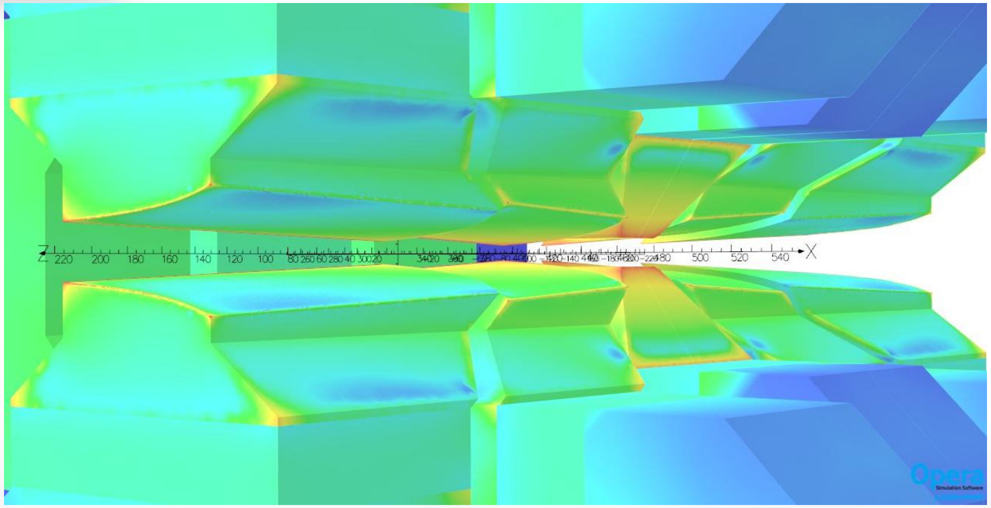
Development of a high-field longitudinal gradient dipole at CIEMAT



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NANOBEAMS TECHNOLOGIES
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Outline

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Introduction

- CLIC: Damping rings (DRs) **to reduce the emittance** of the injector chain incoming beams

- Lattice: theoretical minimum emittance (TME) cell and simple FODO lattice filled with high field superconducting damping wigglers.

- The **horizontal emittance** is further reduced below the TME limit for a given magnetic structure by considering **dipole magnets with longitudinal variable bending field**

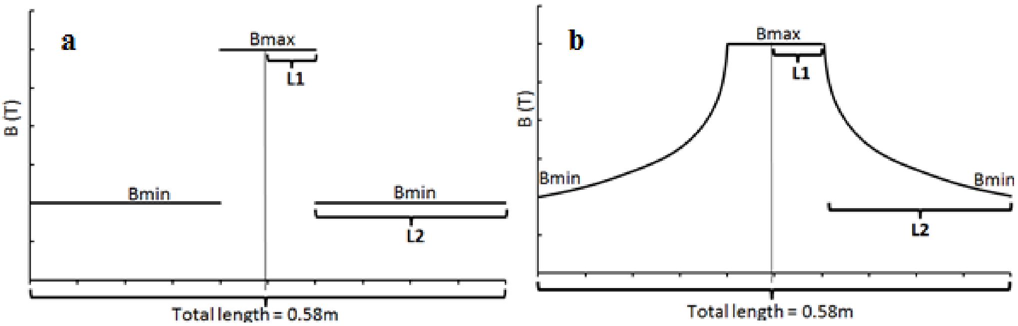
- **Trapezium field profile dipoles are preferred** in the CLIC DR lattice

Technical specifications

TABLE I
TECHNICAL SPECIFICATIONS

Good field region radius [mm]	5
Field harmonics [units 1E-4]	~1
Transverse gradient [T/m]	11
Magnet length [m]	0.58
Aperture diameter [mm]	13

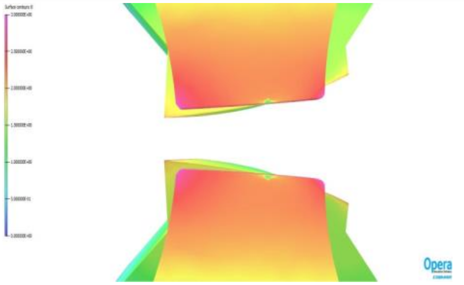
	Step profile	Trapezium profile		
		Case 1	Case 2	Case 3
# of dipoles	96	90	90	90
Dip. field [T·m]	0.625	0.667	0.667	0.667
Bmax [T]	1.7666	1.7666	1.7666	1.7666
Bmin [T]	0.8737	0.7791	0.7508	0.7146
L1 [mm]	65.858	3.352	13.836	26.488
L2 [mm]	224.142	286.648	276.164	263.512



