

DE LA RECHERCHE À L'INDUSTRIE



Développements d'aimants supraconducteurs pour les collisionneurs de particules

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03 octobre 2019

MOTIVATION POUR AIMANTS À HAUT CHAMP DANS LES COLLISIONNEURS DE PARTICULES

Accroître l'énergie de collision des faisceaux

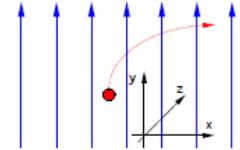


Dipoles pour courber la trajectoire du faisceau

Beam energy

$$E[GeV] = 0.3 \underbrace{B[T]}_{\text{Dipole field}} \rho[m]$$

Bending radius



Accroître la luminosité (le nombre de collisions)



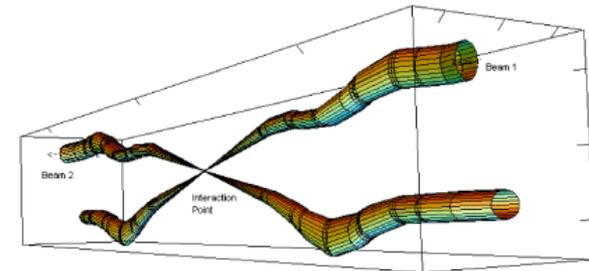
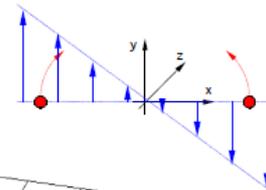
Final focus quadrupoles pour réduire la taille du faisceau au point d'interaction

Peak coil field

$$\underbrace{B}_{\text{Peak coil field}} \ell_q \approx \frac{1}{\sigma^*}$$

Quadrupole length

Beam size at the collision point



Relative beam sizes around IP1 (Atlas) in collision

COLLISIONNEURS CIRCULAIRES EN BREF

Large Hadron Collider

2013 Nobel Prize with the discovery of the Higgs Boson

Reliable operation at 6.5 TeV (13 TeV c.o.m)

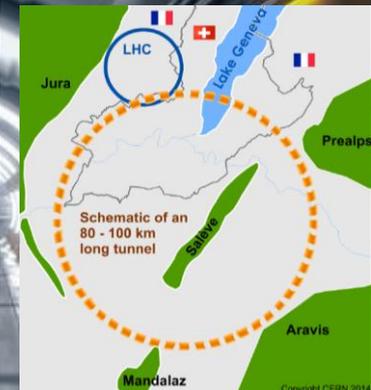
Dipole Bore field: 7.7 T

Target 7 TeV (14 TeV c.o.m)

Dipole 8.33 T

FCC-hh Future Circular Collider

100 km - **16 T**: 100 TeV (c.o.m)



Courtesy of CERN

HL-LHC : High Luminosity LHC

- **Focusing triplet:** Gradient of 132.6 T/m in a 150 mm bore => 11.4 T peak field
- **11 T Bending dipoles** to allow space for new collimators

 **SPPC
Super Proton
Proton Collider**

100 km - **12-24 T**: => 75 to 150 TeV (c.o.m)

Courtesy of Q. Xu, IHEP

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Clément Lorin, Ve 4/10

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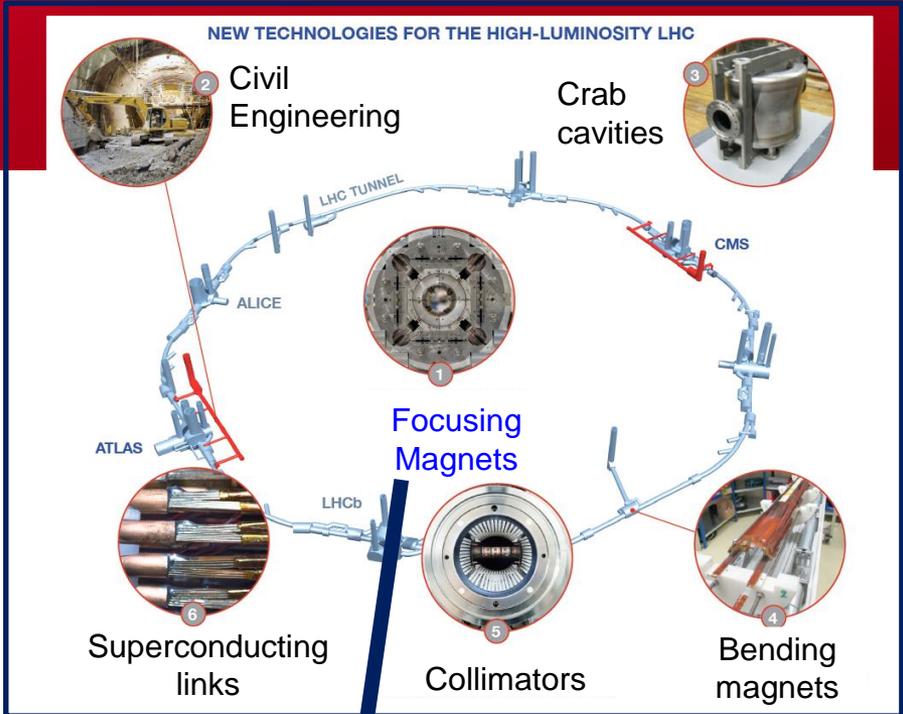
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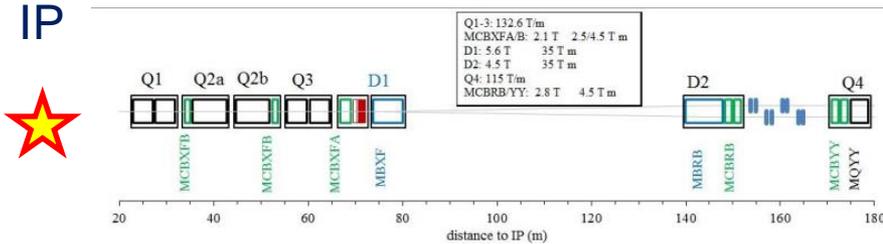
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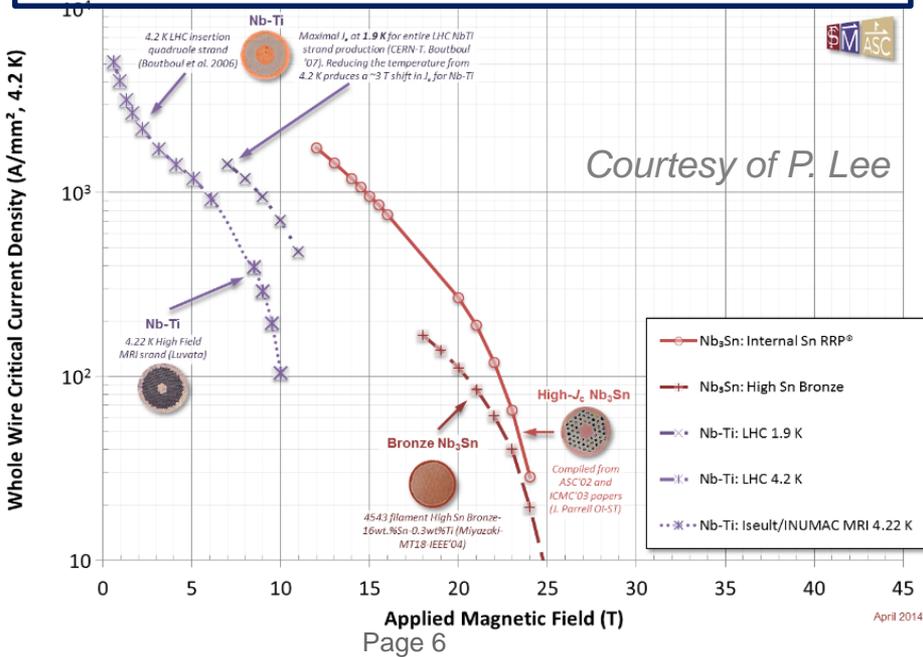
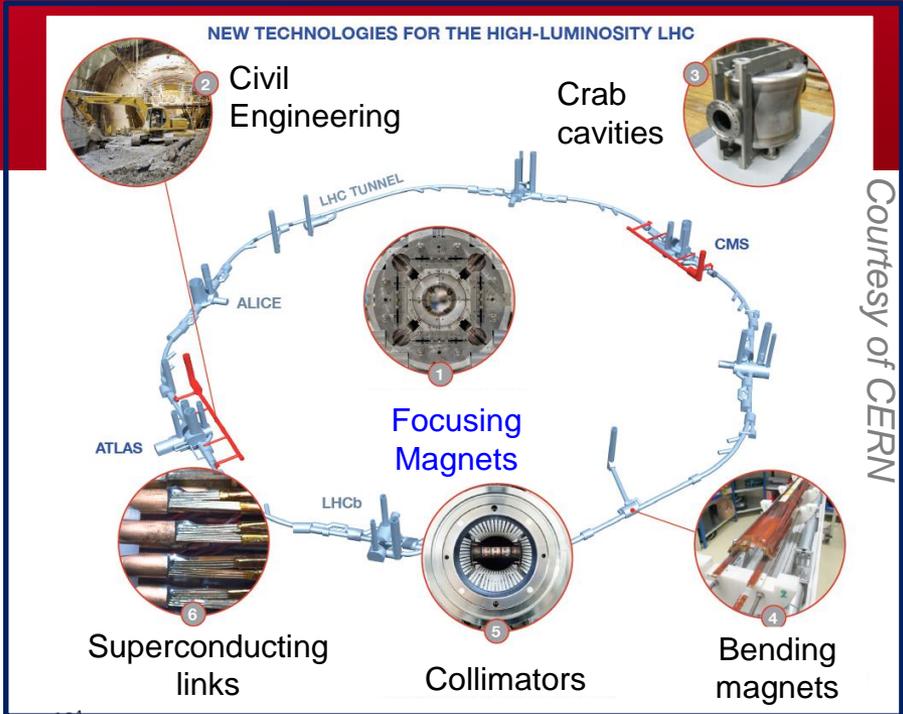
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DÉFIS RELATIFS AU Nb₃Sn

Techno LHC



Courtesy of CERN

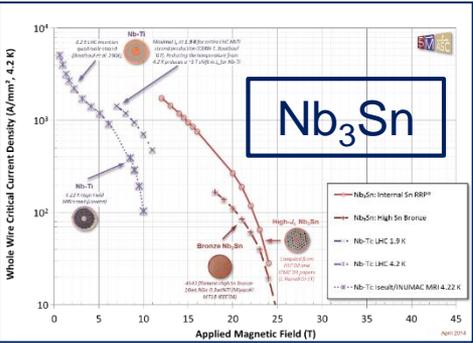
Au-delà du LHC

Techno des bobines

Traitement thermique à 650°C

Wind and react technology

Imprégnation sous vide Epoxy



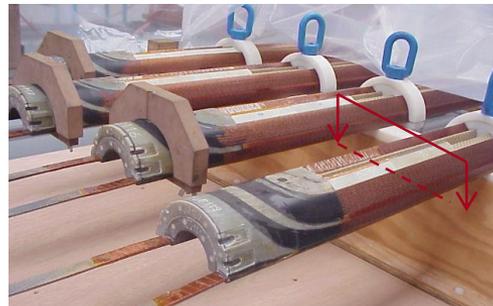
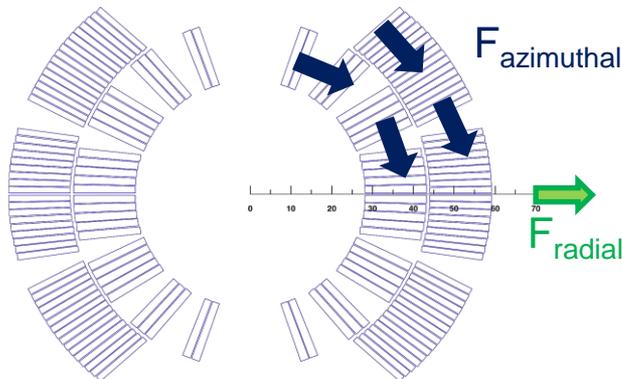
Sensibilité à la déformation mécanique

