Studies of Single Aperture IR Quad Mechanics

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OUTLINE:

- Φ = 90 mm, stand-alone collars (DC)
- Φ = 110 mm, collars + partial outer shell support (GA)
- Φ = 90 mm, outer shell support (bladders & keys) (SC)
- “Octagonal-collar” concept (NA)
- Conclusions and plans

Magnetic forces

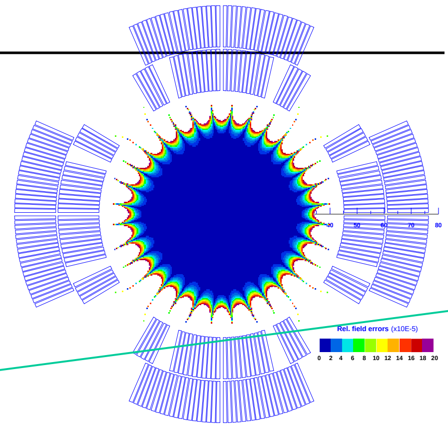
- Forces at 228 T/m (per octant)
  - 24 % margin (forces)
- 90-mm 2L quad has 23% higher forces than present HGQ
- 110-mm 4L quad has 139% higher forces than present HGQ

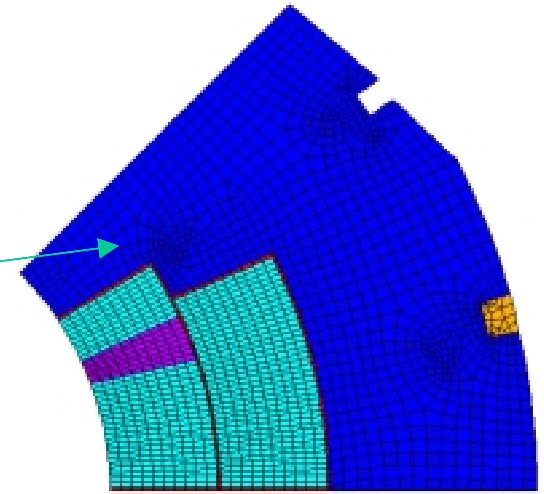
- Forces @ 228 T/m

	HGQ† (MN/m)	90 mm 2L (MN/m)	110 mm 4L (MN/m)
F_X	1.6	1.9	4.2
F_Y	-1.9	-2.4	-4.1

† KEK design scaled to 228 T/m

Φ = 90-mm – stand alone collars†



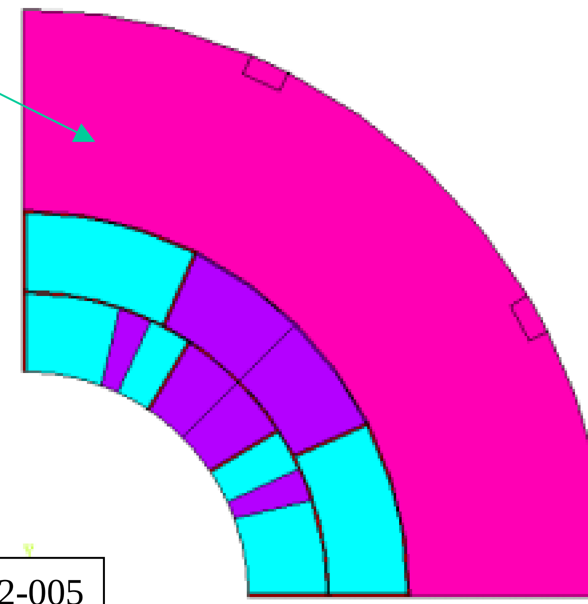


Mechanical design concept:

Stand-alone collars

30-mm thick stainless steel

- **1st: pole is part of the collars**
  - Same design of present HGQ
- **2nd: ring-collars (pole stays with coil)**
  - Compatible with FNAL cosθ fabrication tech.
  - Smooth transition from straight section to ends

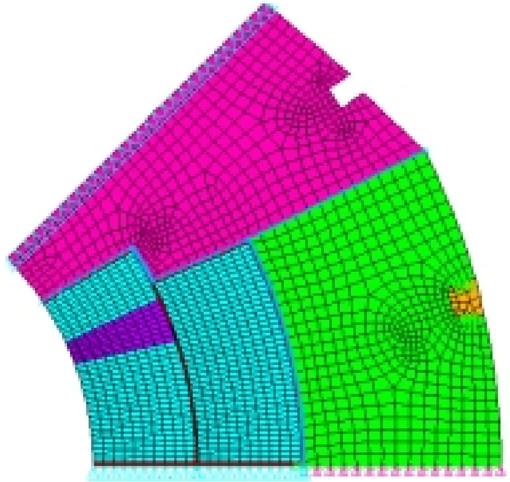


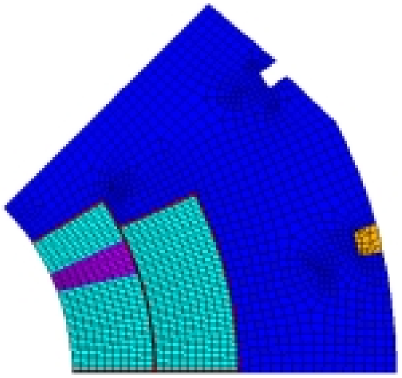
Criteria:

- **Peak stress in the coil < 150 MPa**
- **No gaps at 240 T/m (operation + margin)**
- **Max collar stress < than the yield stress**
- **Max coil displacement under Fmag < 0.13 mm**

†D. chichili, *A preliminary mech design and analysis of 2nd generation HGQ*, TD-02-005