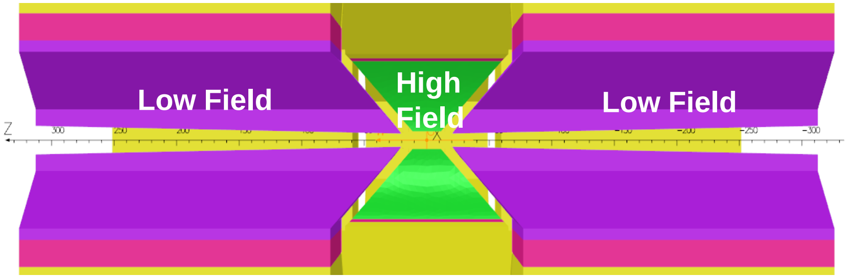
Magnetic design

- Permanent magnets based design
- Max Temp variation ±0.1ºC => No specific temperature compensation
- Extremely low energy deposition expected => No cooling
- Taking into account radiation tolerance, volume and weight, maximum remanent magnetization, cost,…:
  - SmCo in the outer modules
  - NdFeB in the inner modules
- Result comparison/validation: **Ansys Maxwell, ROXIE, COMSOL and Opera**

Magnetic design



- Combined function magnets: dipolar and quadrupolar field. Hyperbolic pole tip profiles



- Longitudinal trapezium profile: tough challenges. Achieved introducing a **variable gap** along Z axis

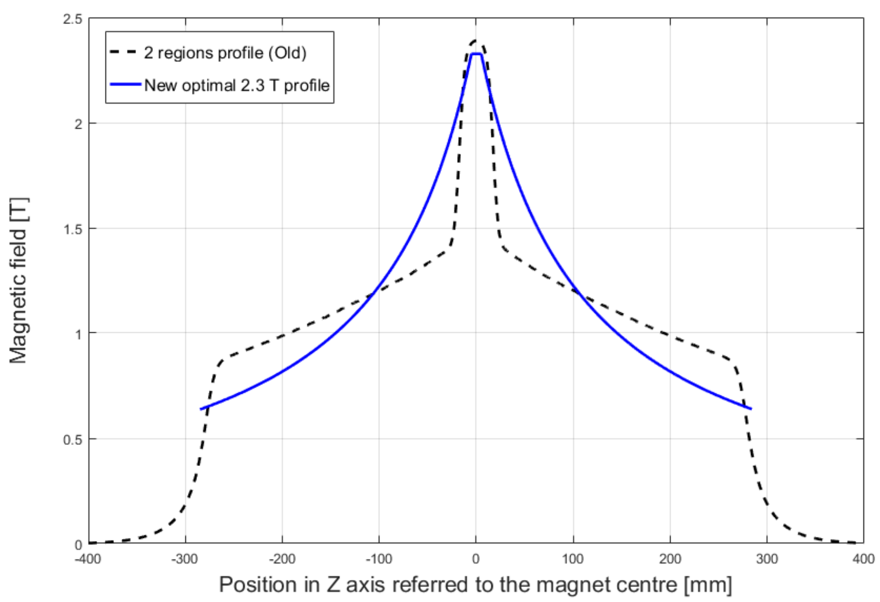
- Magnet originally limited to 1.77 T peak field as a reasonable value for a non-superconducting magnet

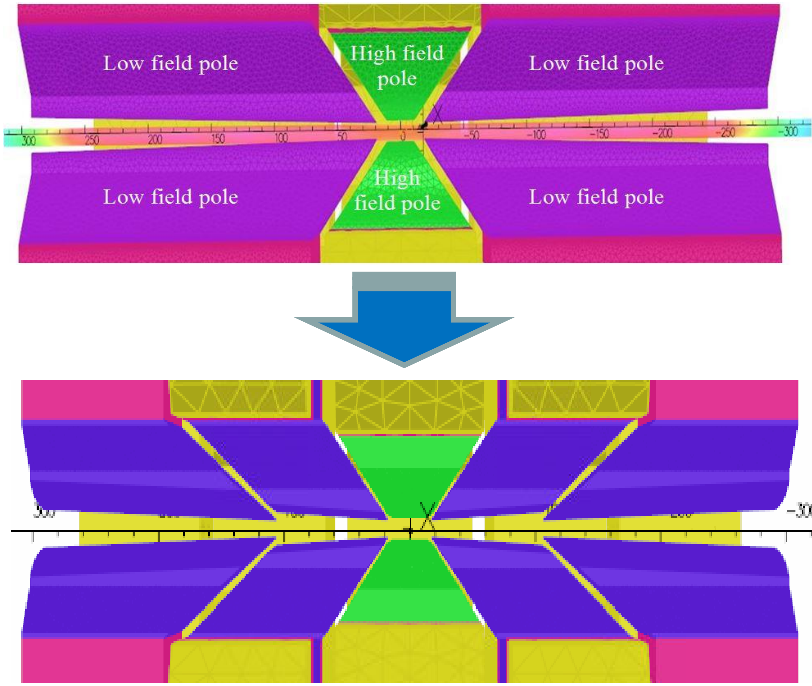
- 3D simulations: peak could be increased above 2 T