- I_c réduction (réversible)*
- I_c dégradation (permanente)*

Impact sur tous les aspects de conception et de fabrication

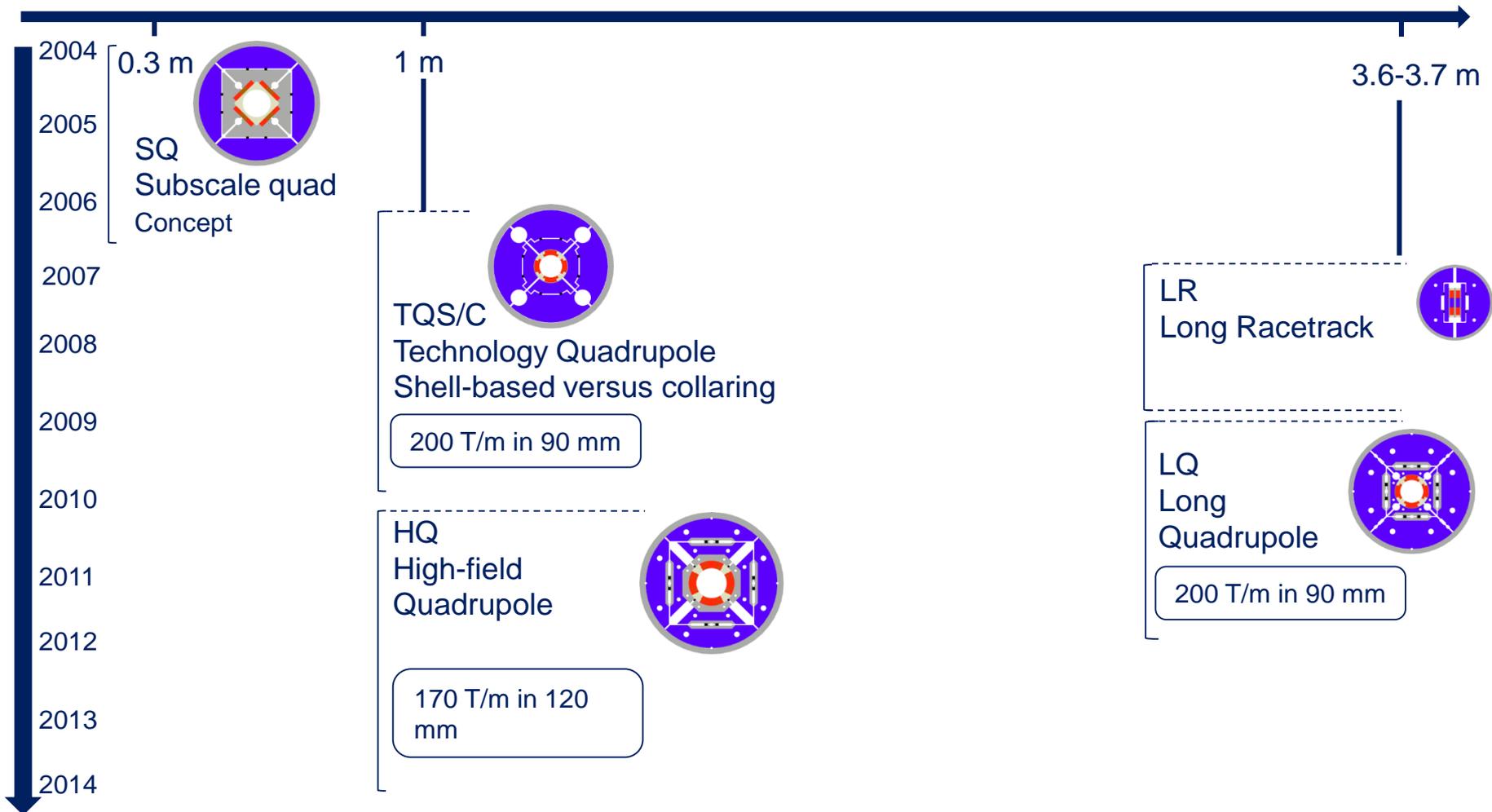
Courtesy of P. Lee

PROBLÉMATIQUE DE LA PRÉCONTRAINTE



- **Critères requis pour la structure mécanique**
 - Minimiser les mouvements sous champs
 - Préserver mécaniquement le Nb_3Sn
- La précontrainte consiste à l'application avant excitation et via la structure mécanique d'une force équivalente aux forces de Lorentz
- **Défis pour les hauts champs:** grandes forces (centaines de tonnes) et Nb_3Sn sensible à la déformation mécanique

Objectif: démontrer la viabilité du Nb₃Sn pour les aimants d'interaction

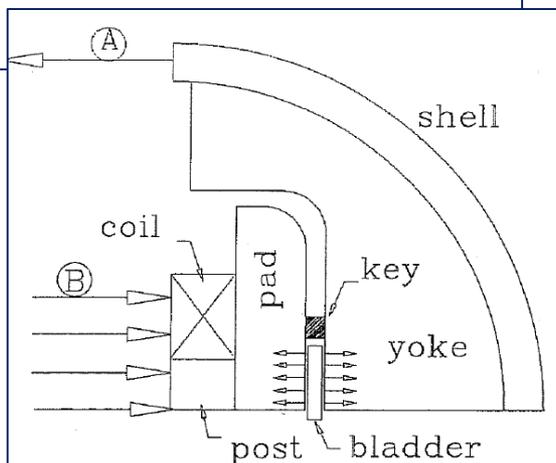


CONCEPT INNOVANT DE STRUCTURE MÉCANIQUE

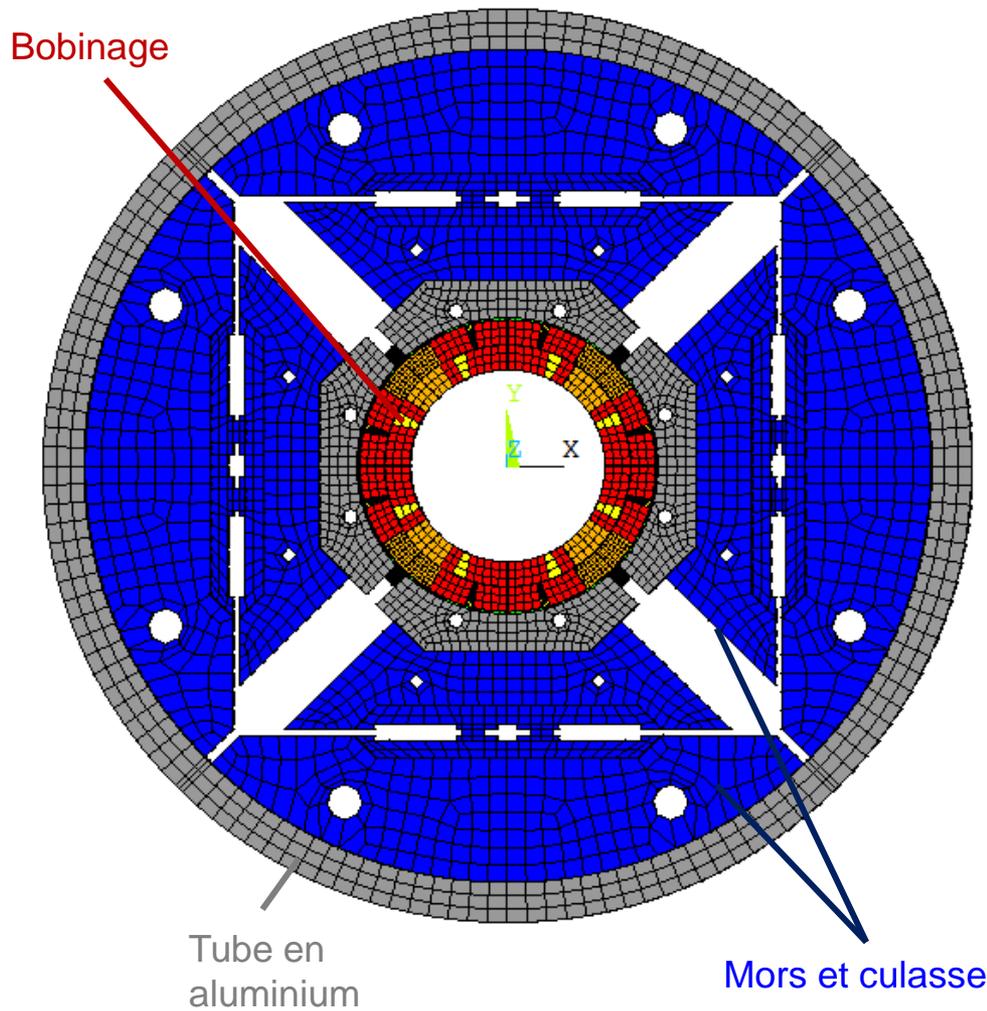
**La structure mécanique =
Enjeu majeur des aimants à
haut champ**

