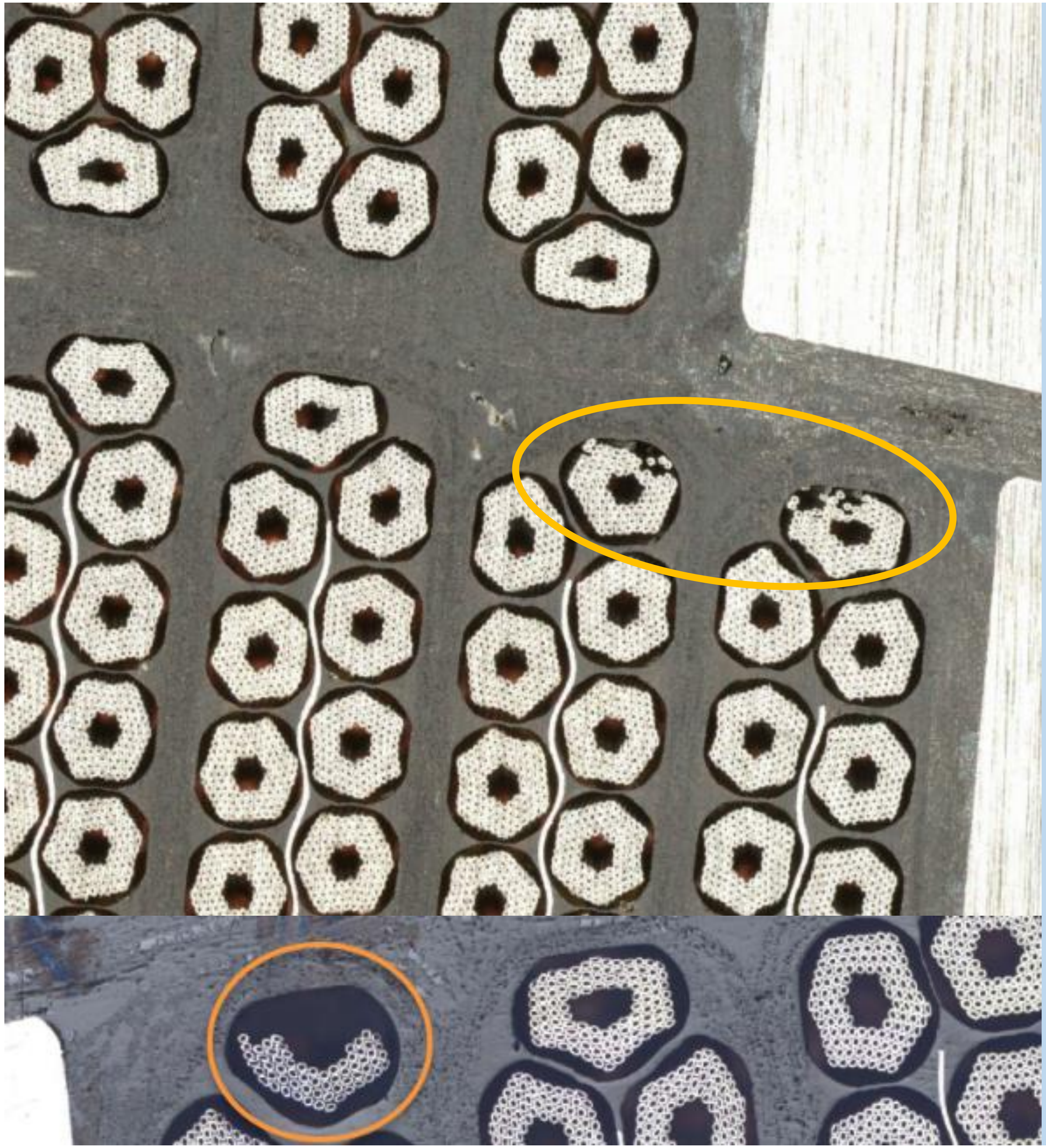




Nb_3Sn is a brittle material.

