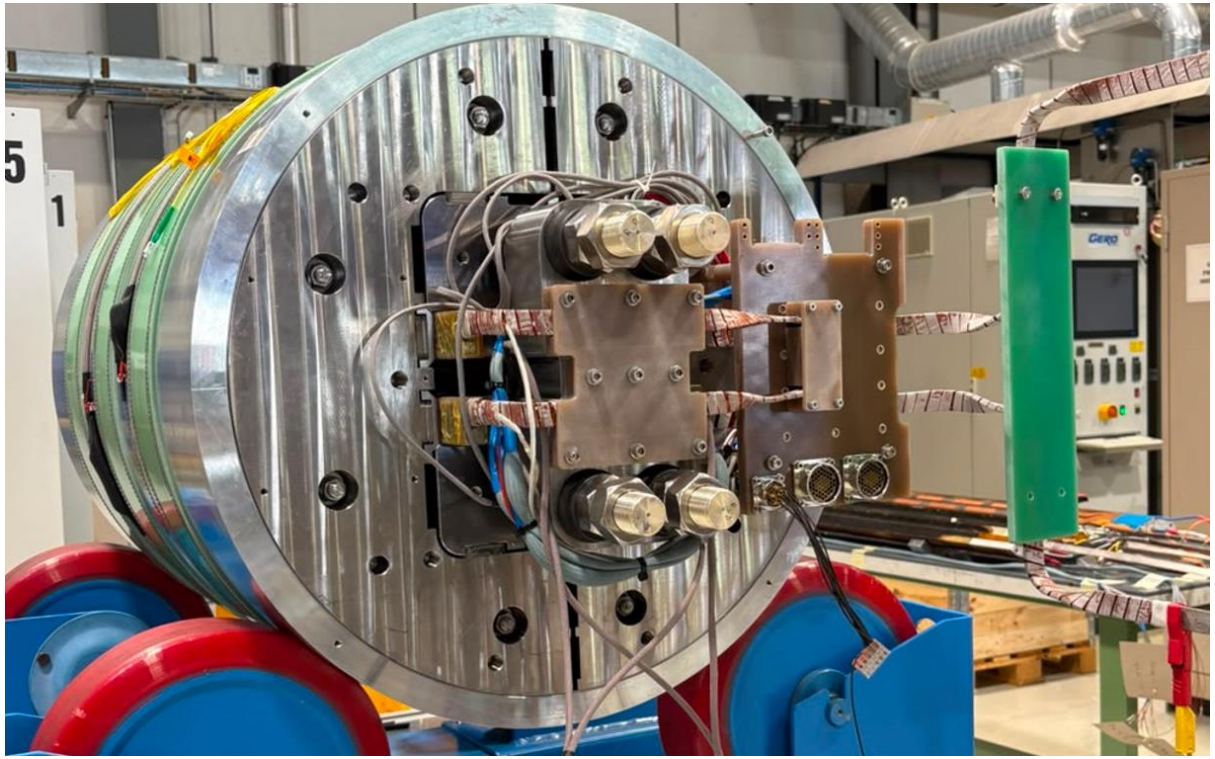


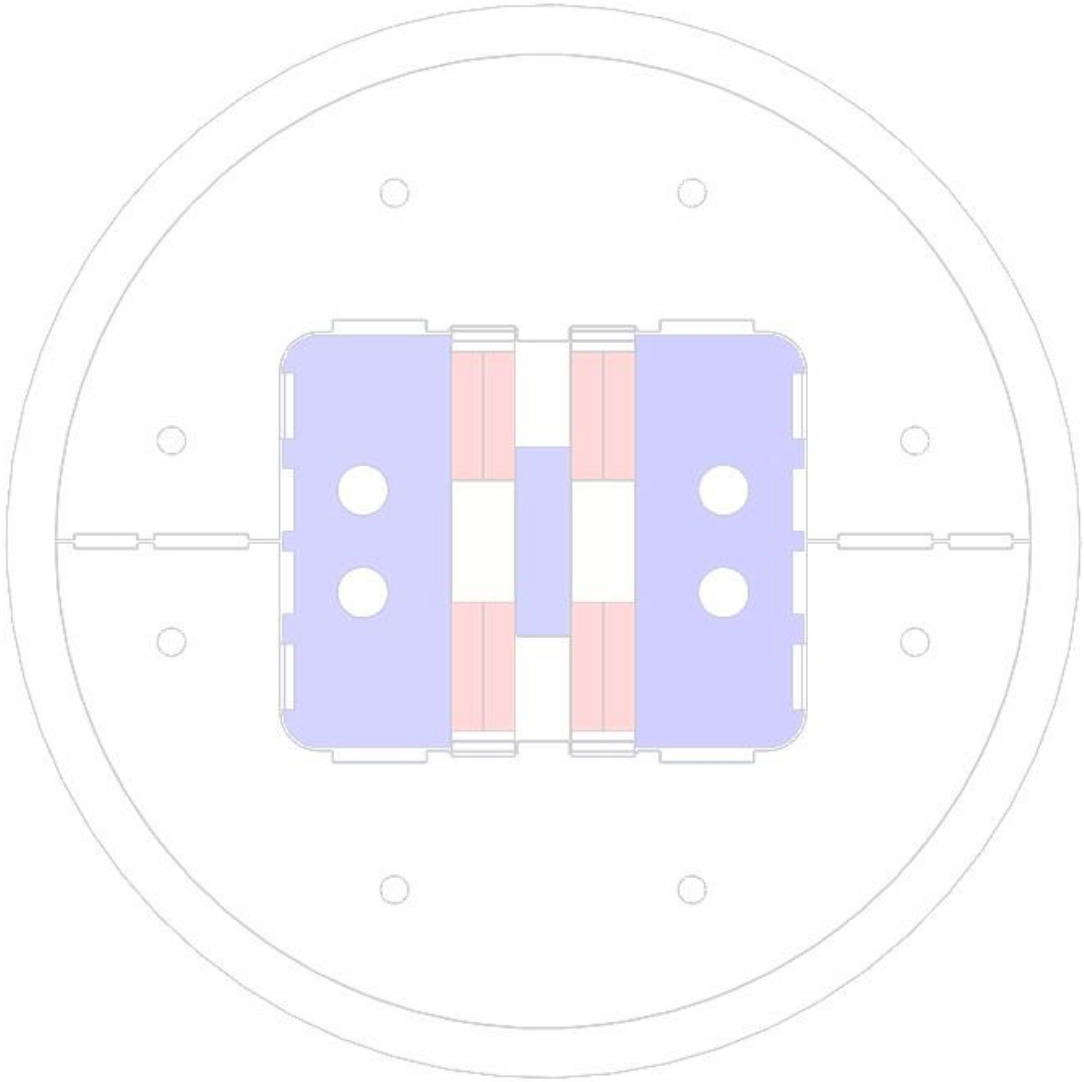
ISAAC: A High Field Superconducting Magnet Demonstrator for Particle Colliders