**Bladders & Keys = structure
innovante**

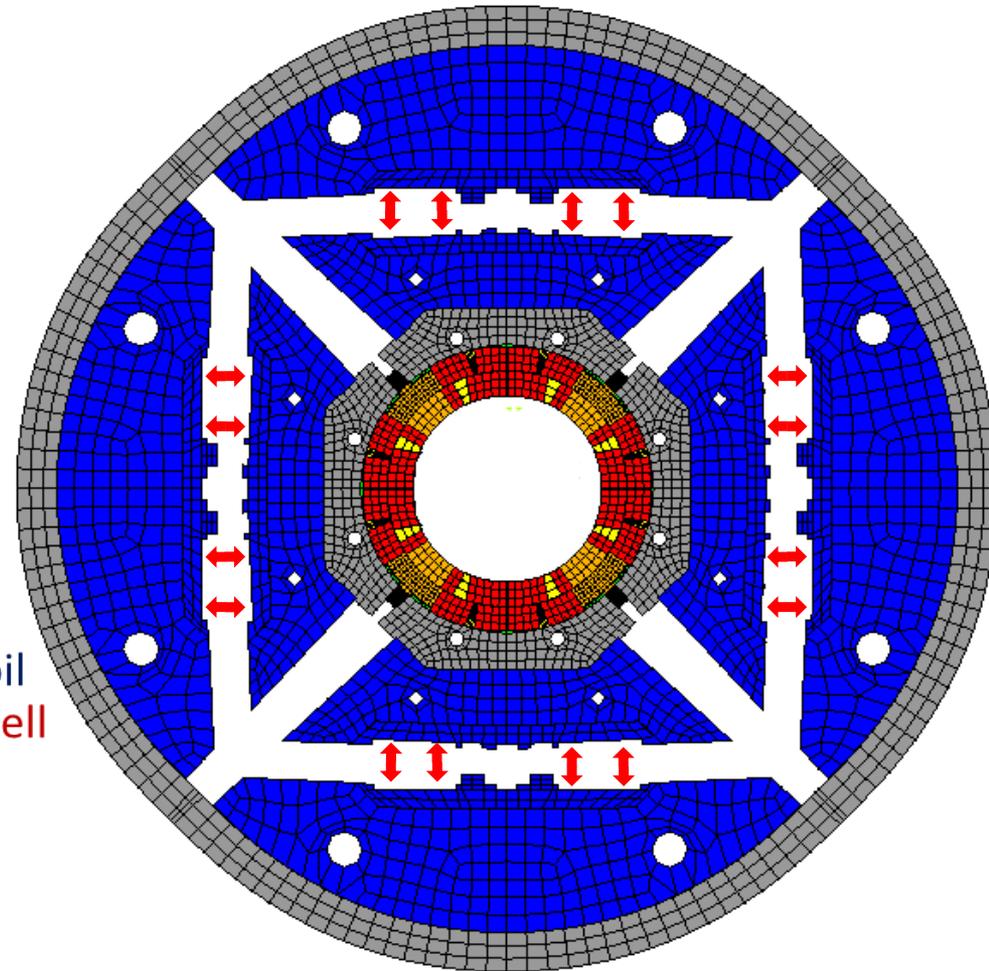
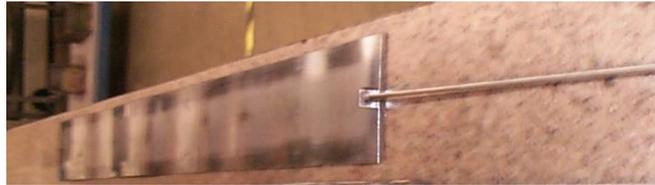
**Concept développé en 2001 au
LBNL**



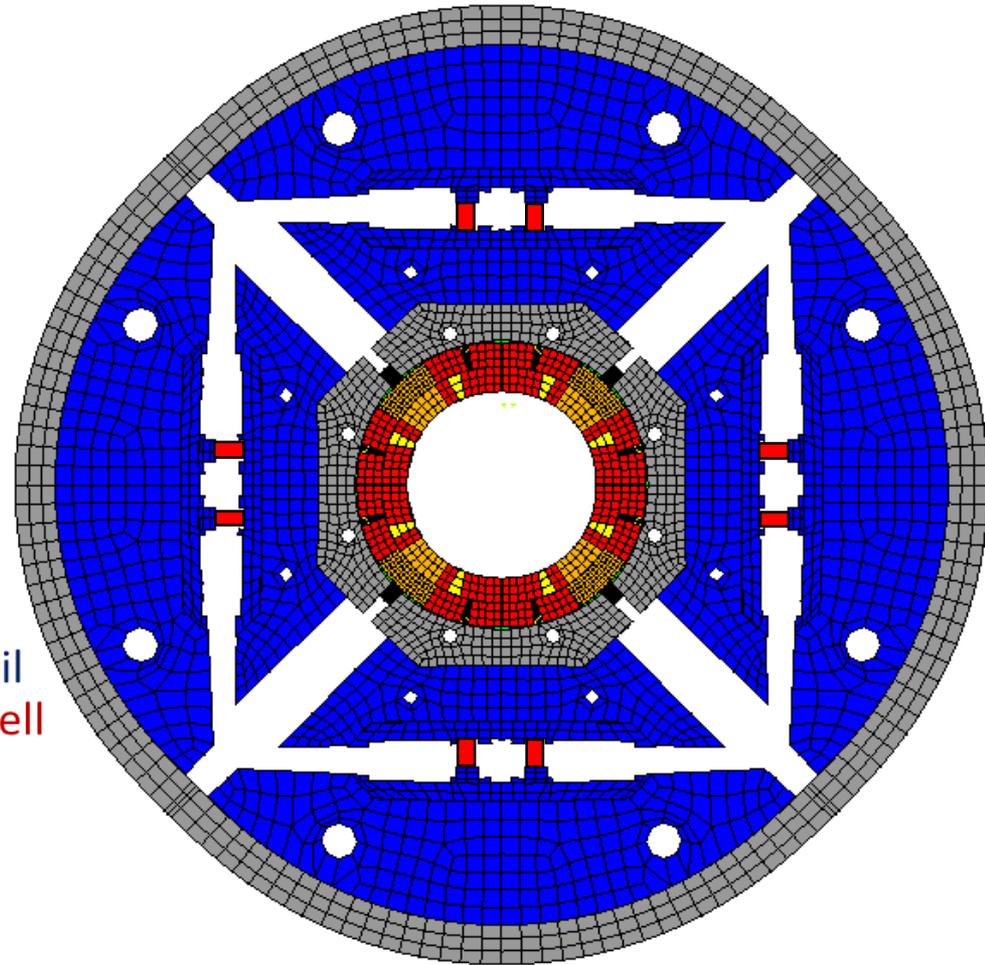
*Courtesy of S.
Caspi and R.
Hafalia, LBNL*



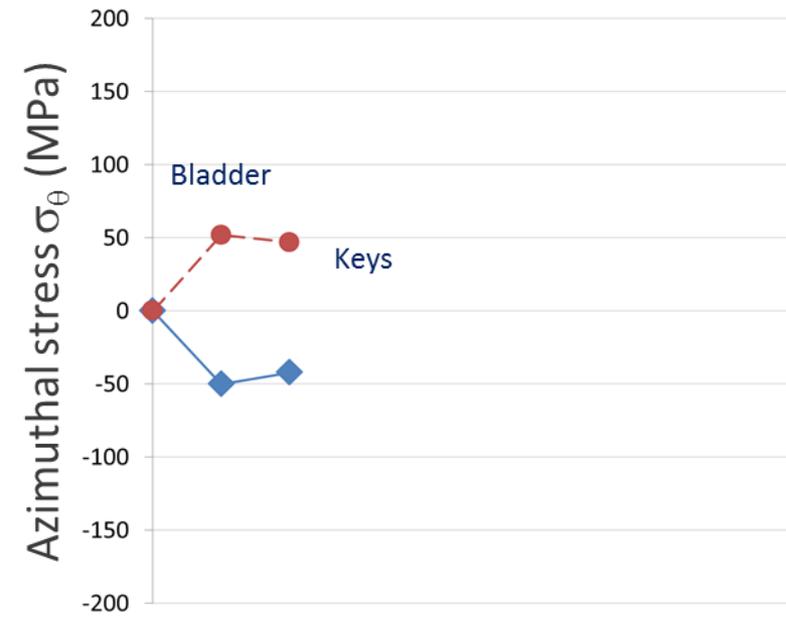
Mise sous pression des bladders



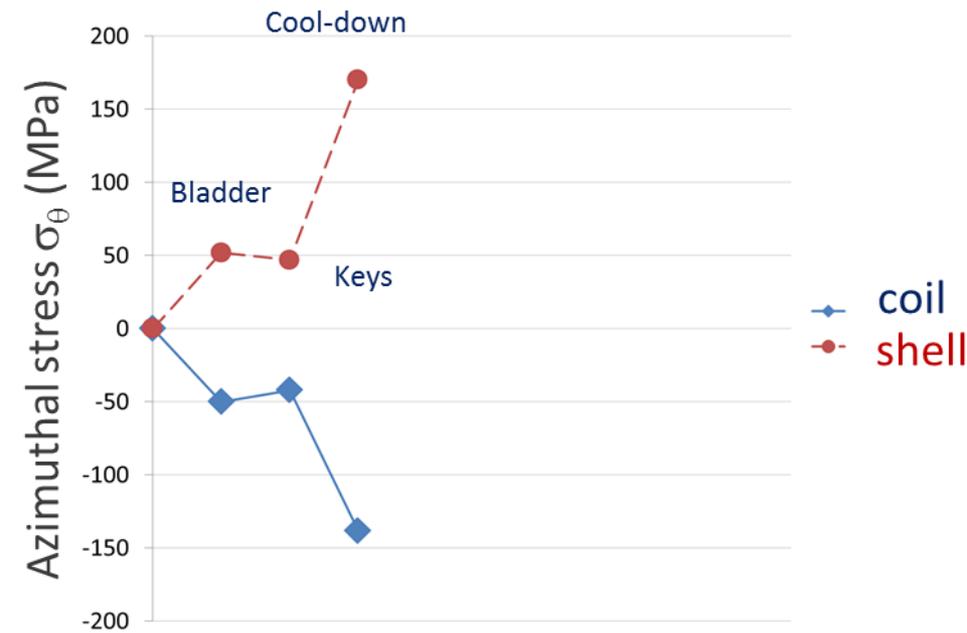
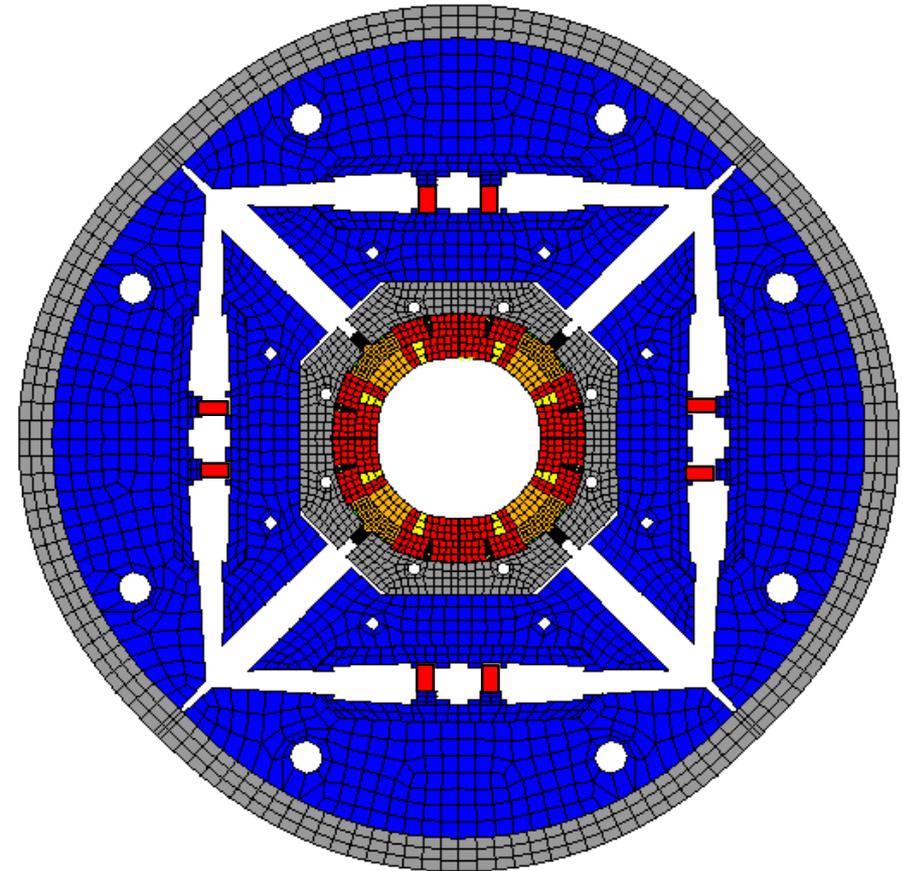
Positionnement des clavettes