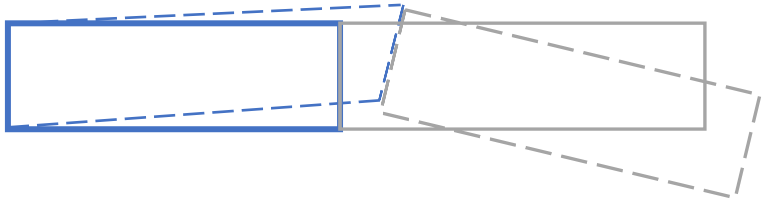
- We have an increasing number of analysis saying that compression in the cable generate cracks and problems during manufacturing can break the filaments.
- Opinions are different concerning the effect of small cracks present in little number. Will the situation evolve during the use of the magnet? Fatigue?
- The first cracks in single cables under pressure arrive at a pressure of the order of 120 - 130 MPa. Then the amount and extension of cracks increases with the pressure.

Decision for the 12 T program:

- σ_{MAX} < 100 MPa at room temperature (and as low as possible)
- σ_{MAX} < 120 MPa at cold during powering

Piling-up tolerances

- Tolerances of size
- Tolerances of shape
- Lever arm effects



A Sum of Gaussian Random Variables is a Gaussian Random Variable

S_n sum of n statistically independent random variables x_i

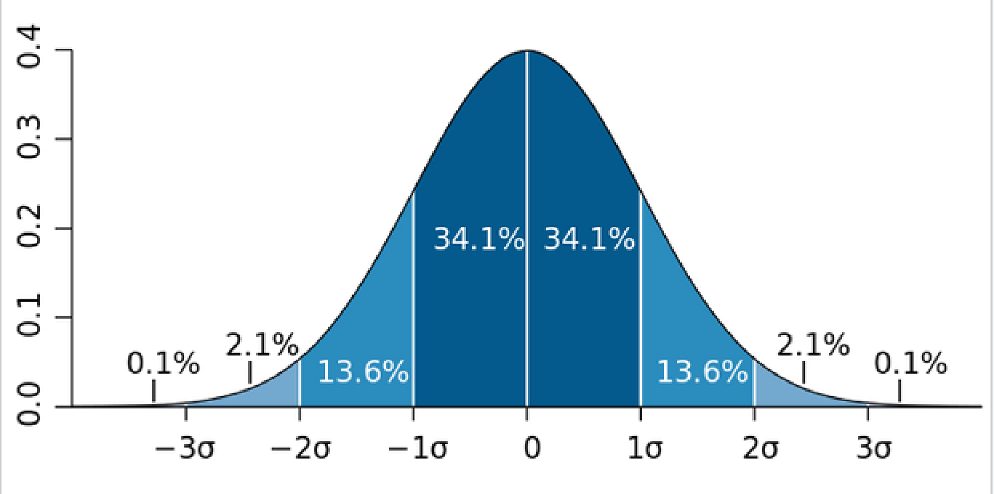
$$S_n \equiv \sum_{i=1}^{n} x_i$$

The mean value of the sum is the sum of the individual means.
The variance of the sum is the sum of the individual variances.

If all the individuals x_i have the same probability density we have:

$$< S_n >= nE_i \ , \qquad Var(S_n) = n\sigma_i^2$$

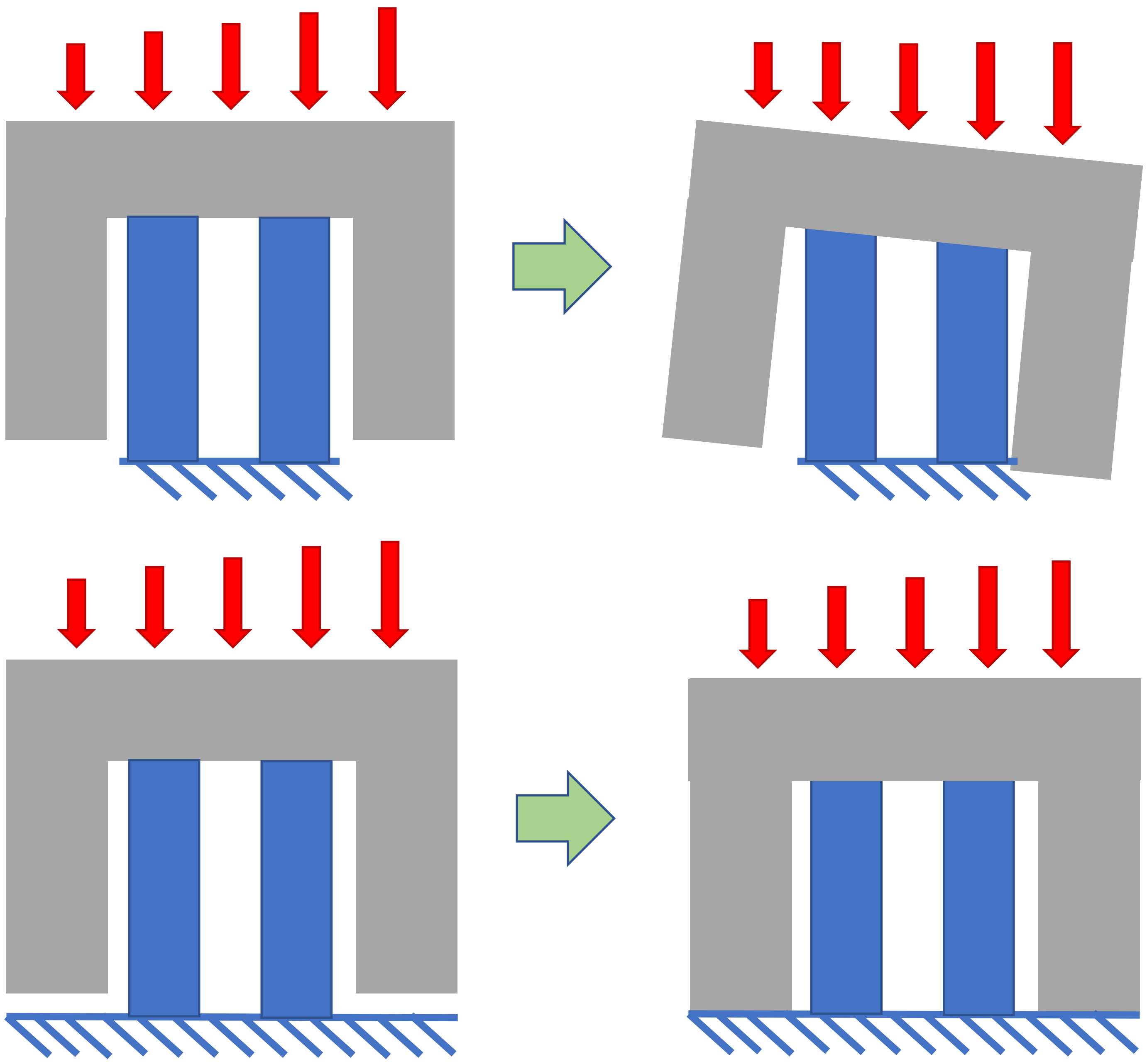
The width of the Gaussian Sn grows as $\sqrt{n}$ while the mean of S_n grows as n (in our case n is the number of tolerances of the pieces of the dipole cross section).



For the normal distribution, the values less than one standard deviation away from the mean account for 68.27% of the set; while two standard deviations from the mean account for 95.45%; and three standard deviations account for 99.73%.

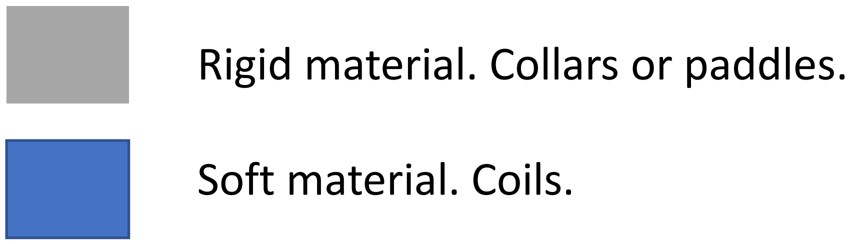
Reduce the number of pieces to be less sensitive to tolerances

Intrinsically safe structures



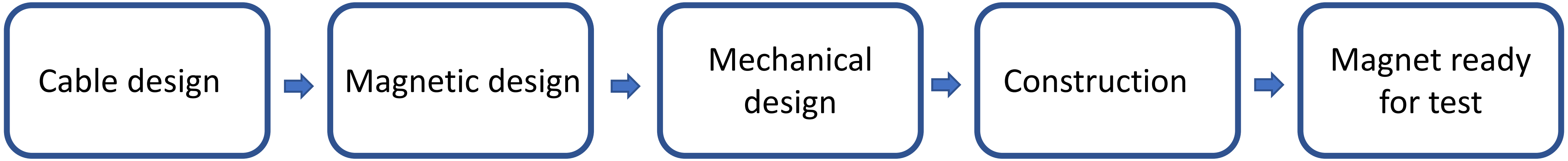
Work with closed cavities (whenever possible)

- To protect the coils from over stresses.
- To control unbalanced stresses. The alignment precision of long presses or long ‘force’ tools is limited.