Carla Martins (on behalf of the CIEMAT SMART-Lab team)

20th October 2026

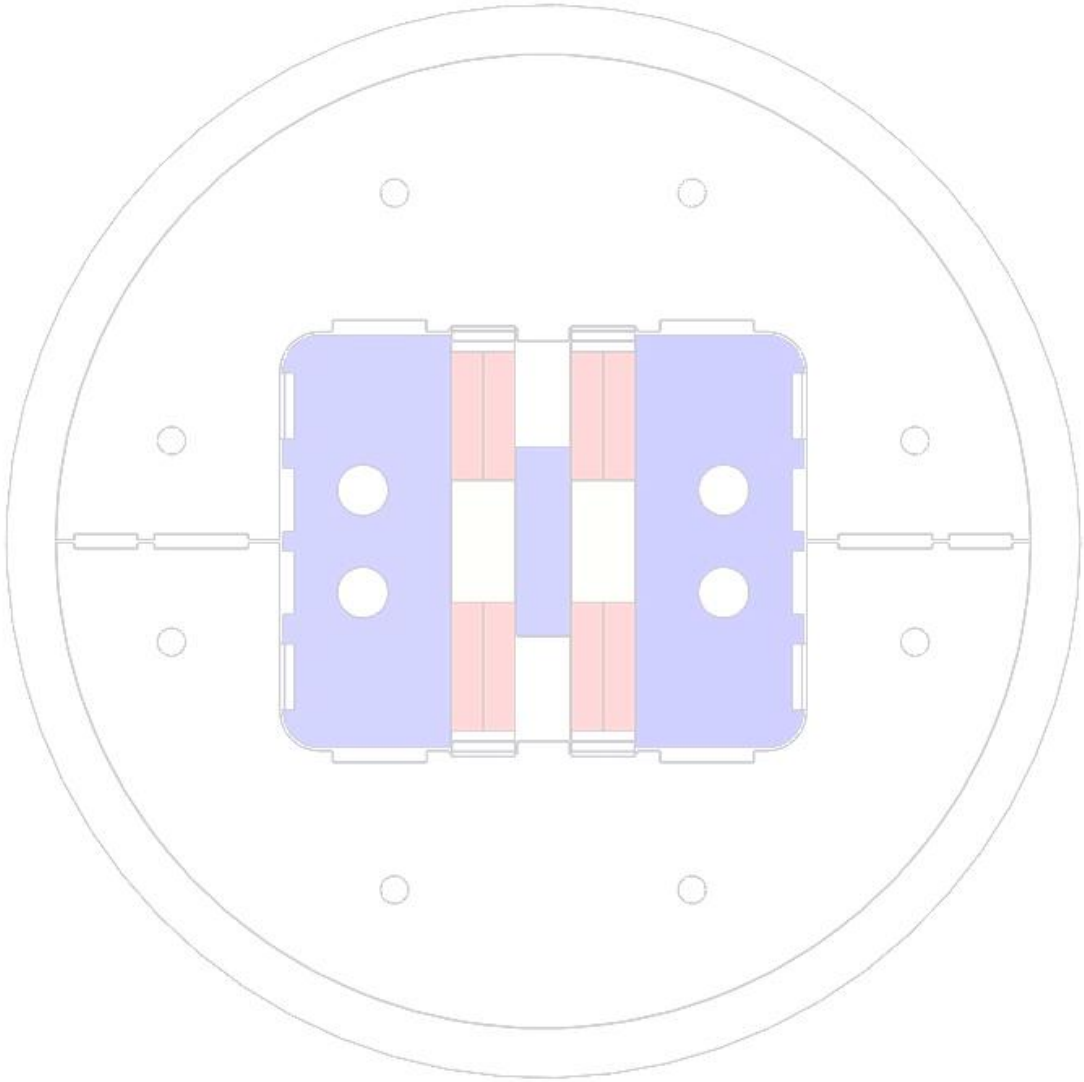
Outline

- Introduction
- ISAAC34
  - Concept
  - Assembly
  - Powering Test
- Conclusions & next steps



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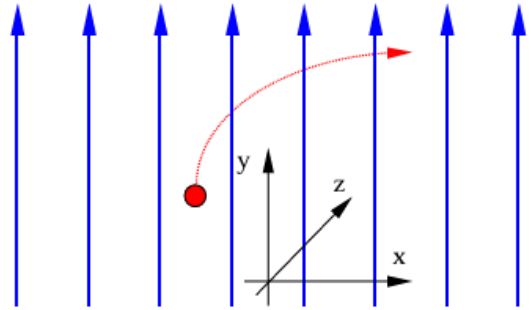


Introduction

- Worldwide initiatives to build **large particle colliders**: ILC, CLIC, FCC-ee, FCC-hh, CEPC, SPPC.
- Superconducting bending magnets (dipoles) above 10 T are necessary for the high energy proton-proton colliders (i.e. FCC-hh, SPPC).
- CERN coordinates the **High Field Magnets (HFM) Program** in collaboration with some European Institutes (CEA, CIEMAT, INFN and PSI) to address this challenge for the FCC-hh (91 km length, 85 TeV collision energy).
- **14 T** is the operational field target for **Nb_3Sn** dipole magnets operating at 1.9 K.
- Demonstrators shall be **scalable to 15 m** magnet length.
- **CIEMAT** is contributing to this program with the design and manufacturing of a 14 T demonstrator in **common coil** configuration.