—●— coil
—●— shell

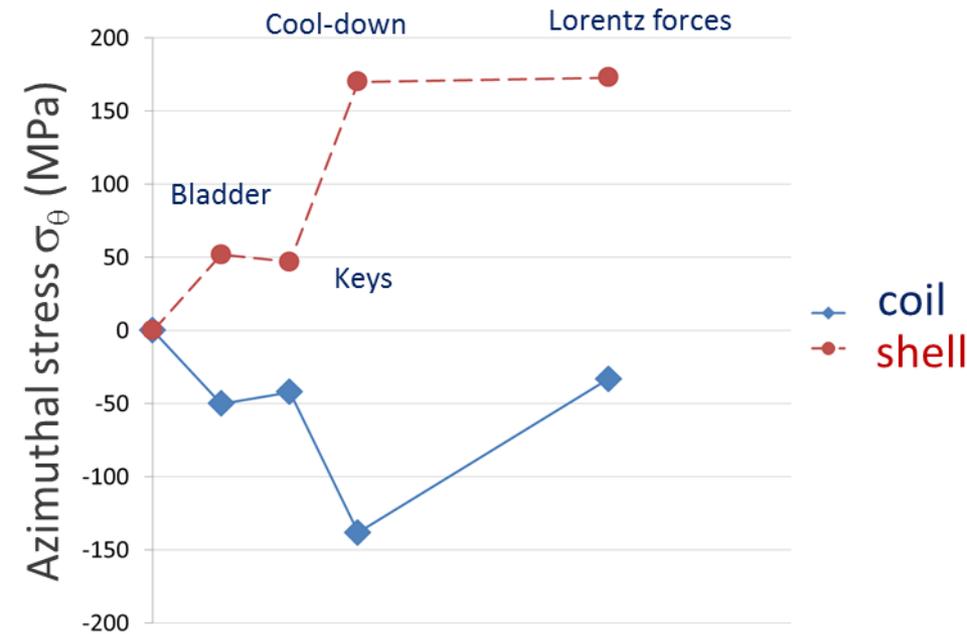


Mise en froid

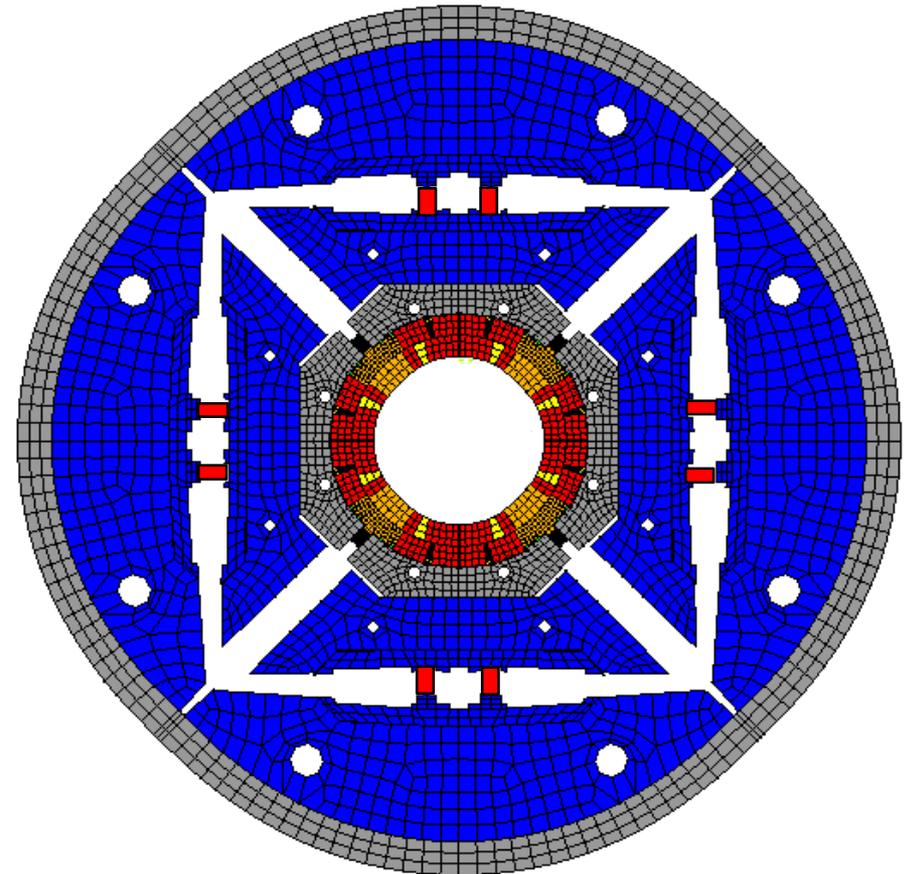


Structure Bladders & Keys

- Application graduelle de la précontrainte
- Précontrainte ajustable
- Assemblage réversible

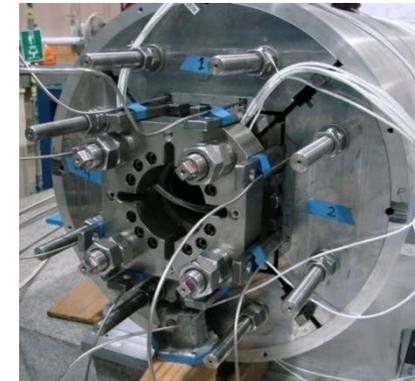
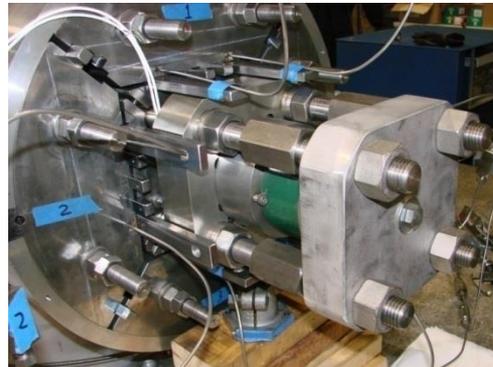


Excitation



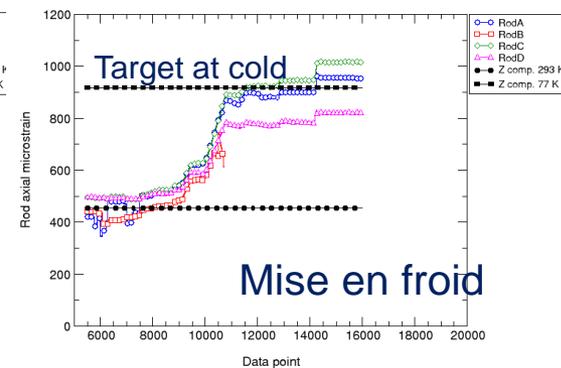
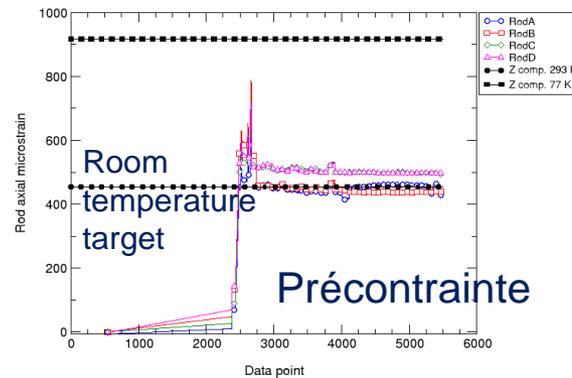
Maturation de la structure Bladders & keys au sein de LARP

- Tirants axiaux** (alu ou inox) précontraints à température ambiante par le biais d'un piston hydraulique et mise en tension des tirants pendant la mise en froid

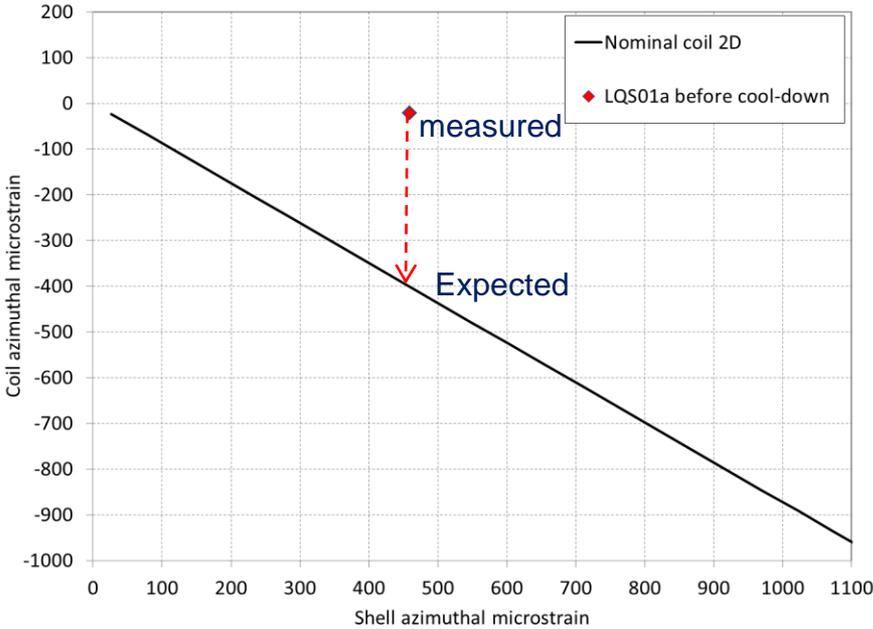
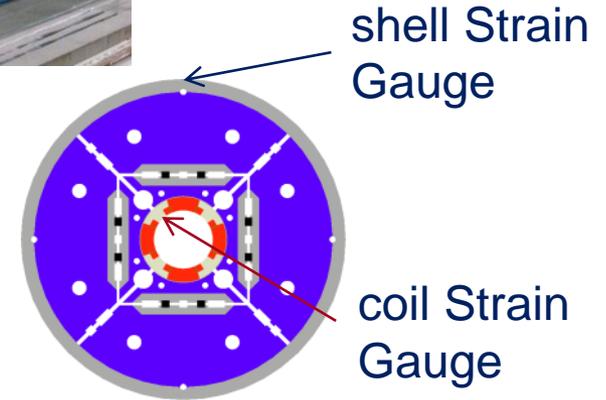