90-mm – stand alone collars – 1st design

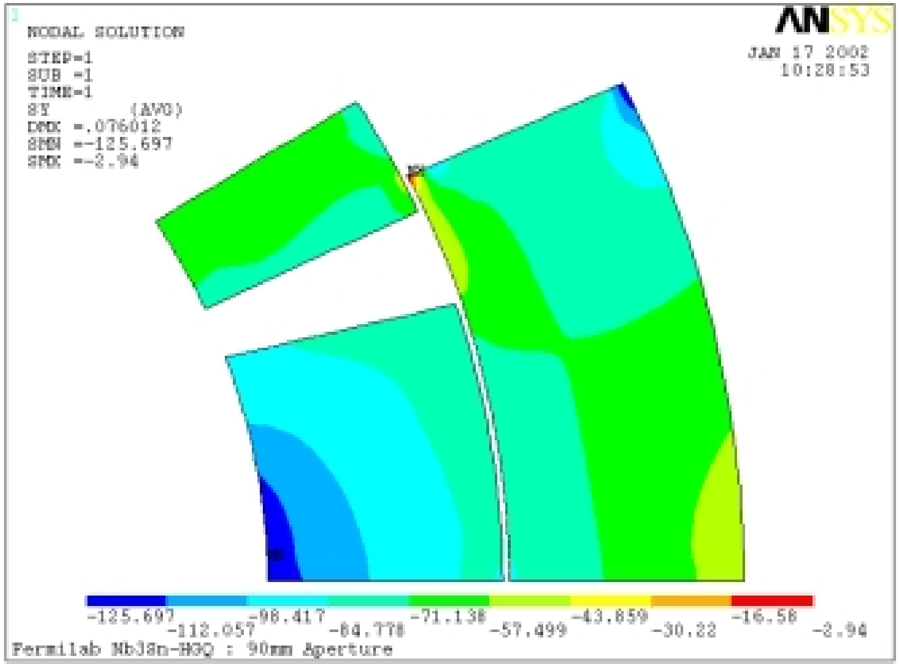




- **Features of the model:**
  - **Simulate laminations:**
    - 2 collar layers
    - Symmetry BC, Coupling,
  - **Pre-stress by azimuthal interference: 75 µm**

- **All steps analysis:**
  - **During collaring (max at 300 K)**
    Keys inserted w/out force
  - **After collaring (spring back)**
  - **At 4.2 K**
  - **At Fmax (240 T/m)**

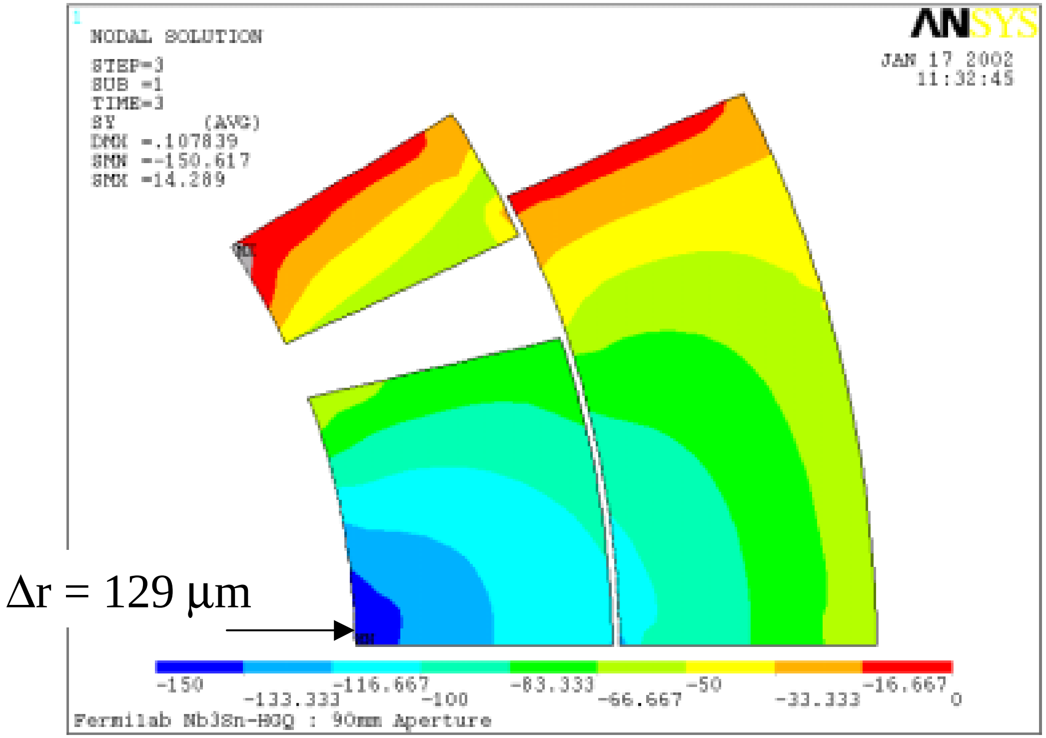
Azimuthal stress distribution in the coil before spring back at room temperature



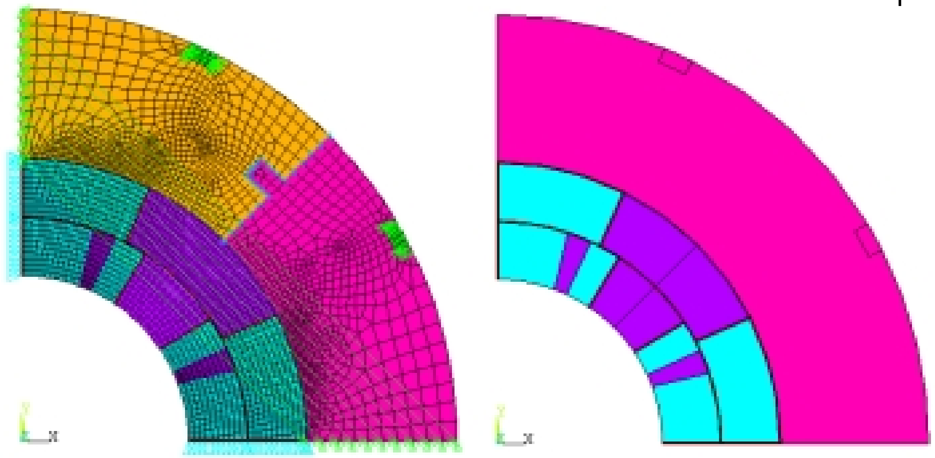
90-mm – stand alone collars – 1st design

- **Pre-stress drops during cooldown:**
  - o **~1/3 is lost**
- **Stress at 240 T/m:**
  - o **< 150 MPa**
  - o **All coils still under compression**
- **Max coil displacement under Lorentz force (240 T/m):**
  - o **129 μm**