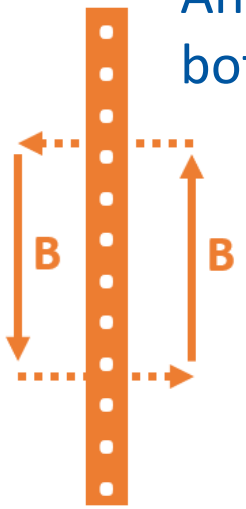
Common Coil configuration

For **beam bending**: constant magnetic field across the aperture -> dipole



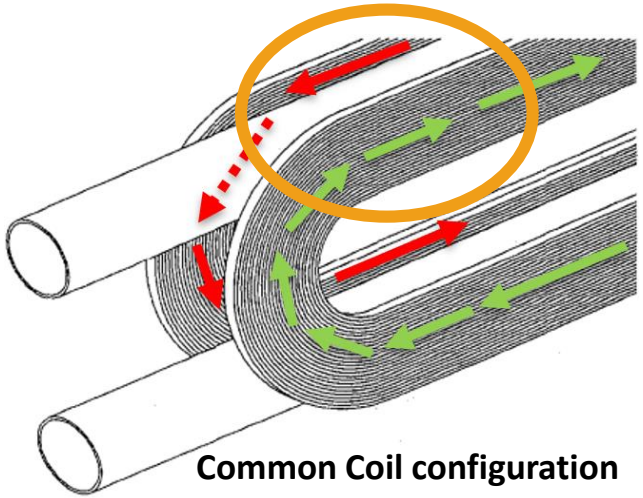
Uniform magnetic field (dipole)

An infinite current sheet generates uniform magnetic field at both sides (opposite directions)



Infinite current sheet magnetic field

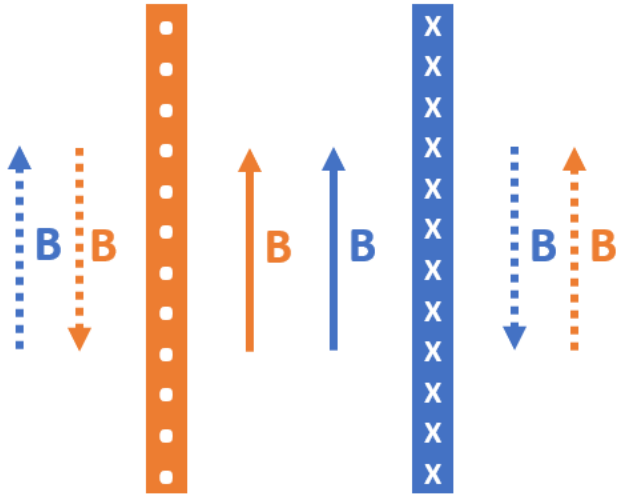
Common Coil: **Double aperture dipole** based on two flat (racetrack) coils powered in opposite directions.



Common Coil configuration

Courtesy R. Gupta

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Two infinite current sheet magnetic field

Advantage: Flat coils have a **simple geometry**, easier to produce with brittle conductors like Nb_3Sn

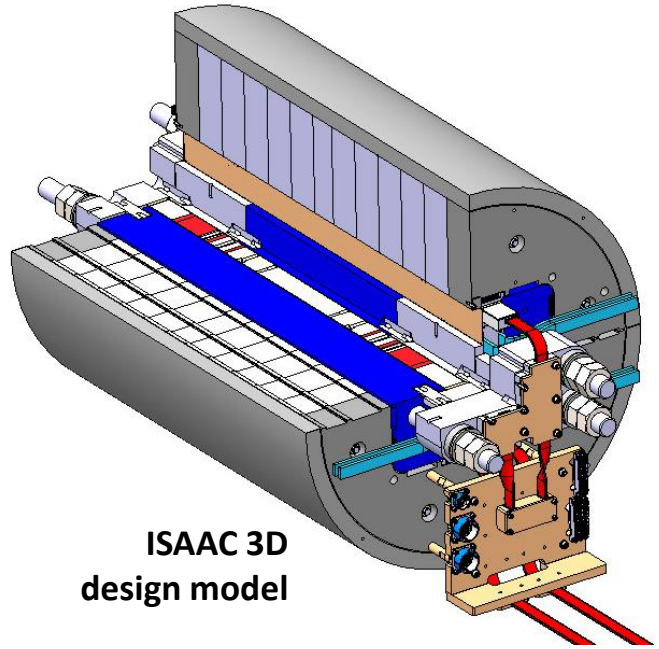
Similar to the theoretical physics concept of **two infinite parallel current sheets** producing a perfect and uniform dipole magnetic field inside the aperture

CIEMAT contribution to HFM

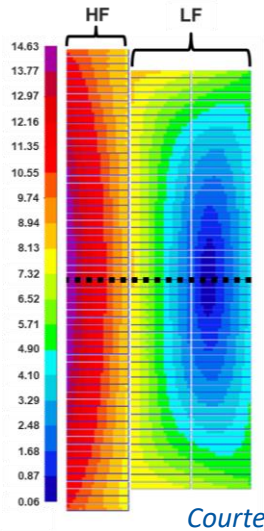
High field magnets based on **common coil** topology & **14 T** aperture field:

- **ISAAC**: **12 T** model magnet with existing coils (RMC) to learn mostly on mechanics. It is our first magnet assembly with Bladder & Keys.
- **DAISY**: **14 T hybrid** model magnet with double layer NbTi coil (Low Field region) & single layer Nb_3Sn coil (High Field region):
  - **Decrease** superconductor material **cost**.
  - **Reduce coil fabrication complexity**: easier handling, no reaction, not so easy to degrade.
  - Potentially **decrease** of **AC losses** and **magnetic instabilities**.

  First magnet with Nb_3Sn coils manufactured in the SMART-Lab.
- **LILAC**: 14 T hybrid model magnet with **accelerator field quality**.