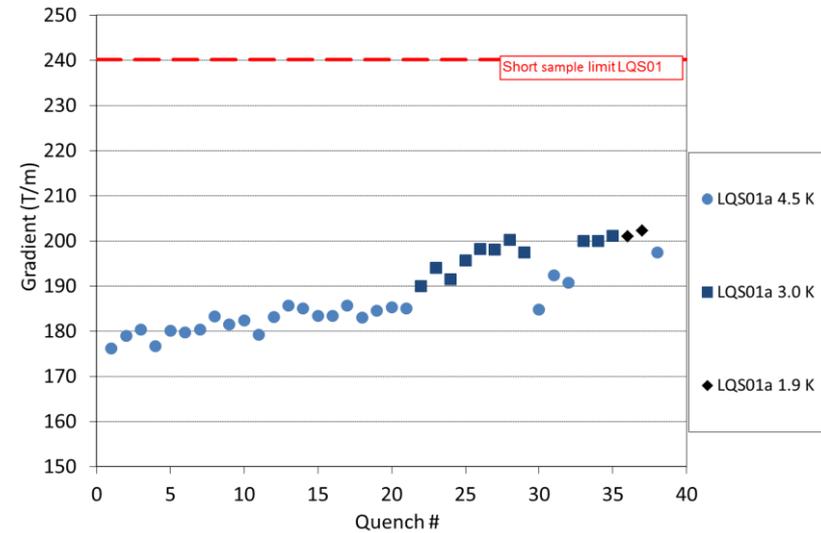
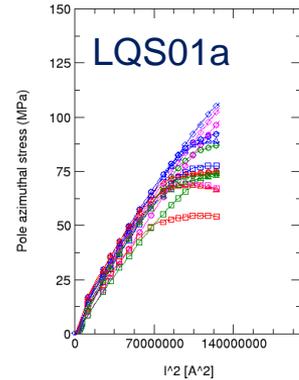
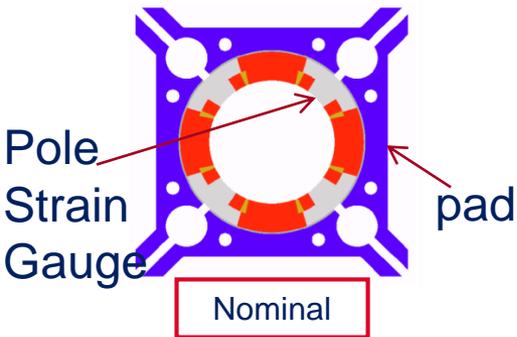
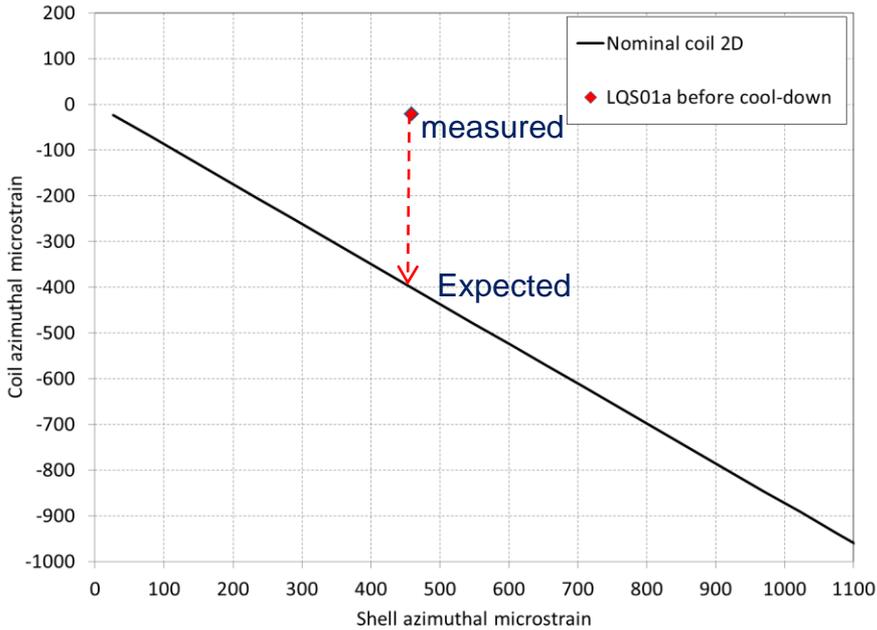
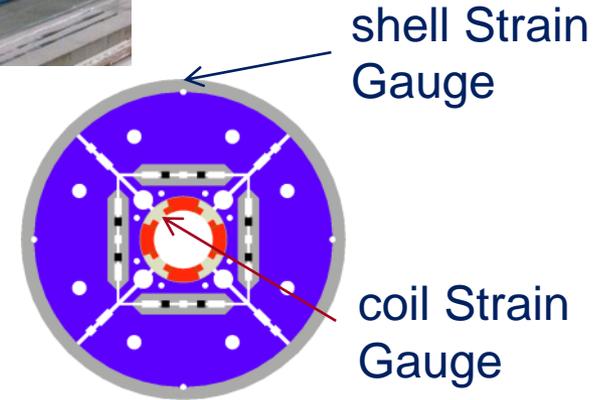
- Précontrainte définie via 3D FEA** et mesure par **jauges de déformation**

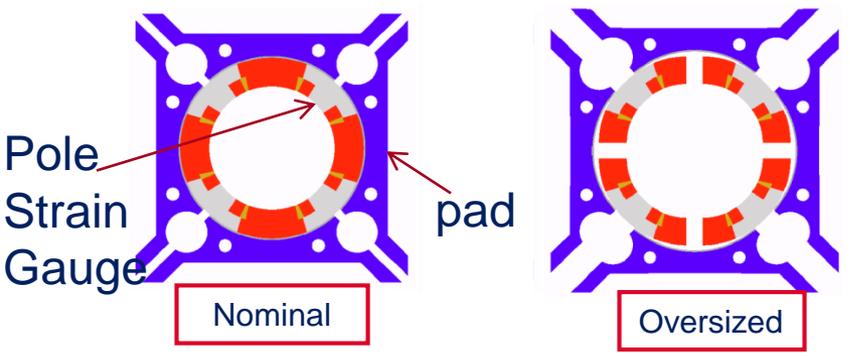
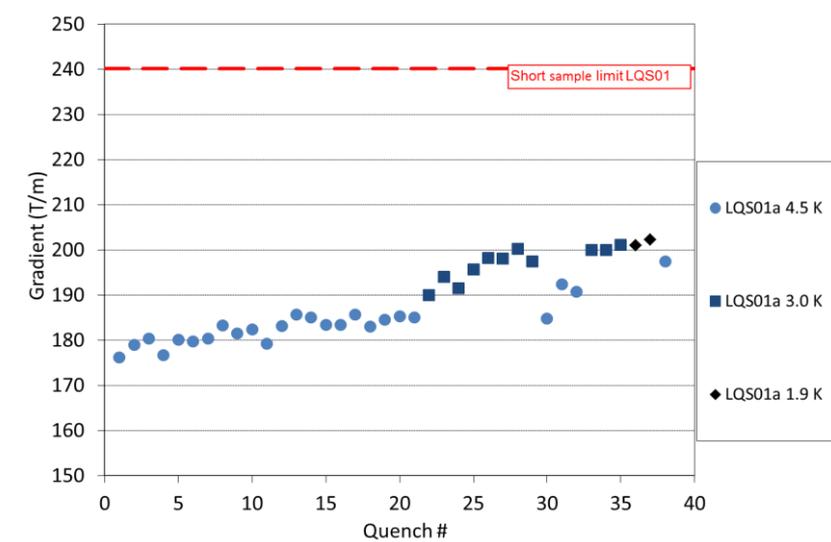
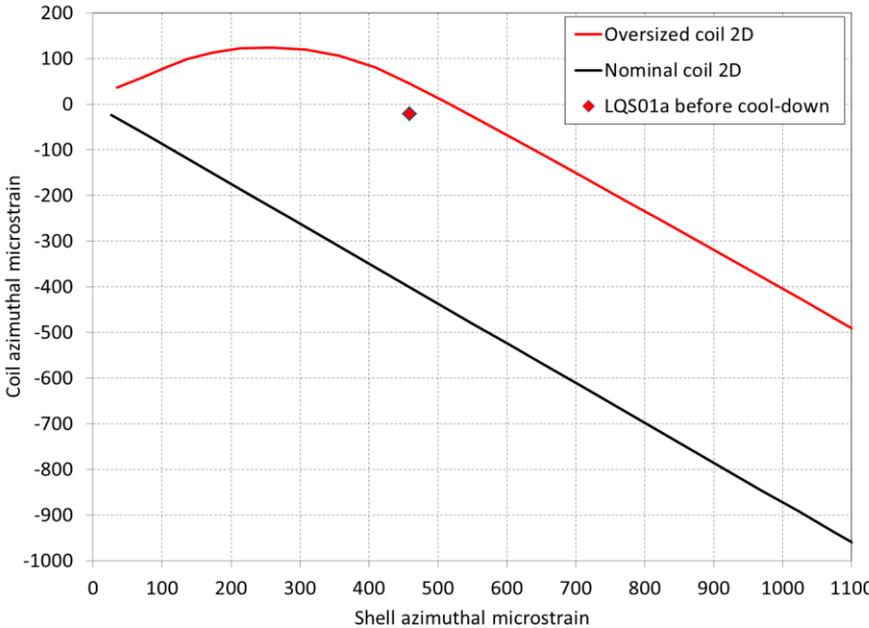
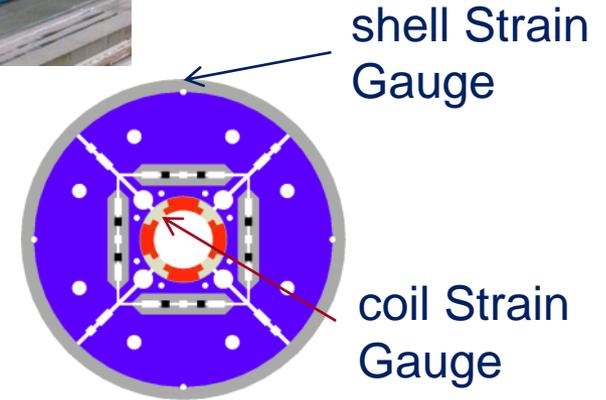
Exemple de mesures de jauges sur les tirants