Azimuthal stress distribution in the coil at 240 T/m



90-mm – stand alone collars – 2^{nd} design



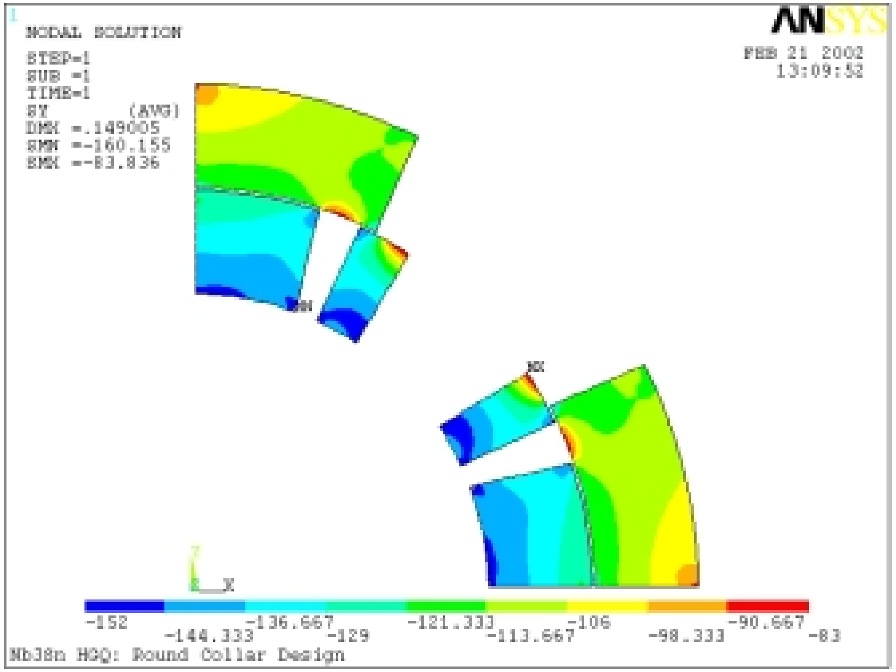
❖ Features of the model:

- **Simulate laminations:**
  - 2 collar layers
  - Symmetry BC, Coupling
- **Pre-stress by radial interference: 150 μm**

❖ All steps analysis:

- **During collaring (max at 300 K)**
  - Keys inserted w/out force
- **After collaring (spring back)**
- **At 4.2 K**
- **At Fmax**

Azimuthal stress distribution in the coil before spring back at room temperature



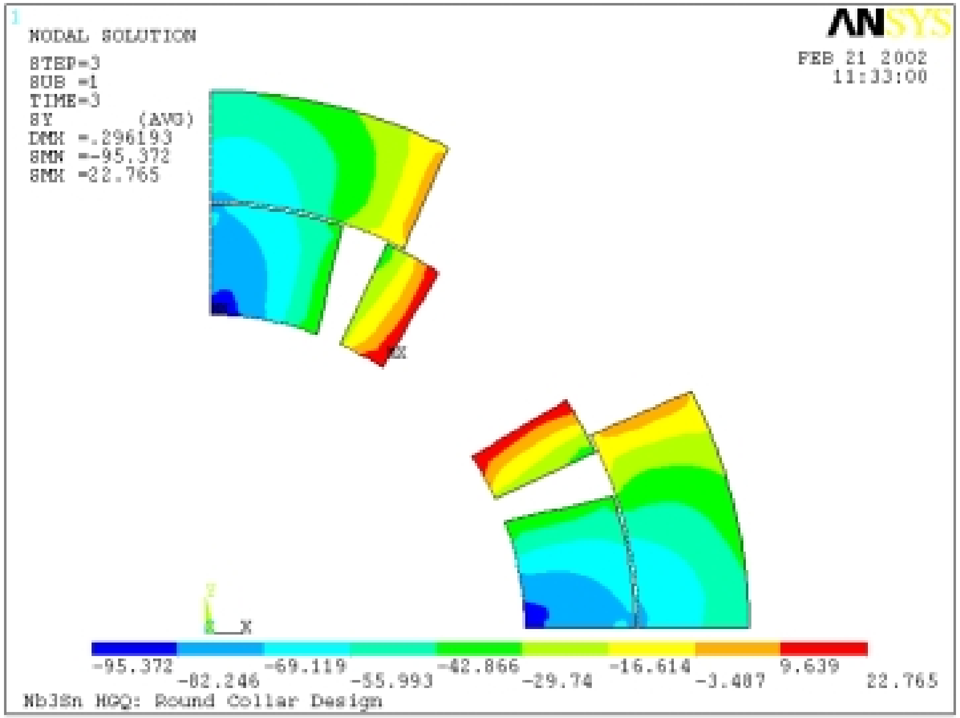
90 mm – stand alone collars – 2nd design

- **Pre-stress drops during cooldown:**
  - **~1/3 is lost**

- **Stress at 210 T/m:**
  - **Max < 95 MPa**
  - **Coil partially unloaded**

    But pre-stress at 300 K cannot be increased

Azimuthal stress distribution in the coil at 210 T/m



90-mm stand alone collars – conclusions

- The 1st design (pole is part of the collars) **meets all requirements**

- The 2nd design (ring-collars) is **too weak** and coils unload at ~200 T/m

  Possible solutions to be explored:

  - The use of tapered keys should allow increasing the pre-stress at room temperature
  - Impregnated collar laminations should increase the stiffness of the collars†

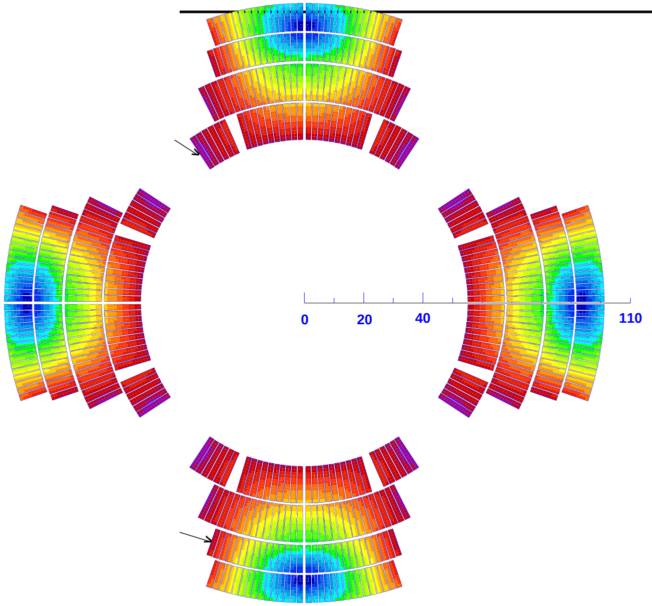
†I. Novitski, et al.,Common Coil Mechanical Model #1, TD-01-074