ISAAC 3D design model



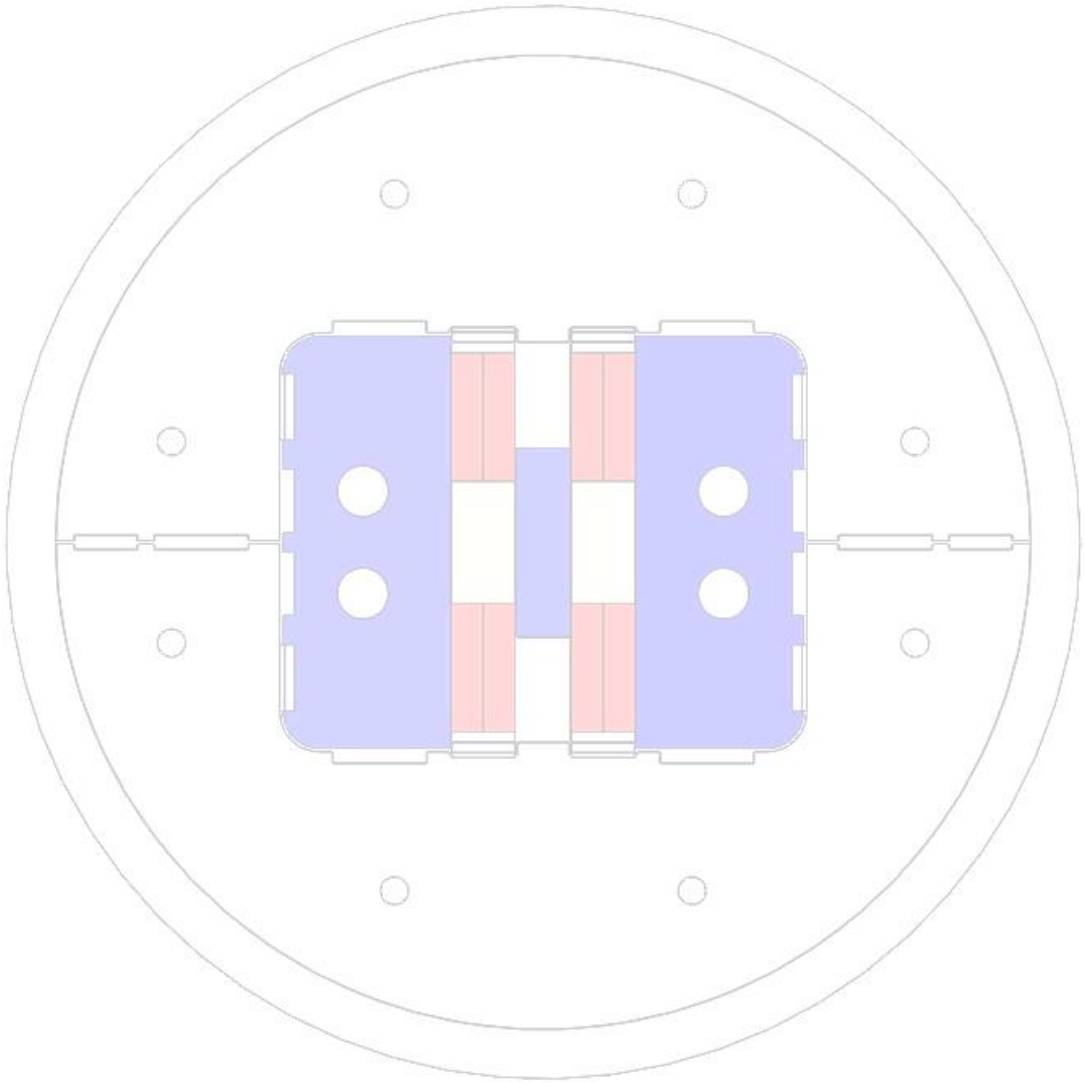
DAISY 2D magnetic model, first quadrant (Q1)

Courtesy J.A. García-Matos

ISAAC: **I**nvestigating **S**uperconducting **A**ssembly to **A**ddress **C**ommon coil mechanics
DAISY: **D**emonstrator for **A**ssembly **I**nnovations in **S**uperconducting common coil technolog**Y**
LILAC: **L**ow-harmonic **I**nnovative **L**ayout for **A**ccelerator-grade **C**ommon-coil magnets

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ISAAC34 (34mm aperture)

Classical support: **high preload** to avoid cable movements (quenches and changes in the field quality).

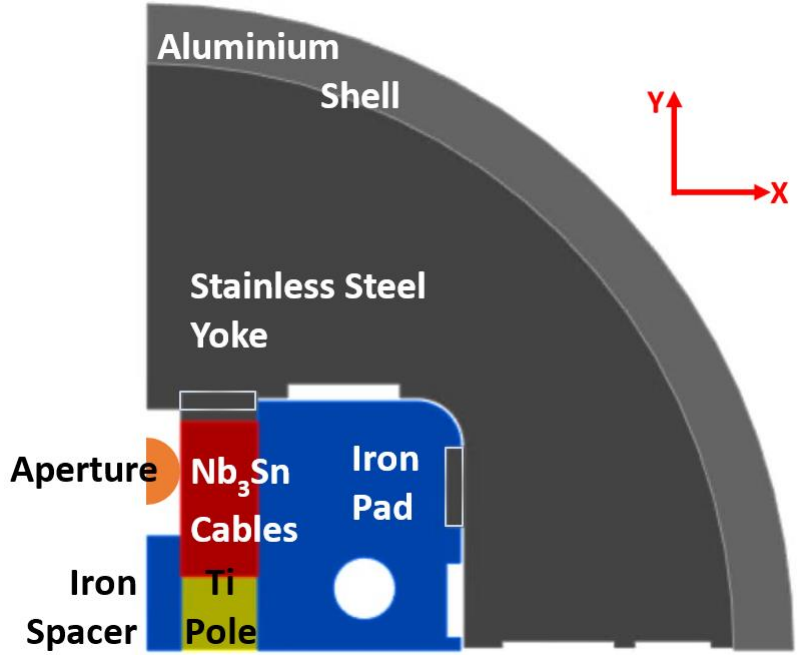
Common coil: horizontal cable deformation/movement has minimal impact on field quality (similar to a perfect wall dipole).

Rigid low-preload mechanical structure with bladder and keys:

- **Yoke horizontally split**: rigid structure limits the coil horizontal displacement & hold large horizontal electromagnetic forces.
- Slight **horizontal** preload (X direction): just **contact**.
- **Low vertical** preload (Y direction) to reduce vertical and shear stress and avoid cable detaching from pole: **0.2 mm** coils-yoke **interference**.

Advantages

- Low preload: **no extra compression** in the cables (only electromagnetic forces).
- No support structure on the aperture side needed: **Better magnetic efficiency** (cables closer to aperture).