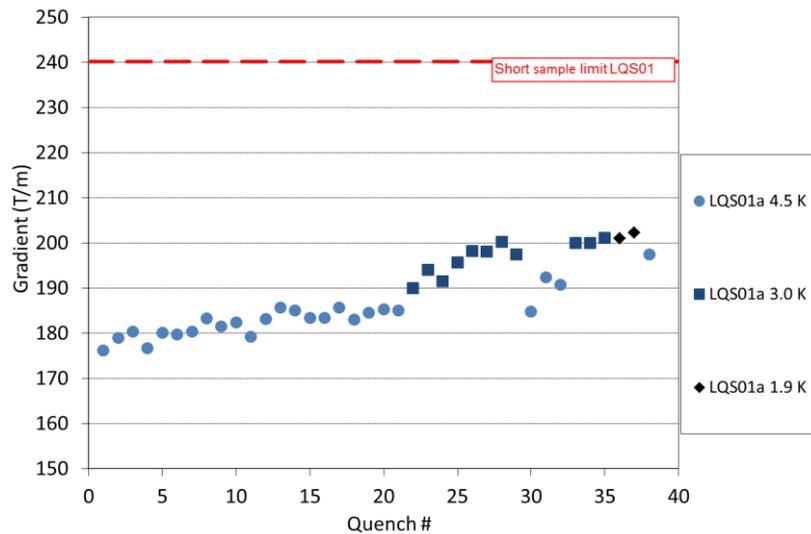
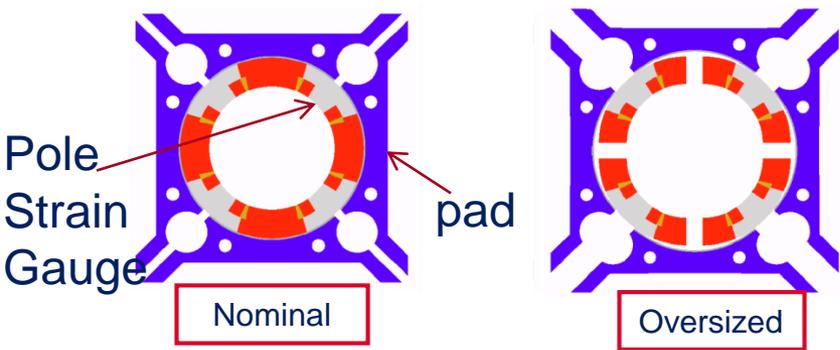
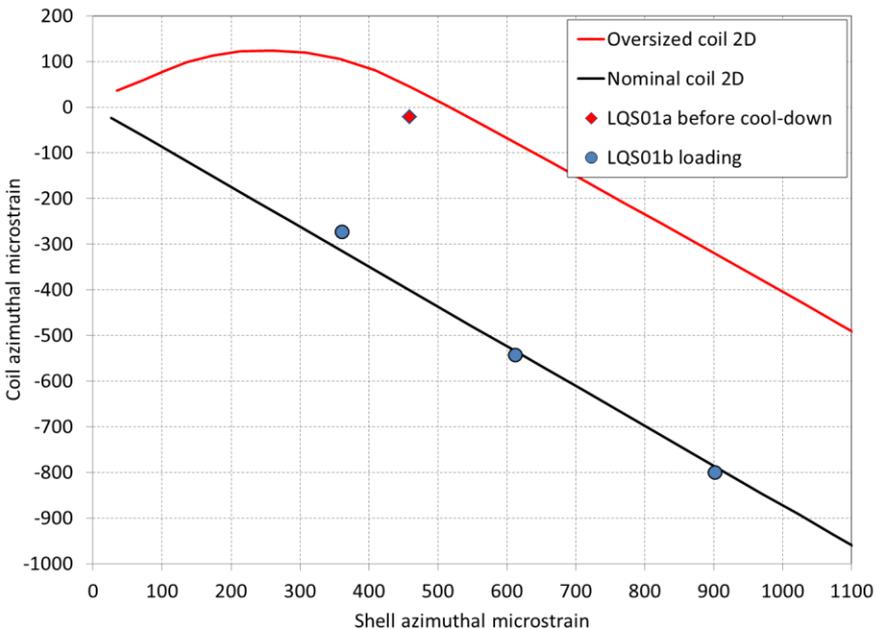
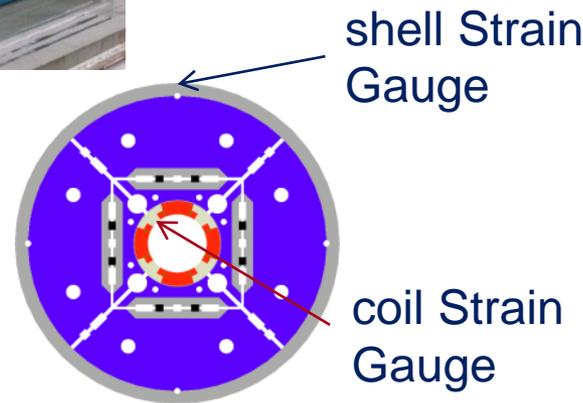


Structure bladders & keys: Précontrainte ajustable azimuthalement et axialement

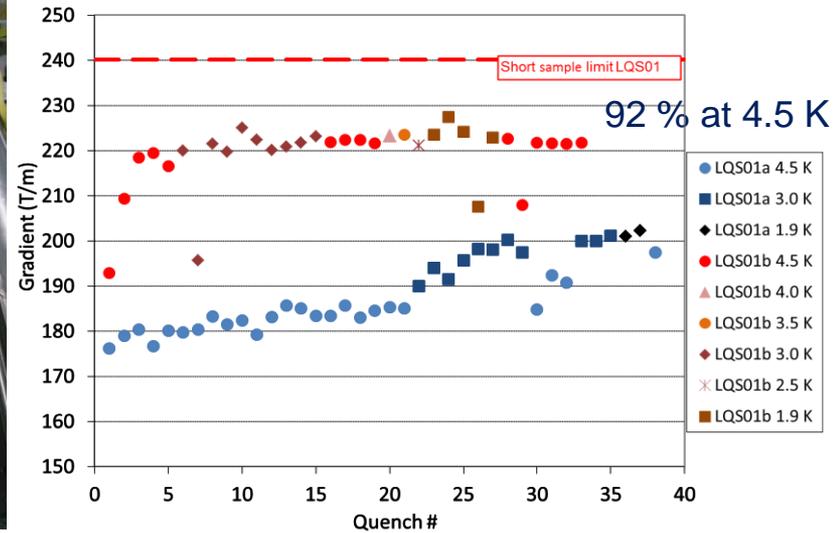
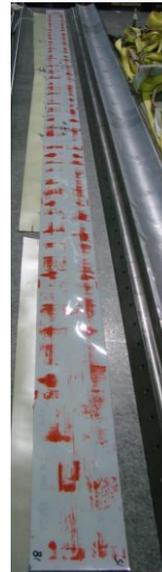
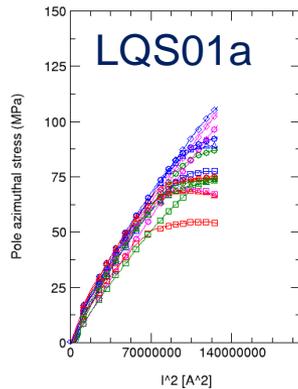
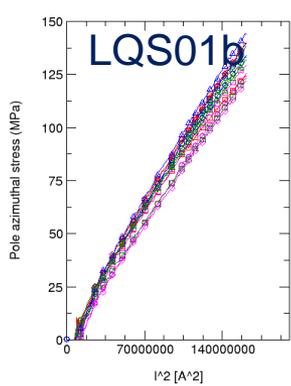
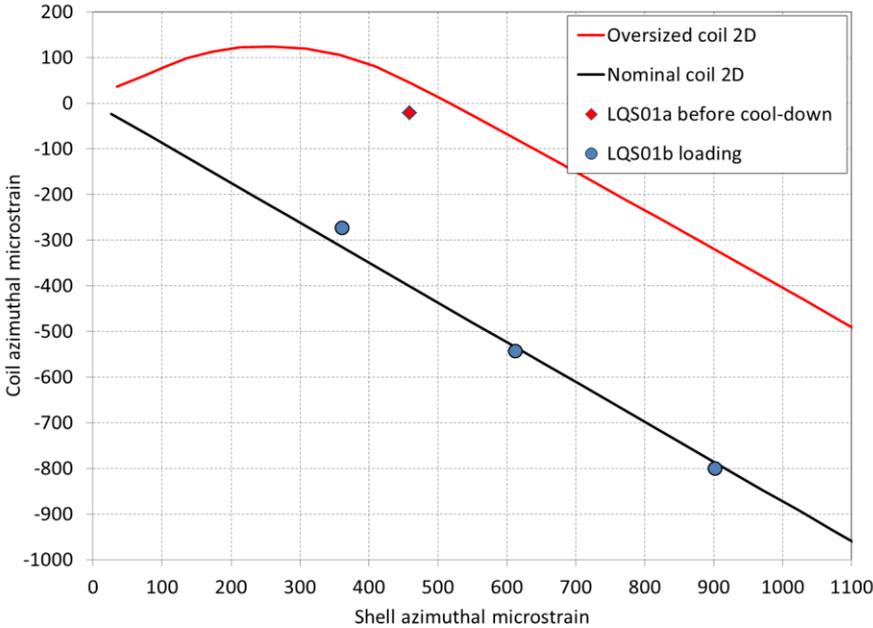
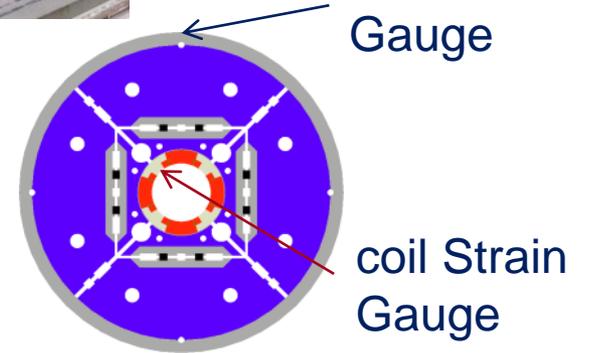