110-mm aperture – Magnetic forces

❖ **Forces @ 228 T/m**

	HGQ† (MN/m)	90 mm (MN/m)	110 mm (MN/m)
F_X	1.6	1.9	4.2
F_Y	-1.9	-2.4	-4.1
F_R			2.8
F_θ			-5

† KEK design scaled to 228 T/m



❖ **1st shell: F_θ = 1.5 MN/m,**

- **Width = 12.3 mm,**

➔ **σ_θ = 122 MPa**

❖ **Bottom half of coil: F_r = 1.7 MN/m,**

- **E_{r_coil} = 50 GPa, E_{r_ins} = 14 GPa**

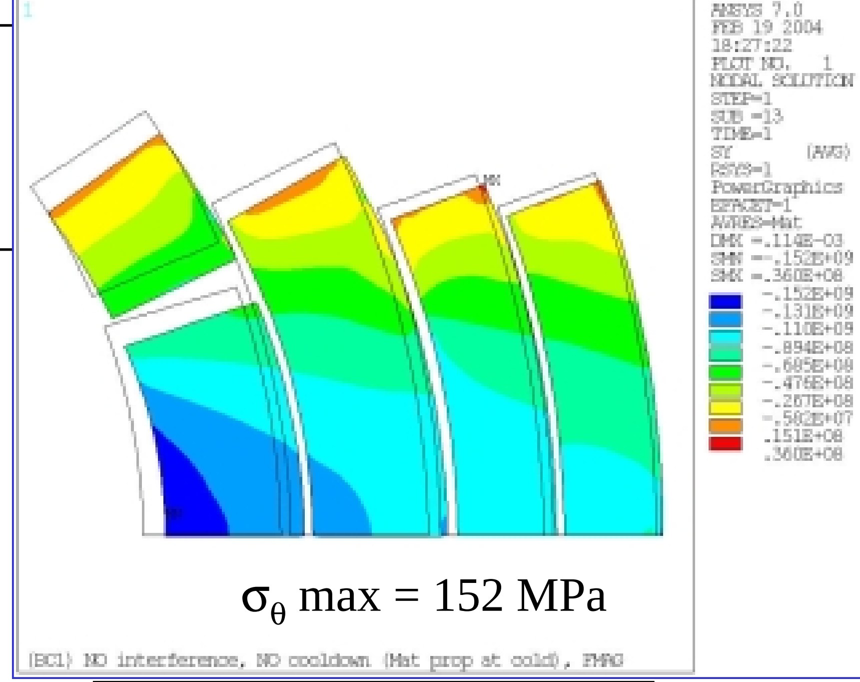
➔ **Δr = 87 μm (average)**

And this deflection is going to increase the stress in the 1st shell!

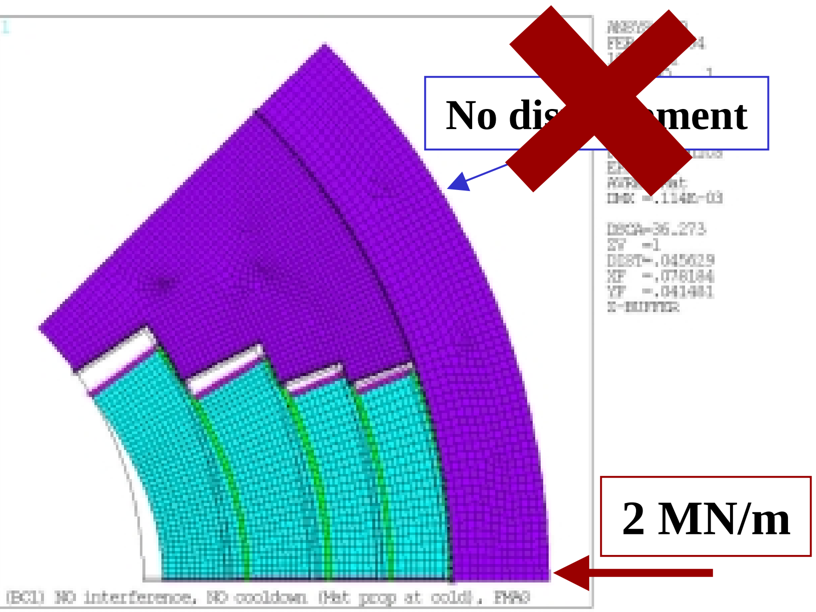
Φ =110 mm preliminary models

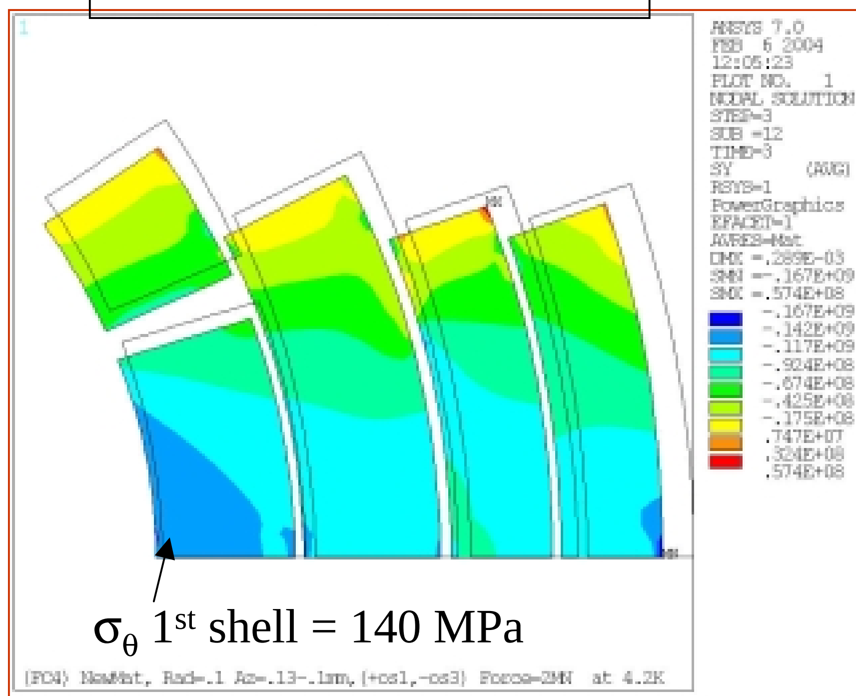
- **Infinitely rigid BC on the outer surface of the collars**
  - o **NO pre-stress**
  - o **Material properties @ 4.2 K**