ISAAC34 Cross section, first quadrant (Q1)

ISAAC34 Main parameters

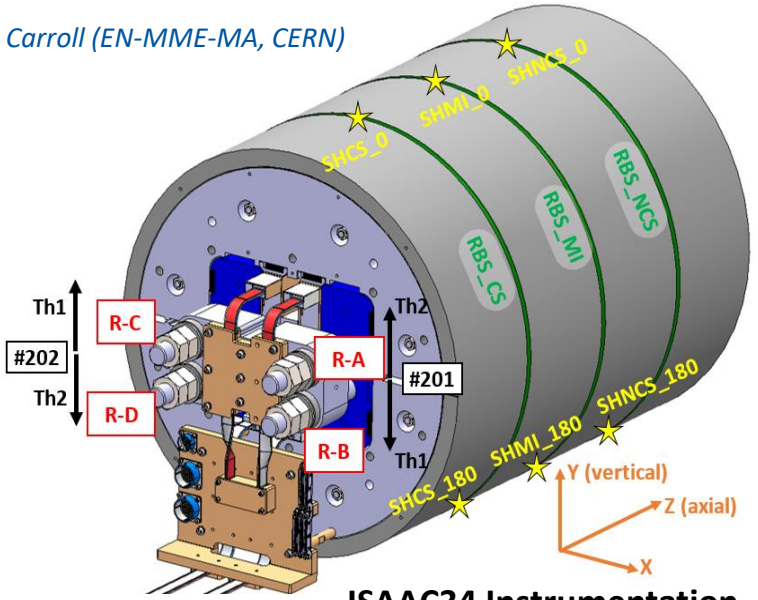
Parameter			Units
Aperture Field	**12**	**14**	**T**
Nominal current	16264	19340	A
Magnetic length	0.55	0.55	m
WorkPoint on LoadLine	85.49	100.59	%
Stored energy	753.9	1049	kJ/m
Peak Field	12.67	14.85	T
Jcu	1314	1562	A/mm^2
Jsc	1576	1875	A/mm^2
Jeng	458	544	A/mm^2
Static L	5.7	5.61	mH/m
F_x (Q1)	4.85	6.56	MN/m
F_y (Q1)	0.28	0.45	MN/m

ISAAC34 Assembly (I)

Courtesy S. Mugnier & H. J. Carroll (EN-MME-MA, CERN)

Instrumentation:

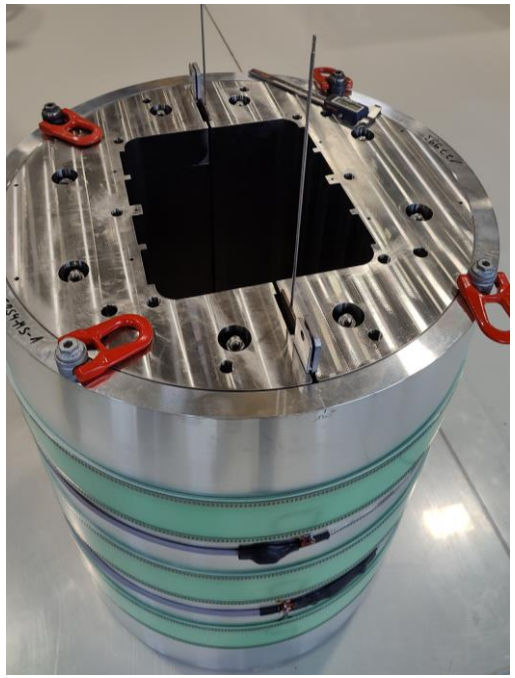
- **Shell**: RBS optical fiber, longitudinal & azimuthal gauges
- **Coils**: Vertical gauges at both sides of the central post of the coils
- **Rods**: Longitudinal gauges



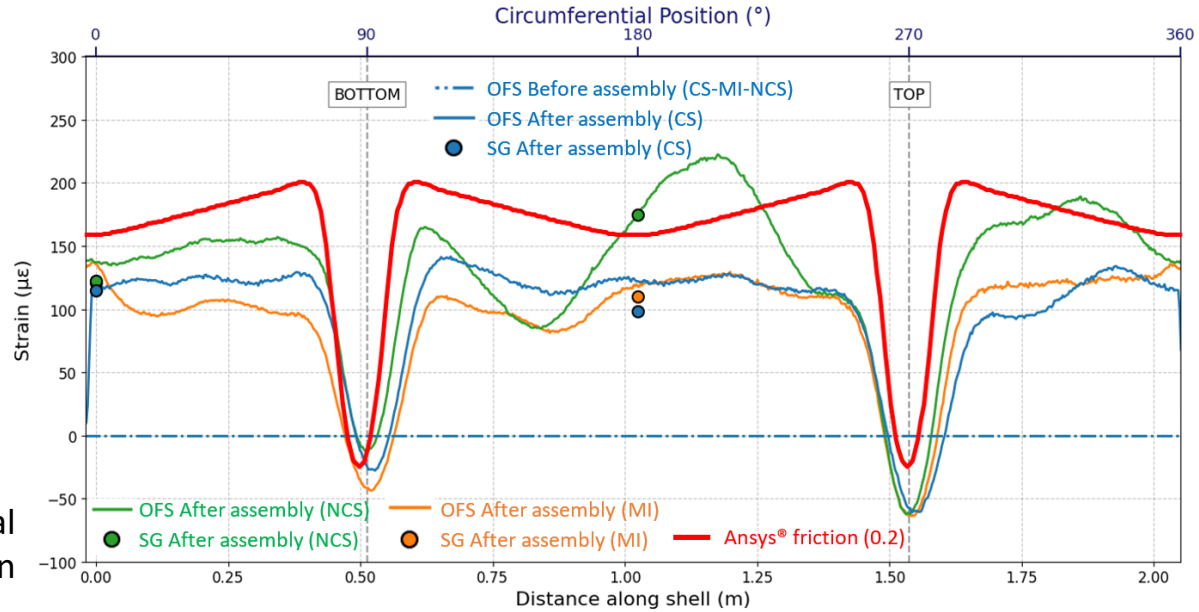
ISAAC34 Instrumentation

Azimuthal strain **gauges**: target 90 με
Measured 123 με after loading
Measured 105 με after relaxation

Yoke & Shell preassembly:



Measured strain values **consistent** with simulations



RBS optical fiber azimuthal strain *vs* simulation

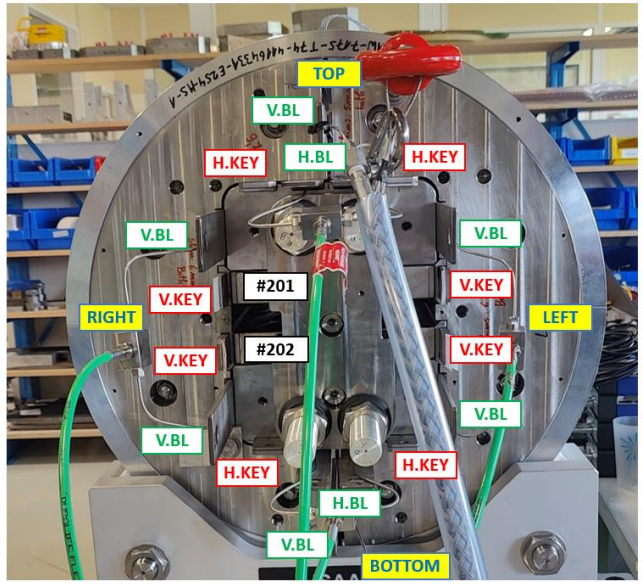
ISAAC34 Assembly (II)