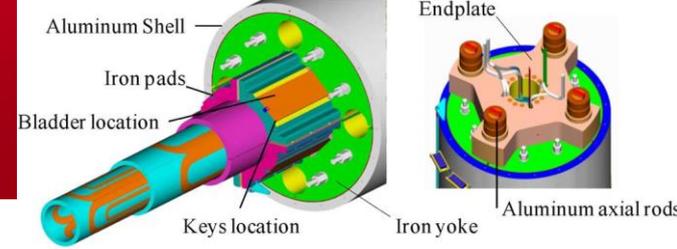






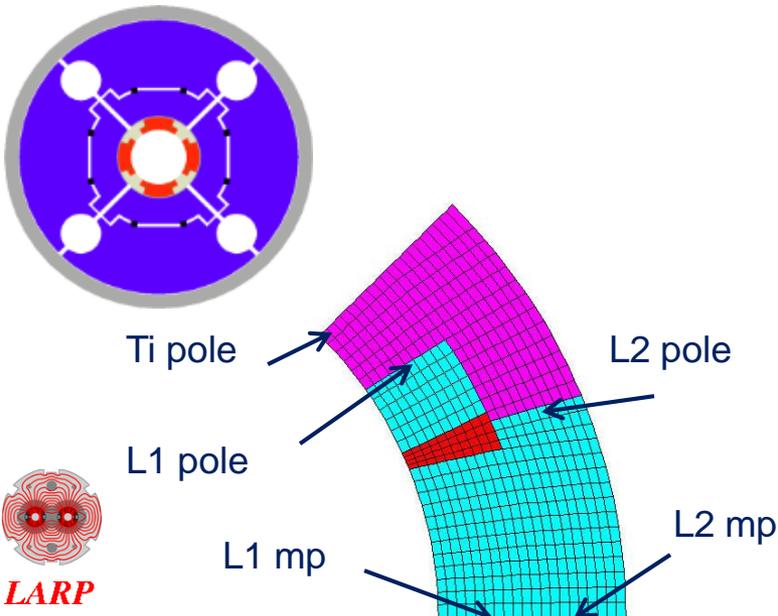
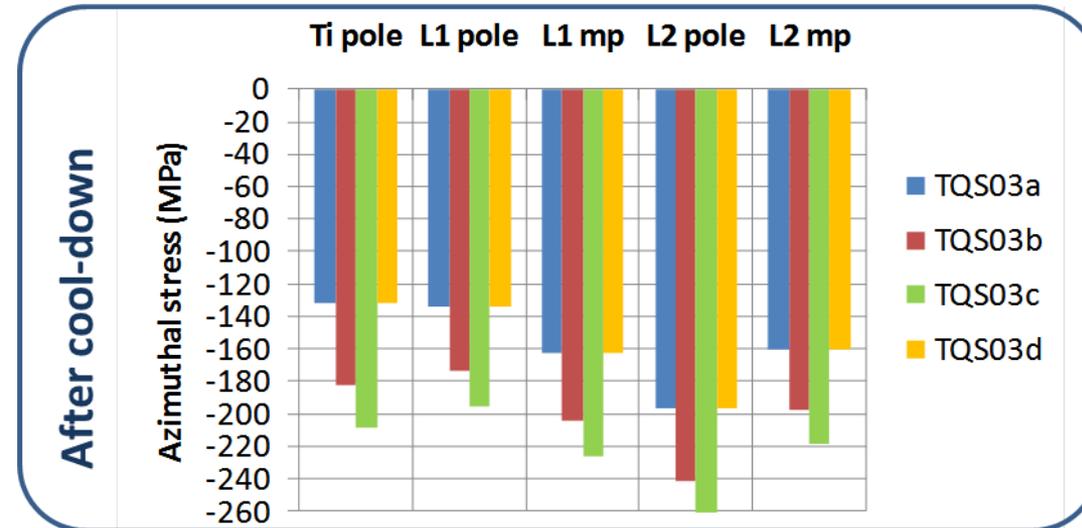
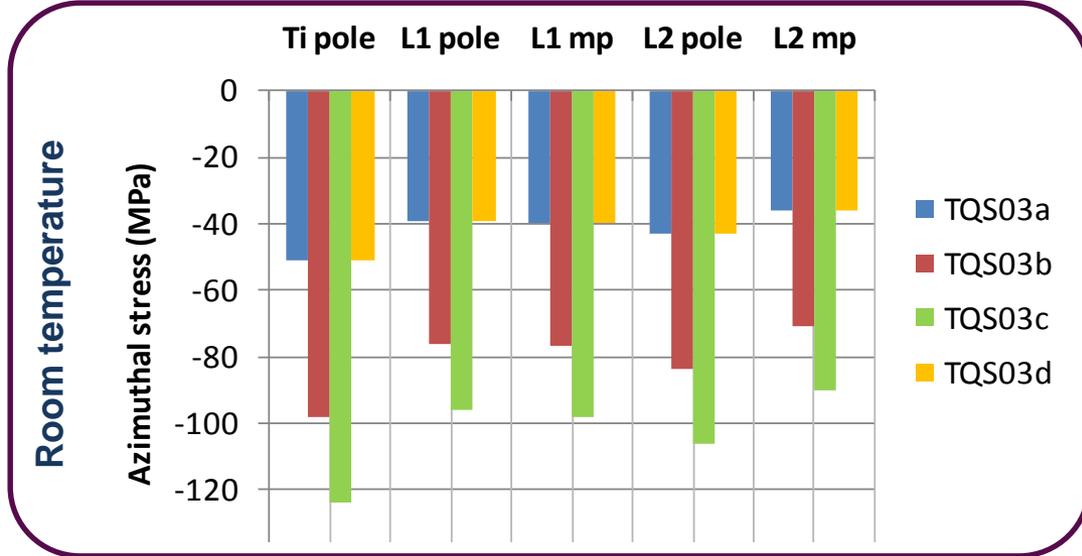
OPTIMISATION D'ASSEMBLAGE ET CORRELATION AVEC LES PERFORMANCES

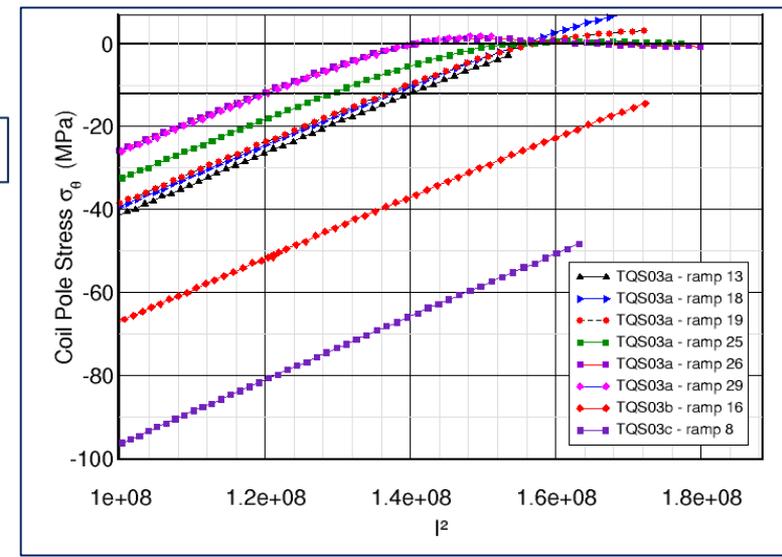
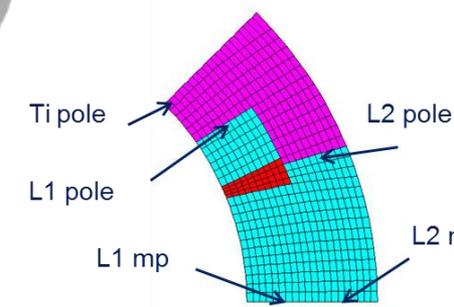
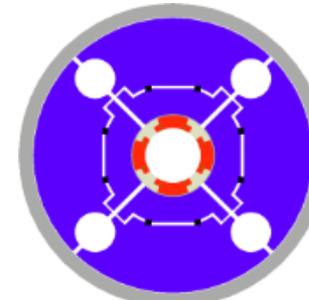
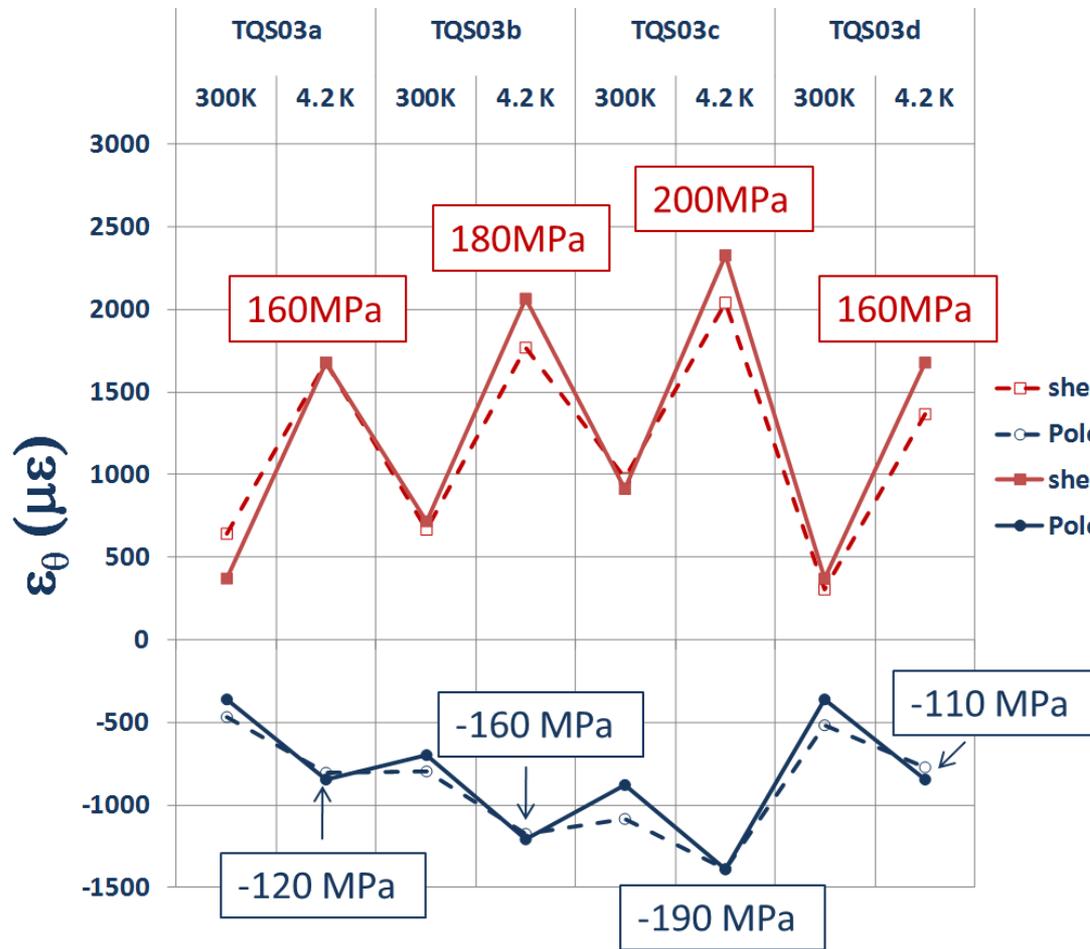




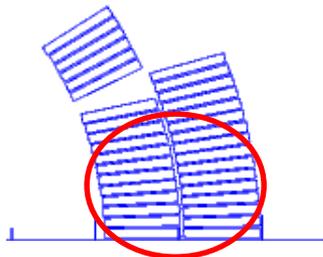
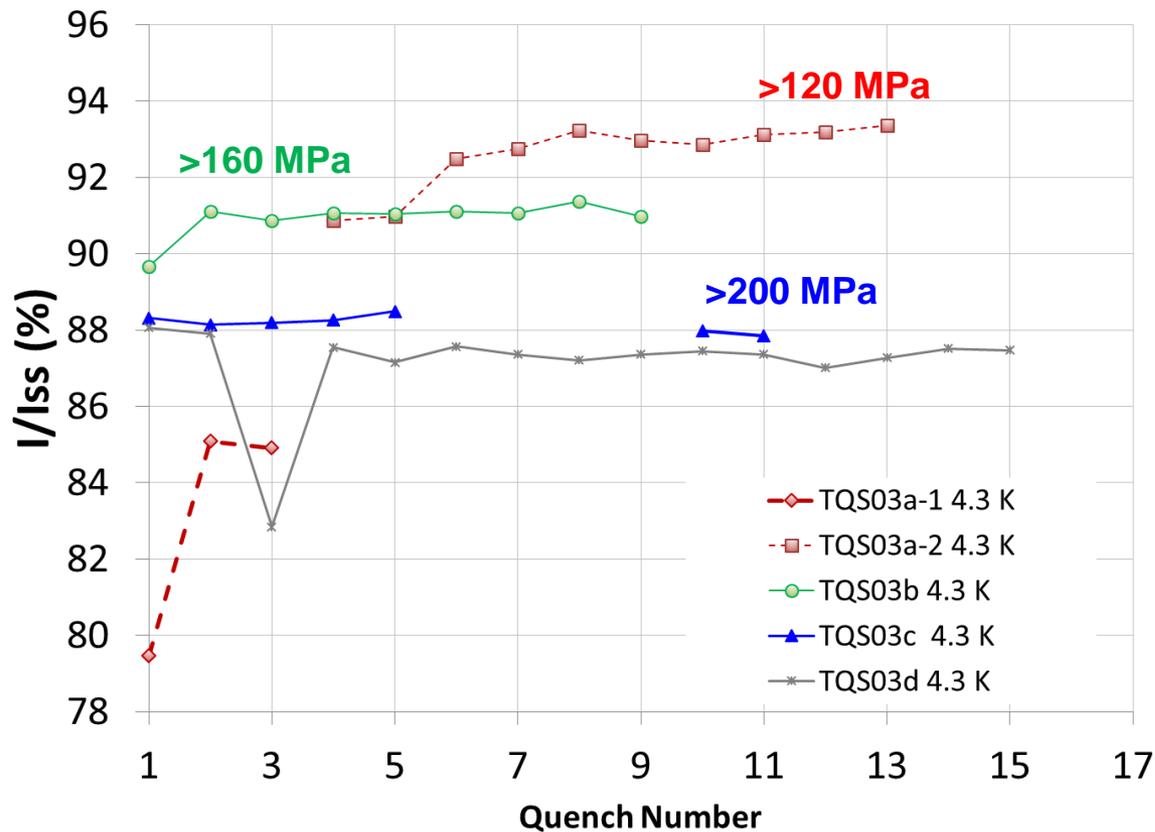
4 tests: TQS03 a, b, c et d