- **Horizontal force on the midplane**
  - o **With some pre-stress <120 MPa**



Azimuthal stress at 228 T/m





Concept for 110-mm aperture

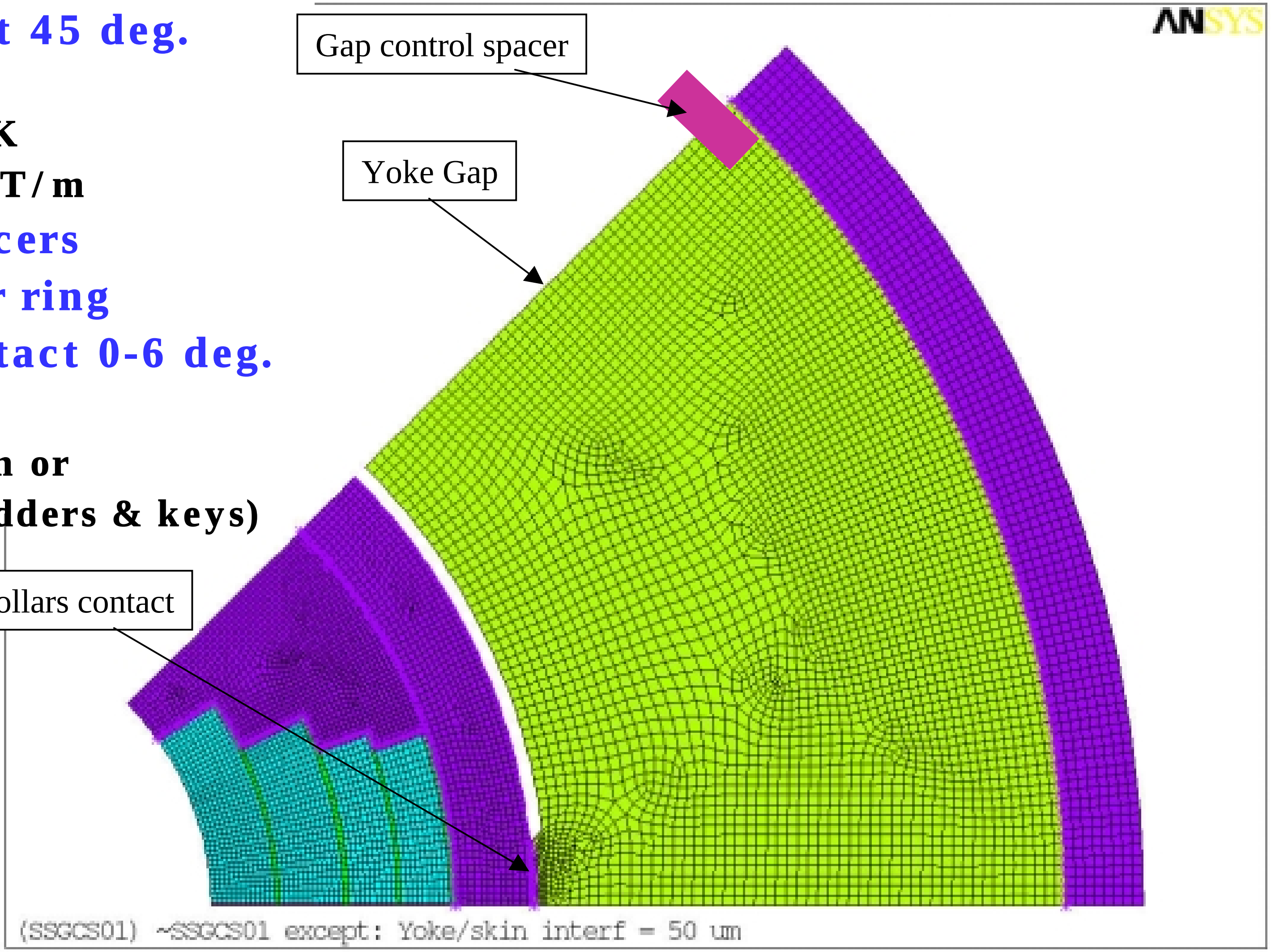
- **Needs:**
  - **Very rigid structure**
  - **Extra force on the mid-planes in order to reduce the coil bending**
- **Solution:**
  - **Almost stand-alone SS collars**
    - Some pre-stress by collars
  - **Additional force on the midplanes from the outer shell**
    - Additional pre-stress **after cooldown**
    - Rigid structure **avoids excessive coil bending**

Model:	***Gap***	***Max Stress***	**Coil displacement:** ***Cooldown – G = 228 T/m***
Thin Al shell (30 mm)	**Closed by key**	**<150 Mpa***	**131 μm**
Thick Al shell (60 mm)	**Open**	“	**153 μm**
Thin Al shell (30 mm)	**Open**	“	**167 μm**
Stainless steel shell (15 mm)	**Open**	“	**158 μm**
Thin Al shell (30 mm)	**Closed**	“	**120 μm**
Stainless steel shell (15 mm)	**Closed**	“	**124 μm**