Magnet preload sequence:

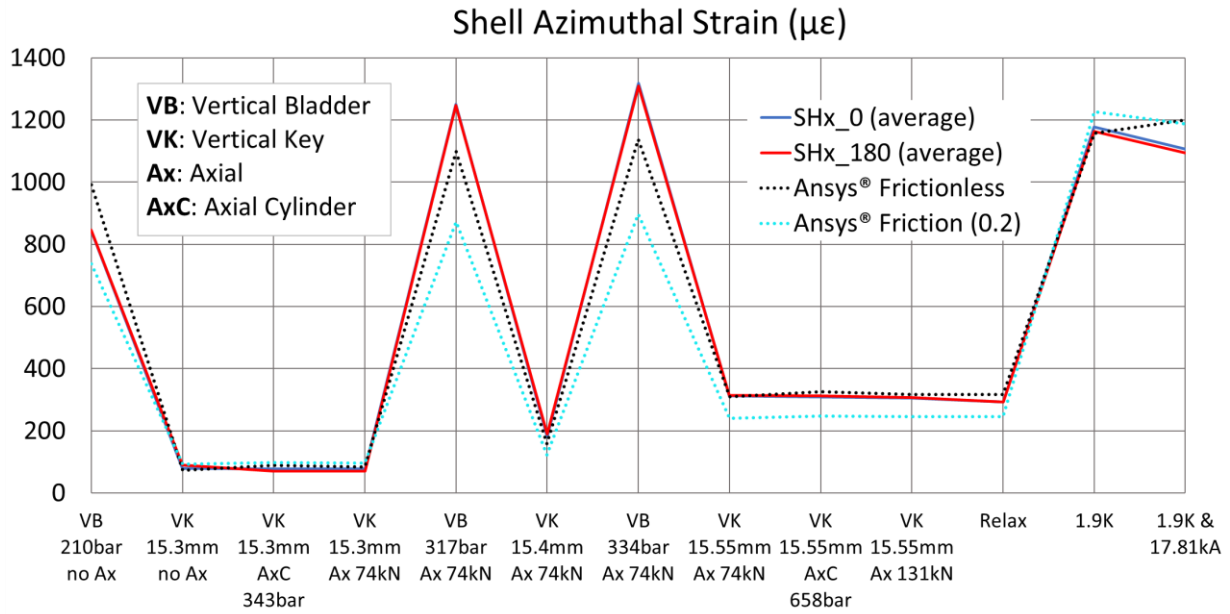
- Half transverse preload (0.1mm vertical)
- Half axial preload (74kN per rod)
- Total transverse preload (0.2mm vertical)
- Total axial preload (148kN per rod)

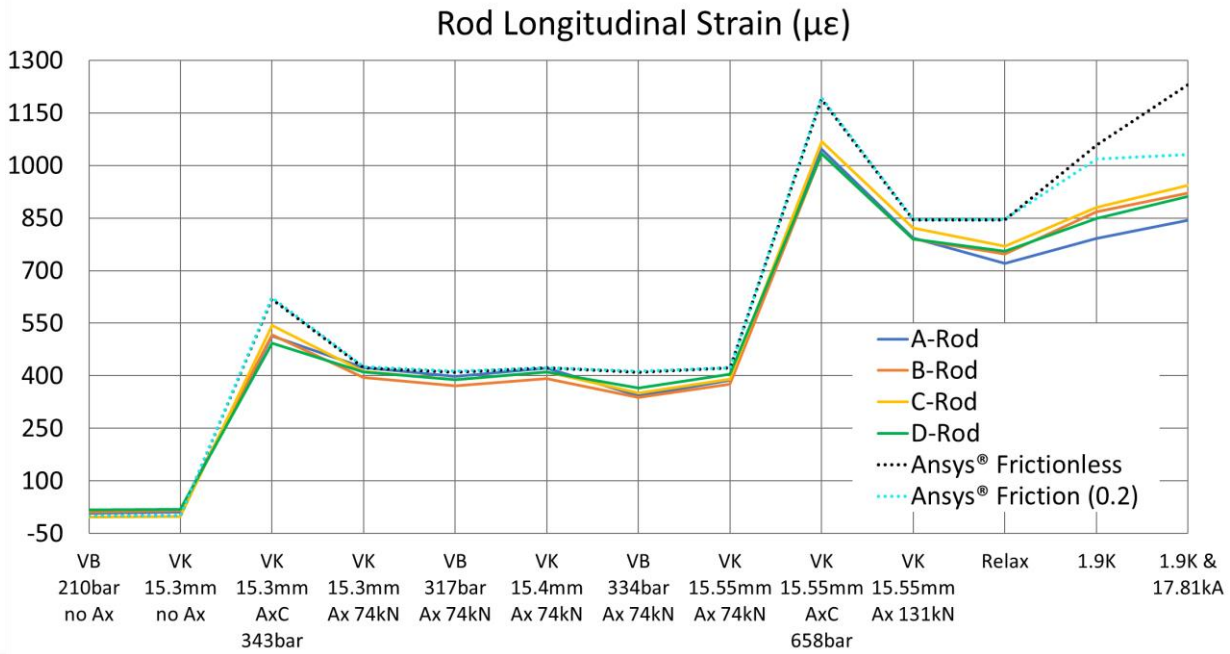
Measured strain values **consistent** with simulations

ISAAC34 Bladder and Keys



Courtesy S. Mugnier & H. J. Carroll (EN-MME-MA, CERN)





ISAAC34 Powering test (I)

Courtesy V. Di Capua (TE-MSC-MQA, CERN)

***Quench**: Sudden loss of superconductivity in the magnet, reverting back to its resistive state (i.e. frictional motion, epoxy failure)*