The design process

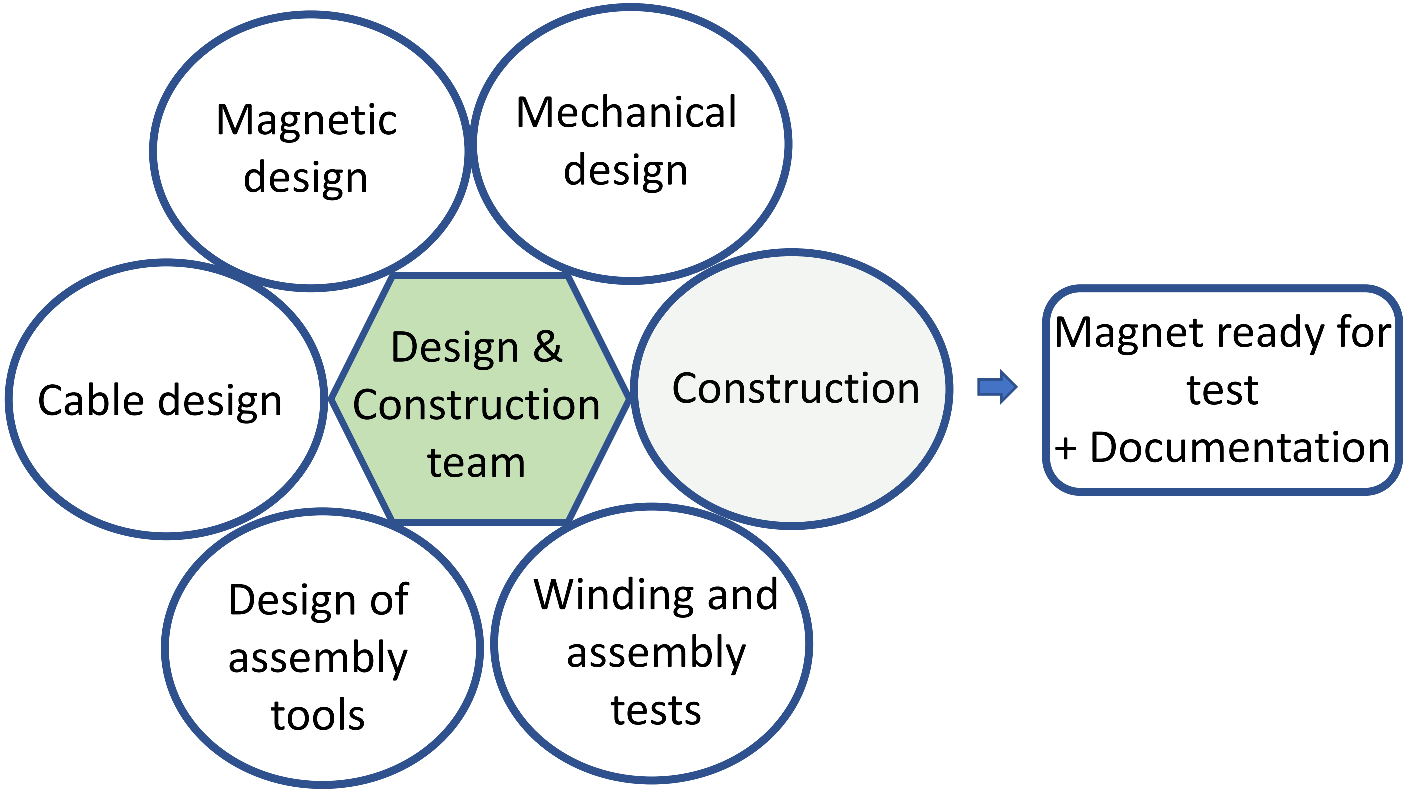
Serial (Cartesian four precepts)