* Except lowest turn on the outermost coil

Φ = 110 mm – gap closed at 4.2 K

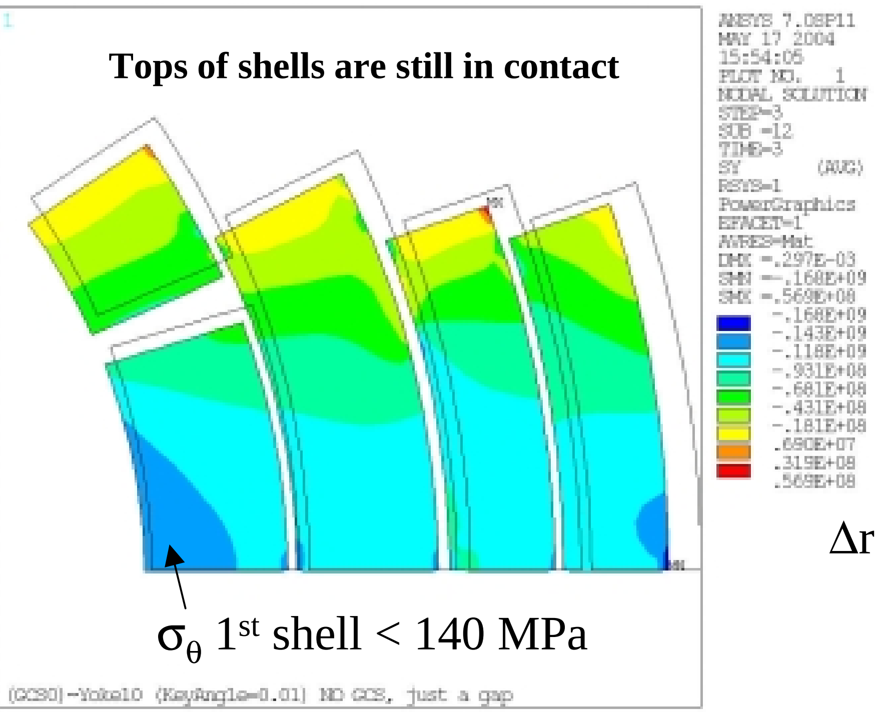
- **Yoke with gap at 45 deg.**
  - **Open @ 300 K**
  - **Closed at 4.2 K**
  - **Closed at 228 T/m**
- **Gap control spacers**
- **15 mm SS collar ring**
- **Collar-Yoke contact 0-6 deg.**
- **Outer shell:**
  - **15 mm SS skin or**
  - **30 mm Al (bladders & keys)**



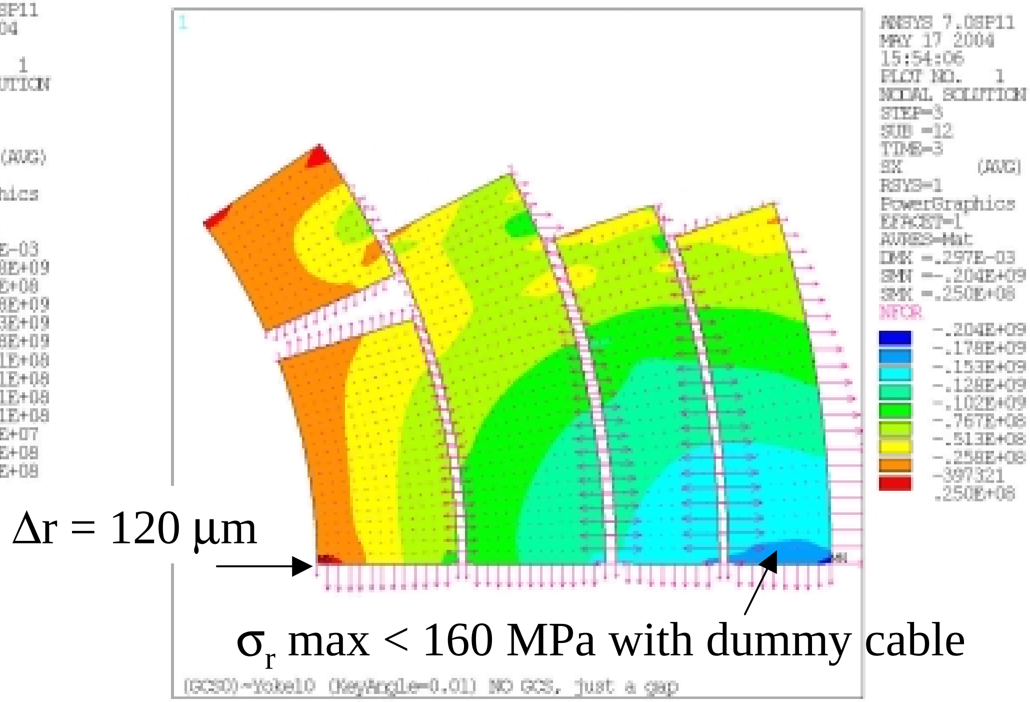
Φ = 110 mm – gap closed at 4.2 K

- **Acceptable stresses at 300 K, after cooldown and at 228 T/m**
- **Acceptable coil displacement under Lorentz forces (Max = 120 μm)**

σ_θ at 228 T/m



σ_r at 228 T/m



Φ = 110 mm - Conclusions

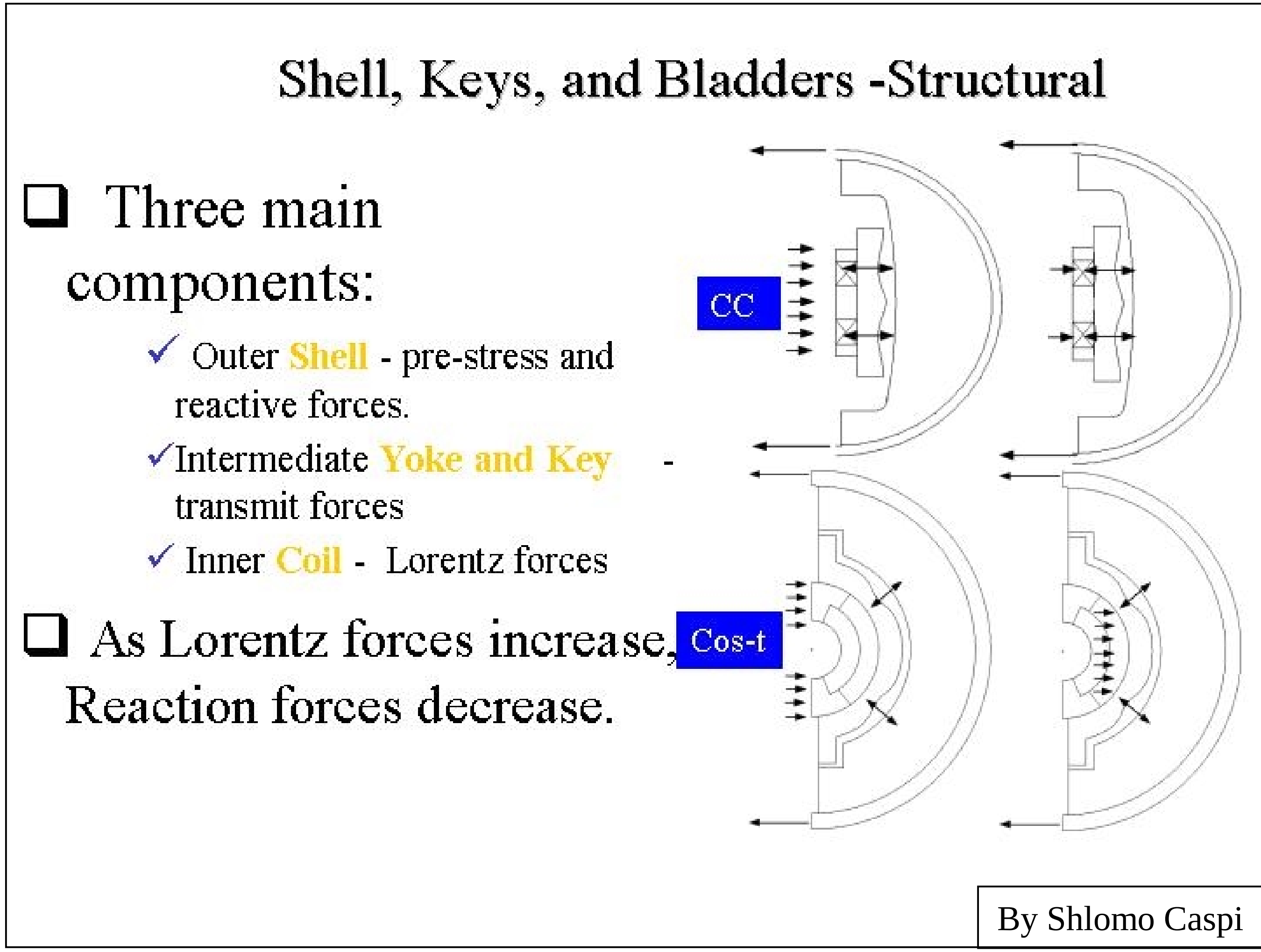
IT CAN BE DONE!!!