***Training**: Normally the magnet improves after a quench finding a more stable mechanical configuration. The target for ISAAC34 was set to 10% over nominal: 13 T (17.9 kA) at 1.9 K*

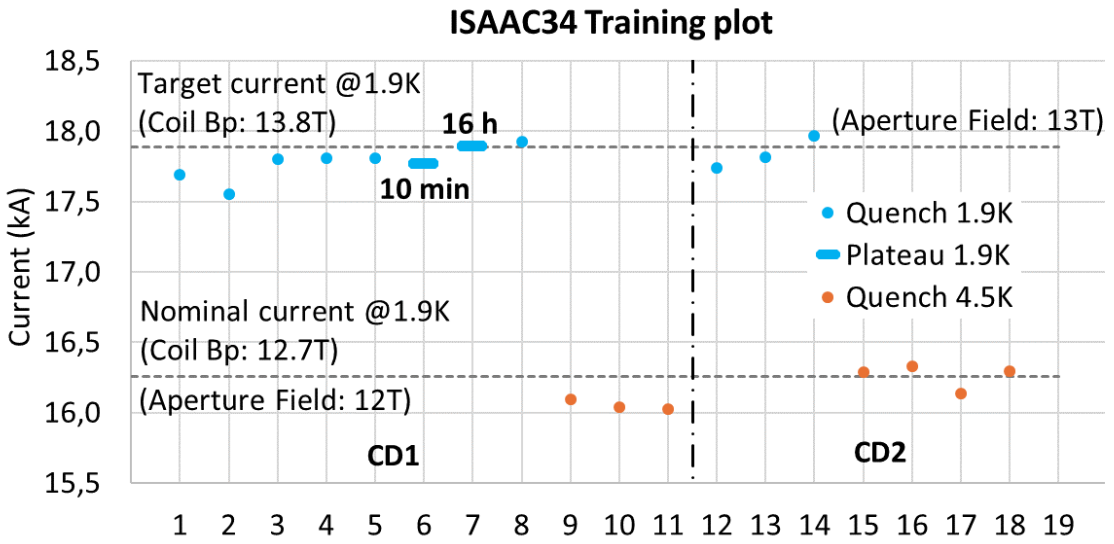
First quenches very close to target, and held **target current without quenches for 16 hours**: **good performance**

*Tests at two **different temperatures** (1.9 K & 4.5 K) give information about magnet limitations (superconducting cable limitations or mechanical issues)*

At both temperatures ISAAC34 reached current levels very close to the cable limits (99.1% of the short sample) **validating the mechanical design concept** of the magnet

***Thermal cycle**: After CD1 the magnet is heated up to room temperature and cooldown again (CD2) to check repeatability.* ISAAC34 performed with a **very good memory**

No signs of cable degradation observed during tests

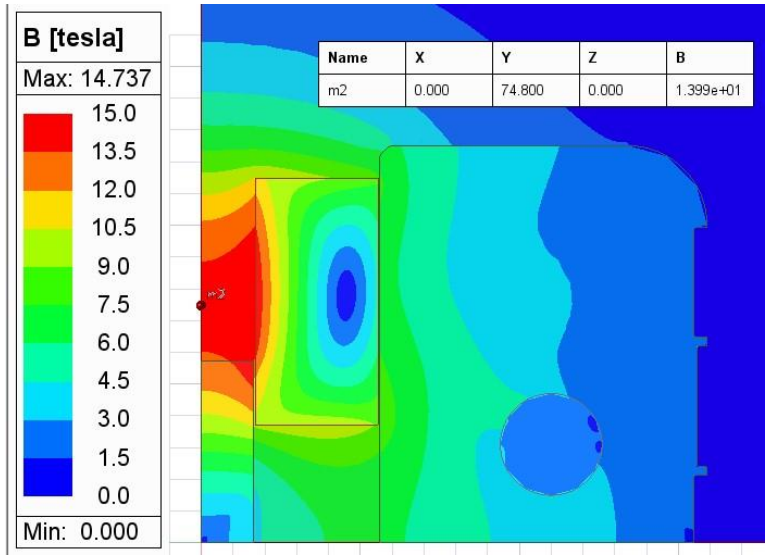


ISAAC34 Powering test (II)

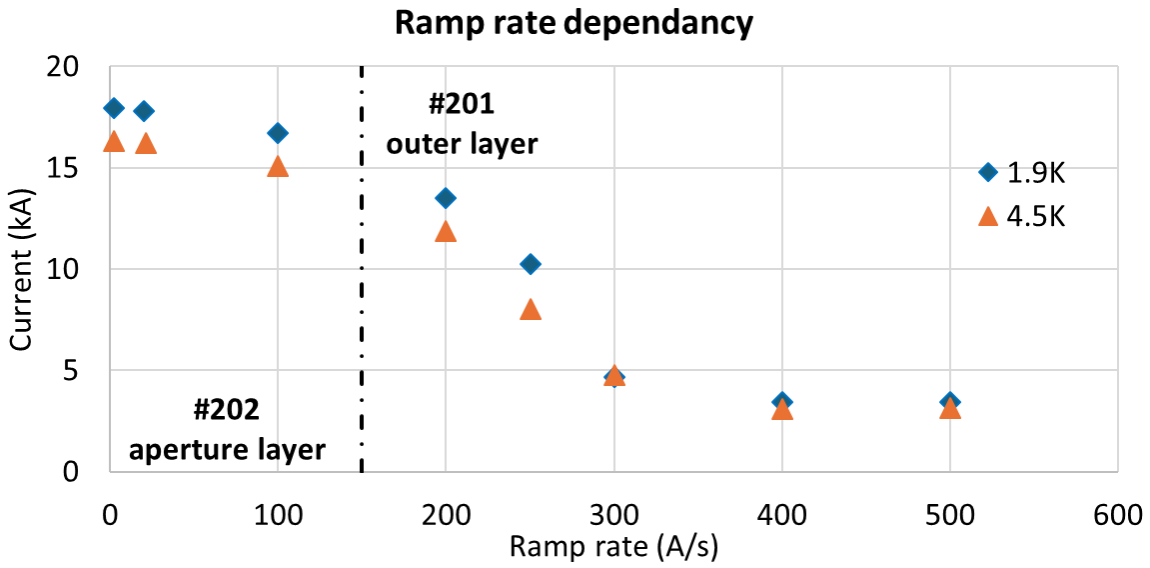
*Tests at **different ramp rates** to evaluate losses due to the Faraday effects (coupling, hysteresis…)*