- Précontrainte variable
 - TQS03a: 120 MPa (Ti pole)
 - TQS03b: 160 MPa (Ti pole)
 - TQS03c : 200 MPa (Ti pole)
 - TQS03d: 120 MPa (Ti pole)
- σ_{θ} max plan median couche 1
~ 220 MPa en compression



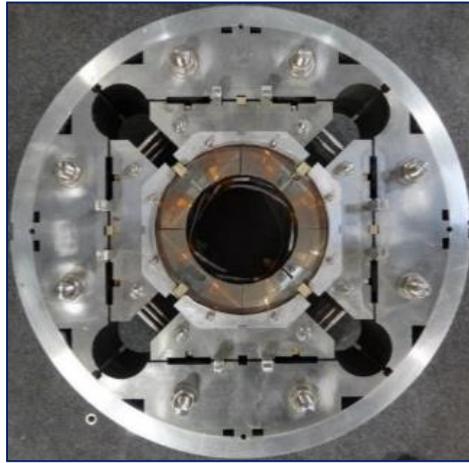


ETUDE DES PERFORMANCES SOUS FORTES CONTRAINTES



- Seulement 5 % dégradation de TQS03a à TQS03c
- TQS03d => dégradation permanente
- Tous les quenches localisés proche du plan median
- **Etablissement d'une limite de contrainte empirique dans un champ de ~12 T**

TRIPLET DE FOCALISATION POUR HL-LHC



Courtesy of D. Cheng, LBNL

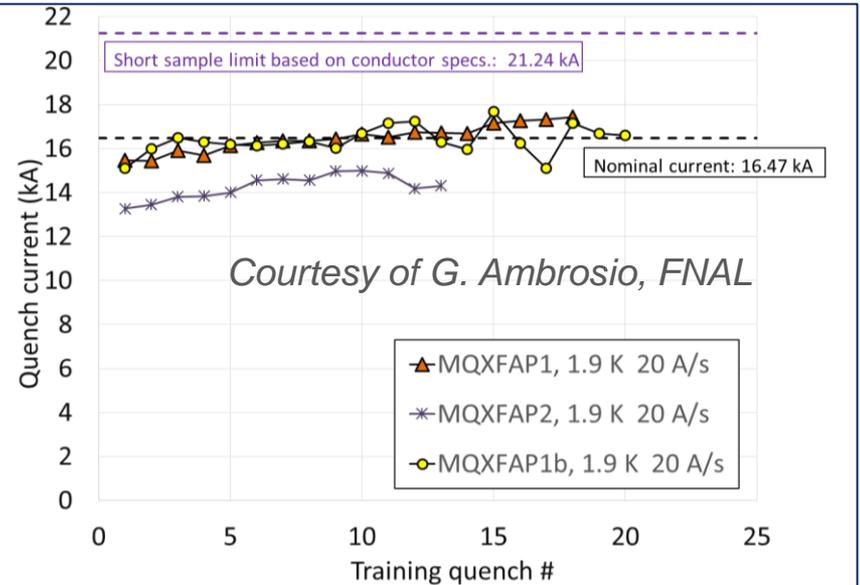
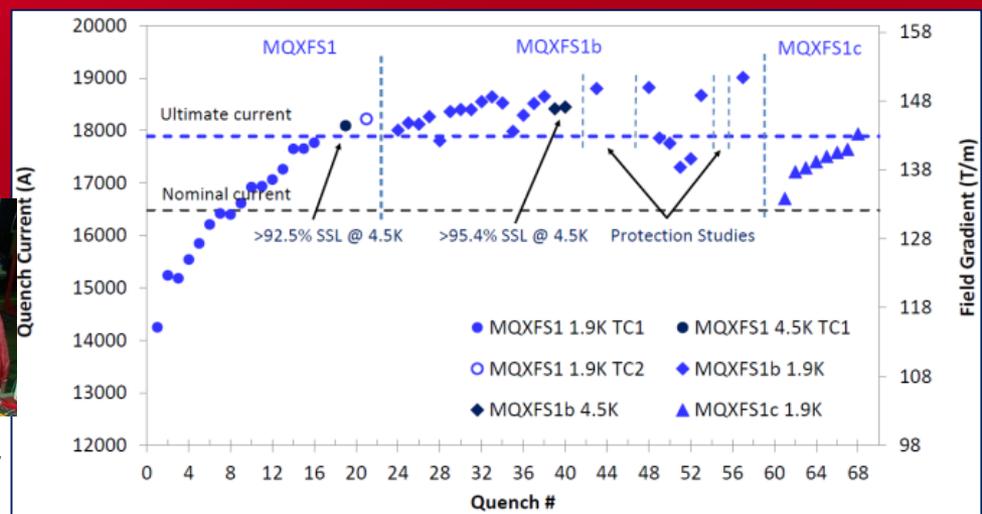
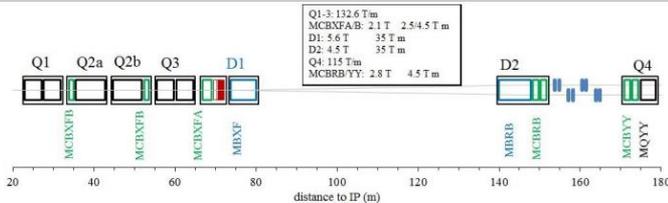


MQXF
132,6 T/m
150 mm

4,2 m
MQXFA3 (pré-série) test prévu en Oct. 2019



IP



Courtesy of P. Ferracin, CERN

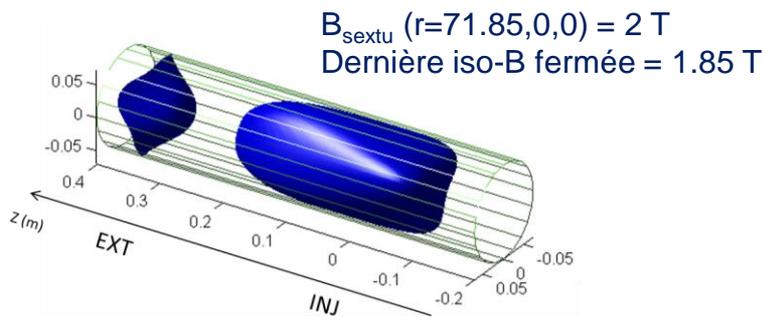
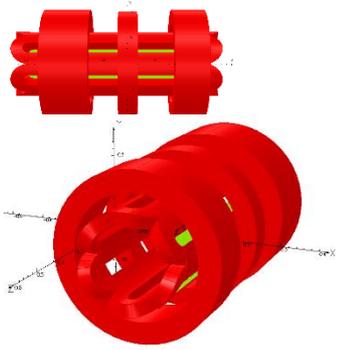


7,15 m
MQXFBP1 test prévu début 2020

ÉTUDE DÉTAILLÉE ET RÉALISATION D'UN AIMANT POUR SOURCE D'IONS DE TYPE ECR

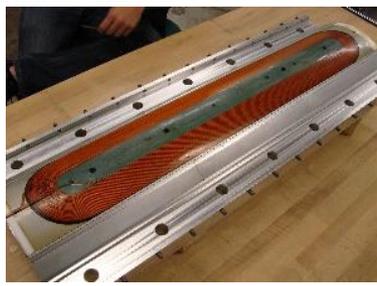
$$B_{ECR} = \frac{f_{ECR} [GHz]}{28} \text{ Tesla}$$

Conception magnétique

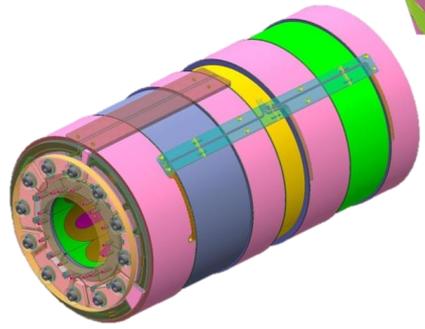
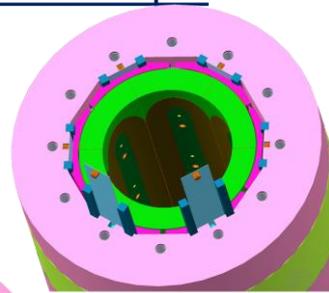


Conception mécanique

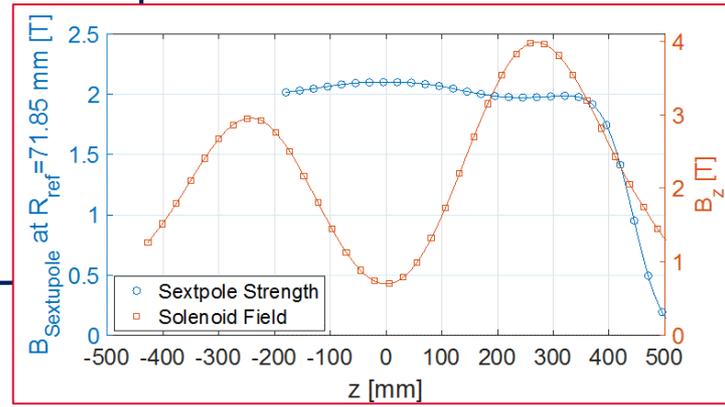
Bobine d'essai



Technique innovante d'assemblage



Courtesy of D. Arbelaez, LBNL



- Un programme d'envergure aux USA a permis d'amener la technologie Nb_3Sn à maturation pour des aimants spéciaux dans le HL-LHC.
- Les USA et l'Europe travaillent conjointement à la production des aimants MQXF pour HL-LHC
- Certains concepts sont utilisables sur d'autres types d'aimants
- Le développement du Nb_3Sn pour des aimants d'accélérateur à plus haut champ est en cours

Commissariat à l'énergie atomique et aux énergies alternatives
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