- **SS collars + Outer shell support + Yoke gap closing during cooldown**
  - **Stresses < 150 MPa in every condition**
    - Only exception is the midplane turn of the outermost layer that could be replaced by a dummy turn
  - **Gap Control Spacer will assure proper gap dimension at room temperature**
    - CERN demonstrated they work well
  - **It's a more rigid structure than with open gap**
    - Gives the minimum coil displacement (field quality)
    - Avoids over pre-stress of the coil
  - **The outer shell can be made of Al (< 30 mm) or SS (< 15 mm)**

90 mm – “bladder & key” tech.

Main features:

- **All pre-stress and support by Al outer shell**
- **Assembly using bladders and keys**



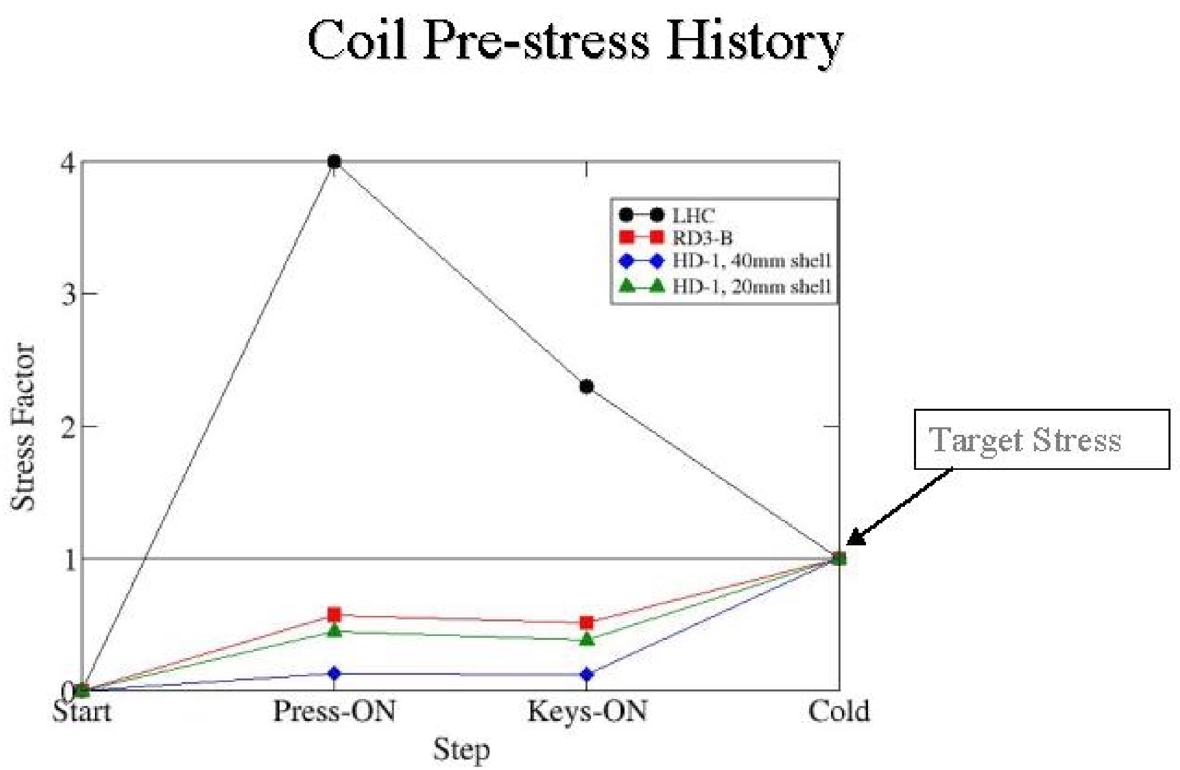
“bladder & key” tech.