At low ramp rates: quench current approaches to target (low losses)

At high ramp rates: quench current decreases due to increased losses and non-uniform current distribution across strands



ISAAC34 2D Magnetic field, First quadrant (Q1)



For high ramp rate quenches, ISAAC34 is limited by high losses and **less efficient cooling** conditions:

- Outer layer in contact with the pad (no direct contact with liquid helium)
- Three polyimide insulation sheets around the coils

Courtesy V. Di Capua (TE-MSC-MQA, CERN)

ISAAC34 Magnetic measurements

Field quality is measured by using rotating measurement coils, expressing the imperfections as a series of harmonic coefficients (b_n and a_n). 1 unit is equivalent to one part per 10000

Measured **multipoles** in the central part of the magnet ISAAC34 were **closely aligned** with the calculated ones

It is possible to analyze the influence of the contraction of the magnet parts during the cooldown and the coil deformation due to the electromagnetic forces during powering

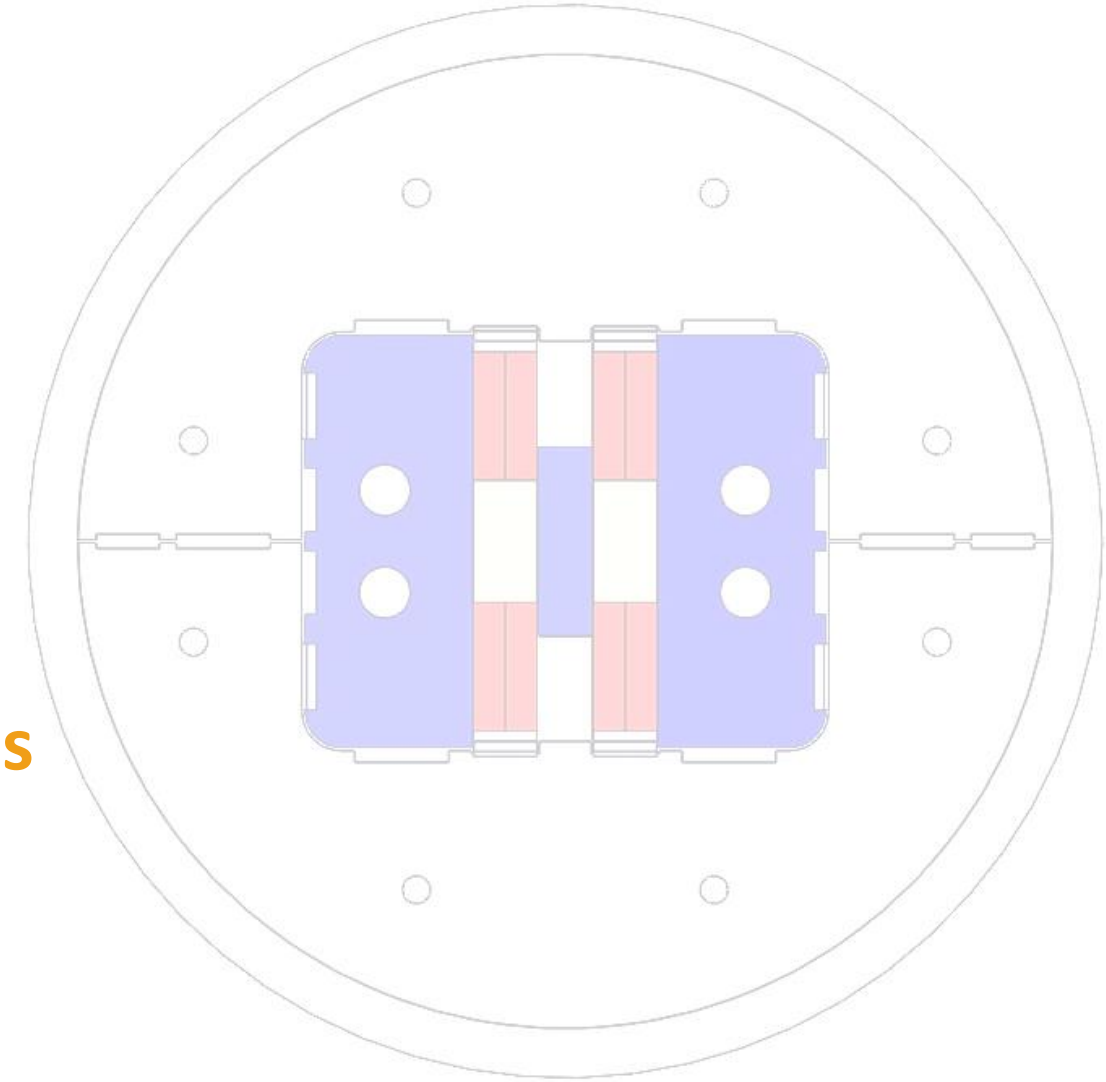
The measurements done in ISAAC34 were not sensitive enough to complete the influence of the coil deformation during powering, but the negligible variation of b_3 (0.9 units) **validates the low preload strategy** for a common coil configuration magnet

Measured aperture field at 16.23 kA (nominal) was 11.8 T, **very consistent** with the calculated one: 11.78 T

Courtesy L. Fiscarelli (TE-MSC-TM, CERN)

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Conclusions & next steps

- **ISAAC34** mechanical design is based on a **rigid low-preload structure**.
- Strain values measured during the assembly consistent with calculations, confirming the **high quality** of the **manufactured components** (Spanish industry, Utimesa) and of the **assembly process** (done at CERN).
- **Excellent performance** of the magnet mechanical design concept, achieving (17.97 kA) **99.1%** of the short sample limit, **13.1 T aperture field** & 13.8 T coil peak field.
- **Magnetic measurements** quite **consistent** with the calculations in Roxie, and validates the **low preload strategy** for the magnet.
- A new assembly **ISAAC24** including **ESC** (Energy Shift with Coupling) protection coils is under study.
- These results are a valuable information for **DAISY** and **LILAC**, the next 14 T common coil demonstrators.

Special thanks to:
Juan Carlos Pérez, Nicholas Lusa & Gregory Maury (TE-MSC-SMT, 927 Lab, CERN)
Sylvain Mugnier & Hannah Jayne Carroll (EN-MME-MA, CERN)
V. Di Capua (TE-MSC-MQA, CERN) & L. Fiscarelli (TE-MSC-TM, CERN)





Thanks for your attention!

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