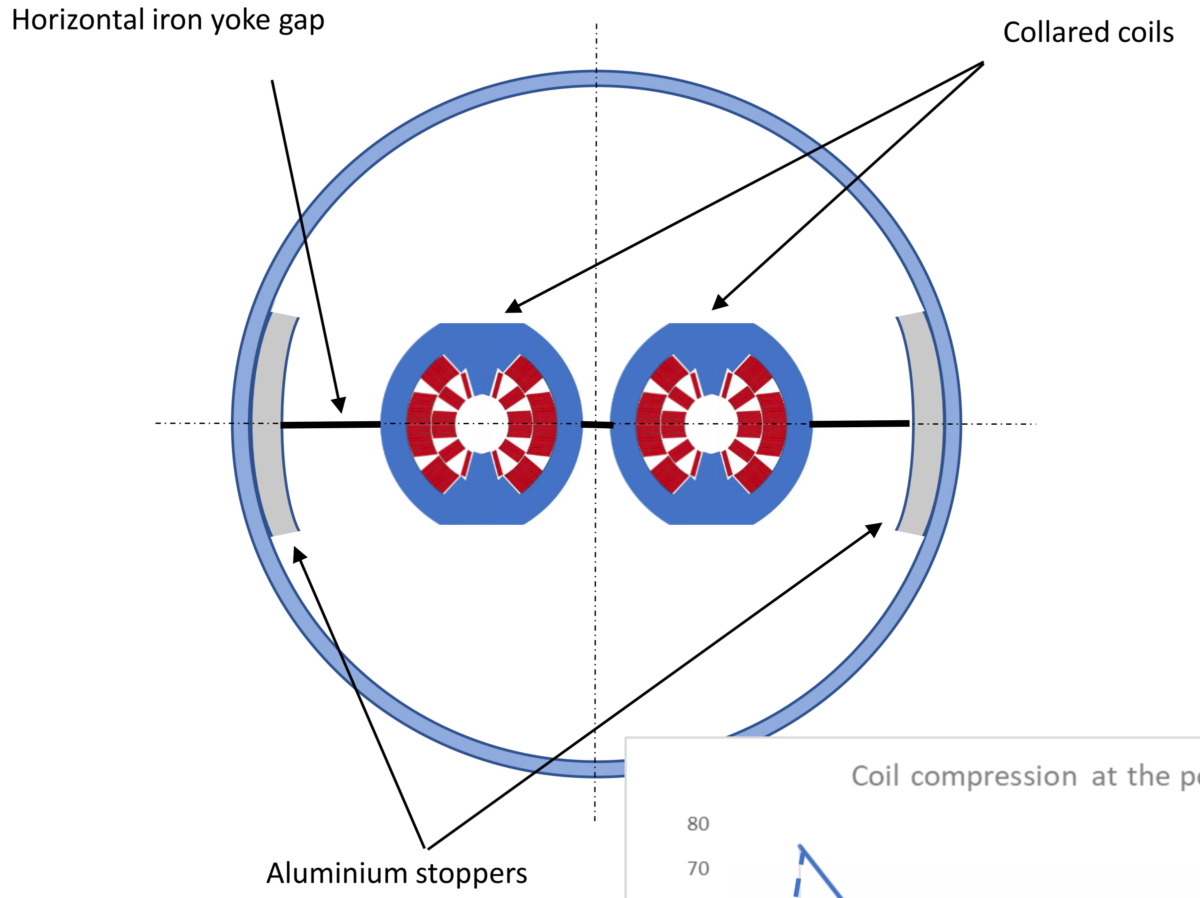
By definition, the Cartesian approach can not manage random events