Advantages (demonstrated with flat coils):

- **No loss of pre-stress**
- **Simple assembly with good control of prestress**
- **Outer shell may be re-used**

Open questions:

- **Effectiveness on shell-type quad**
- **He vessel**

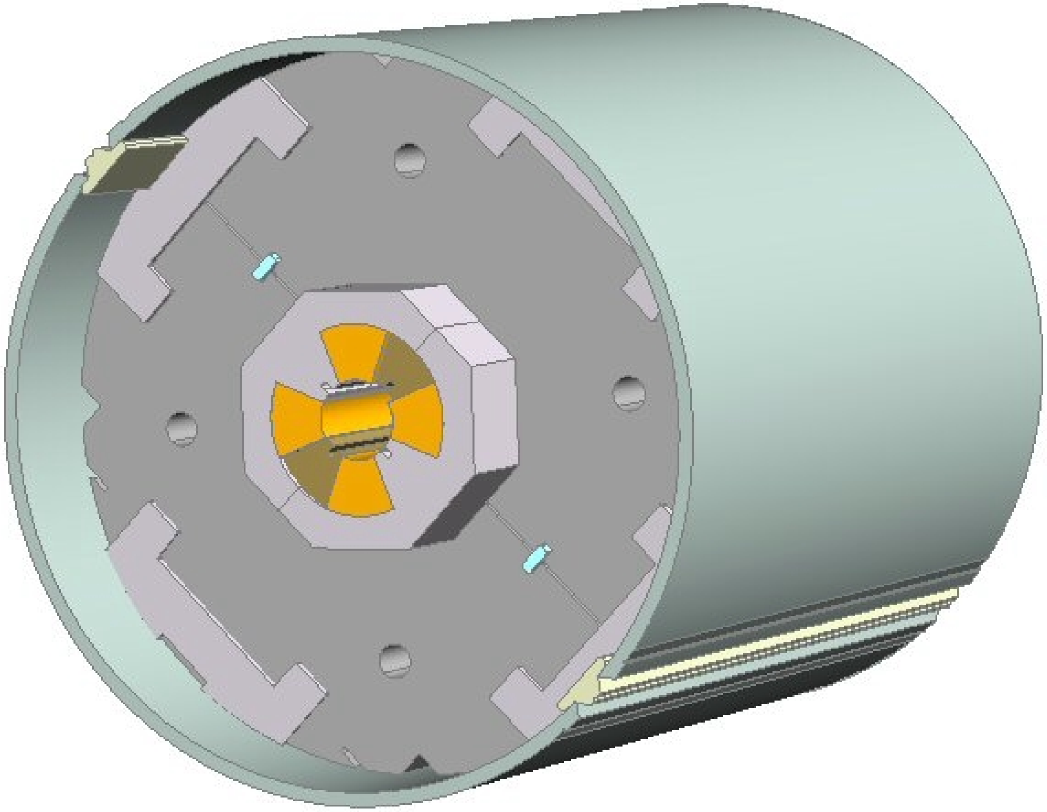


By Shlomo Caspi

"Octagonal collars" concept

Main features:

- **octagonal shape of collars**
  - **collar/yoke interface is stable during cool-down (no angle change)**
  - **this should reduce the coil stress concentration.**
- **alternately split yoke laminations**
  - **will support the coil assembly in two directions.**
  - **gaps between yoke lamination are closed during cool-down and some prestress is created by aluminum clamps and stainless steel skin to keep it closed under Lorentz forces.**



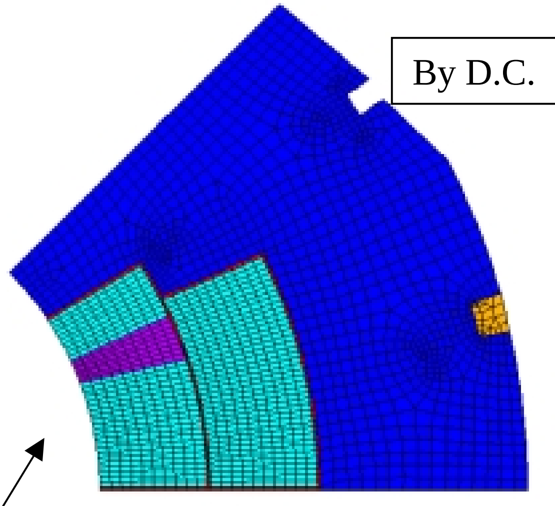
Conclusions

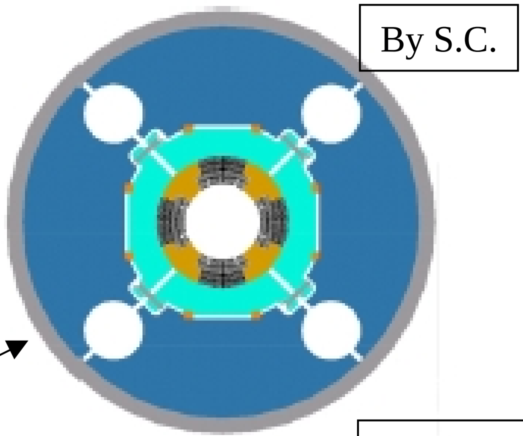
❖ Several designs have been studied, some of them are under further development, some new concepts and technologies will be studied.

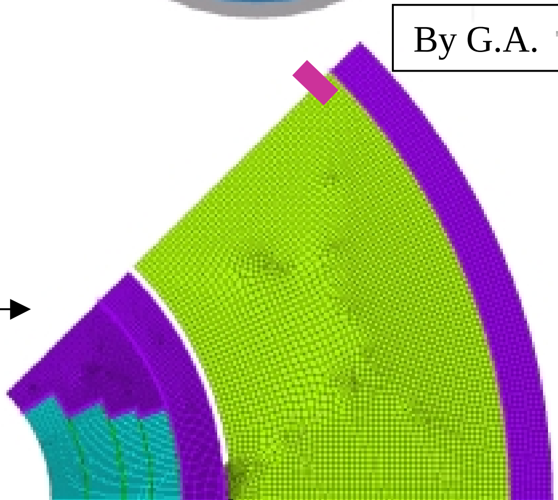
Now we can say that:

❖ 90-mm aperture quad works with:
- Stand-alone ss collars (with pole piece)
- Outer shell (Al) support using bladders and keys

❖ 110-mm aperture quad works with:
- SS ring-collars + outer shell support (Al or SS) on midplanes







Next steps

- First short models will have 90-mm aperture
- Two mechanical designs will be tested:
  1. Al outer shell with bladder & key, w/o collars (TQ4L1)
  2. SS collars with and w/o additional support on midplanes (TQ2L1)
     - 90-mm aperture quad at G≥250 T/m could be used to simulate forces generated in larger aperture quads

These tests are going to show the advantages and limits of each concept. The results will be the base for the design of the final prototype (concept and aperture).

- Meanwhile we will continue to explore alternative concepts (as the "octagonal-collars") and new technologies (as impregnated collars) in order to verify the possible advantages