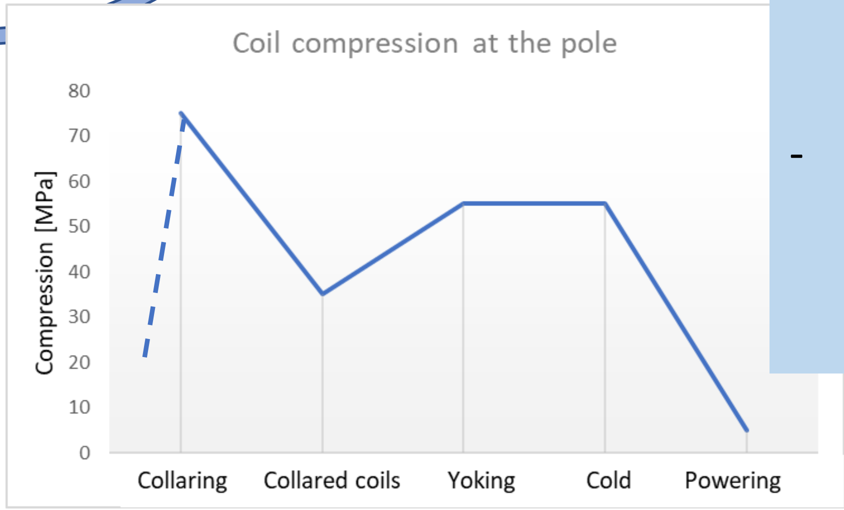
System engineering

ISO/IEC/IEEE 15288: 2015



Collared coils configuration – double aperture

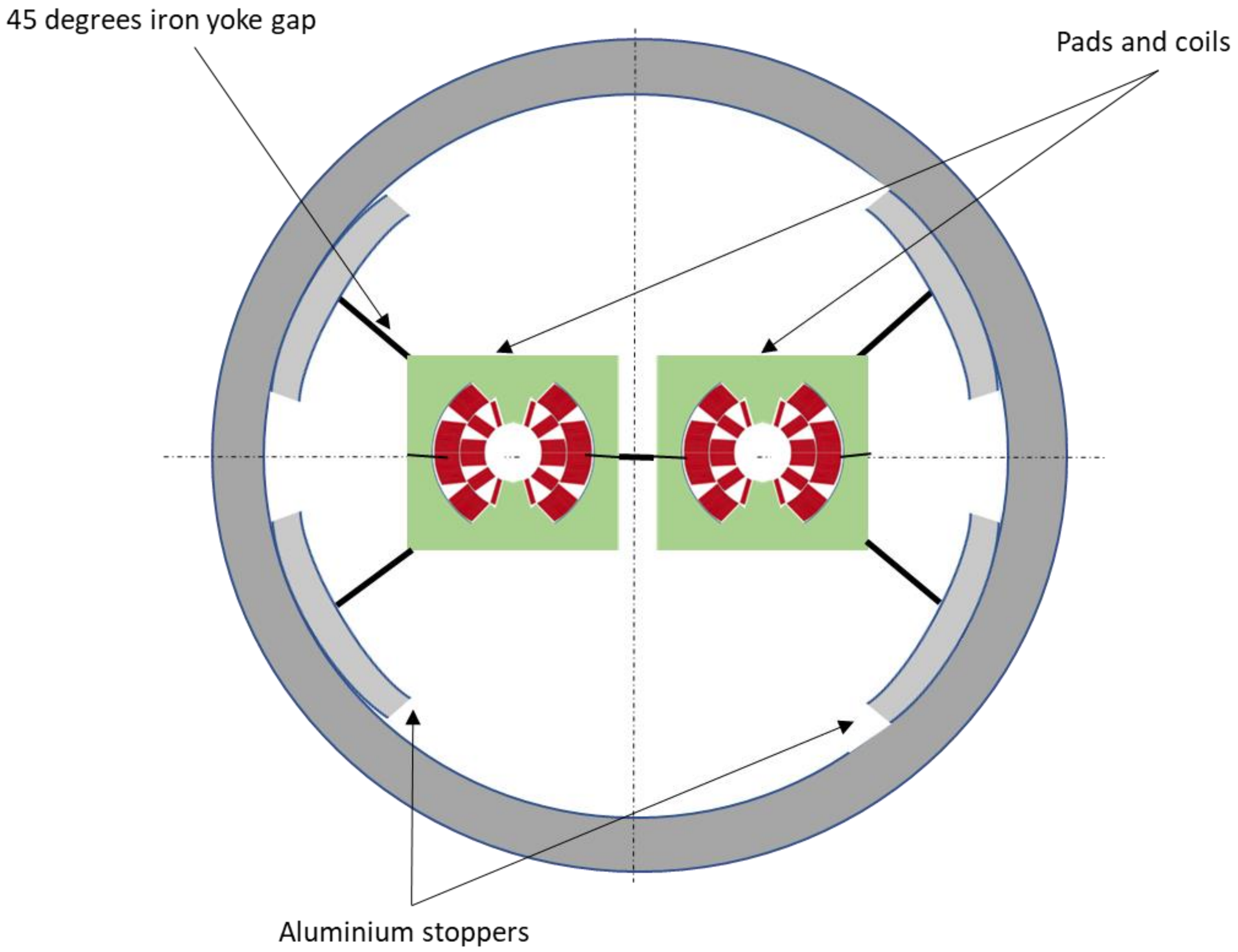




Design guidelines

- Aluminium stoppers (or temporary keys) to protect coils during assembly
- Horizontal iron yoke gap closed at cold
- Moderate coil prestress after collaring 30-40 MPa average
- Average coil prestress after yoking (assembly at room temperature) of the order of 50-60 Mpa
- Average coil prestress at cold of the order of 50-60 MPa. The yoke horizontal gap closes during cool down and the coil prestress stays practically constant

Bladders and keys configuration – double aperture



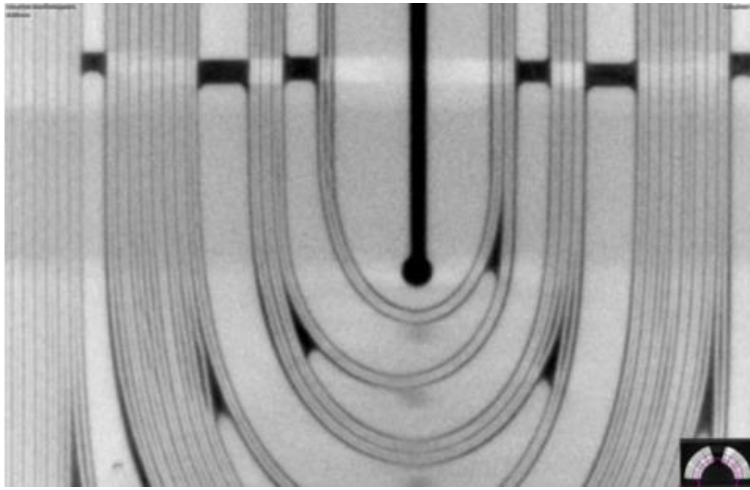
Design guidelines

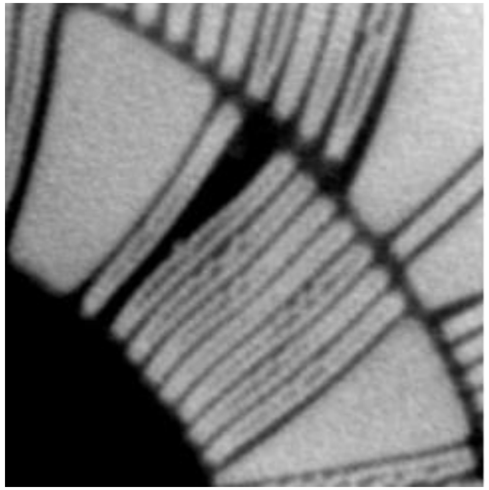
- Aluminium stoppers (or temporary keys) to protect coils during assembly
- Iron yoke gaps (45 degrees or horizontal) closed at cold
- Similar prestress in the coils as in the configuration with collared coils (complete assembly at room temperature, cool down and powering)

Conclusions

Design and construction – good practice

- Design and manufacture good coils.
  - Computations (straight part cross section and ends).
  - **Tests (shape, angles, relative position of end spacers, winding tools, winding machine).**
  - **Optimize the cross section and the end spacers not only in terms of field quality but in terms of coil quality as well (avoid empty spaces, pop-out of strands, cable in wrong position, etc.).**
- Design a good structure (straight part and extremities).
  - Evaluate not only nominal conditions but sensitivity to tolerances.
  - We will build the magnet; put together and align all the parts, control the forces during assembly. Is it 'easy' or 'complicate'?
  - And if something goes differently than expected are the coils safe?
- Design and produce all the structural parts. Tight tolerances, $\pm$ 0.01 mm everywhere is not the right way. A structure demanding too much precision is not a good structure.
- Assembly everything as close as possible to nominal conditions without spoiling the coils.
- Documentation. One day someone (else) could need to reproduce the same or a similar magnet.





So, at the end of the day, is better an aluminium collar or a stainless steel collar?

It depends on what we want to do.

In any case, if we do not manage to manufacture high quality coils, we will not go so far.

Thank you!

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