- A new 2.3 T optimized trapezium profile was finally proposed

Magnetic design

- At that point the magnet **was close to meet** the desired specifications.
- The obtained decay –“Old profile”, black- at both sides of the peak does not match the ideal one (hyperbolic, blue)
- The **low field region is split** in two parts: **low and mid field region**



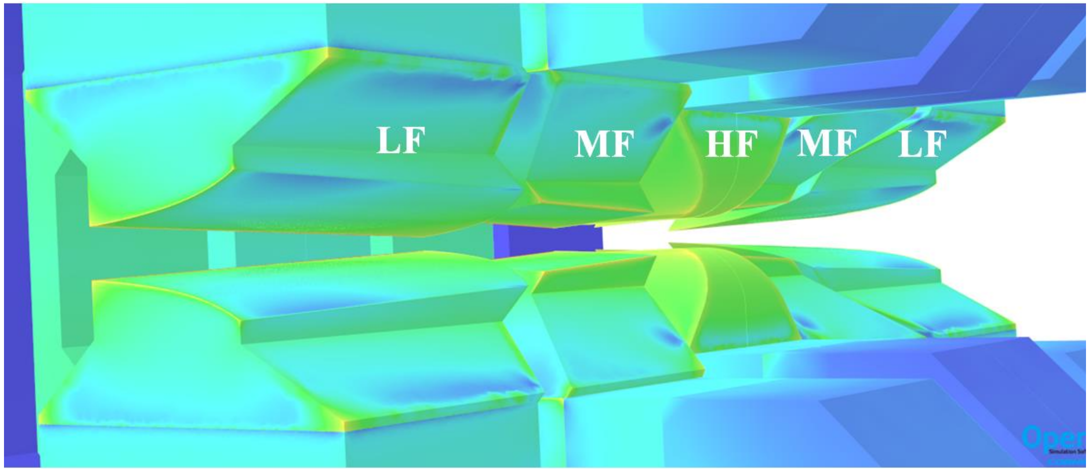


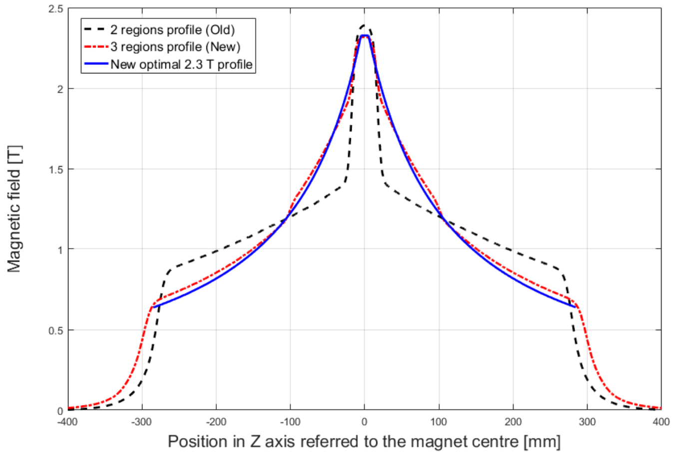
Magnetic design

- **Upgrade: Three** differentiated sections: **low, mid and high field**

- **Maximum field** is increased up to 2.3 T and at the same time the new field decay (red) matches more precisely the ideal hyperbolic desired profile (blue)

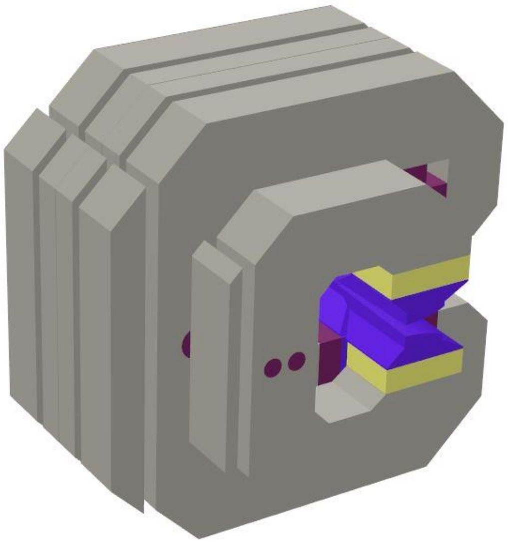
- This allows a higher F_{TME} =7, higher than the one originally proposed (4)





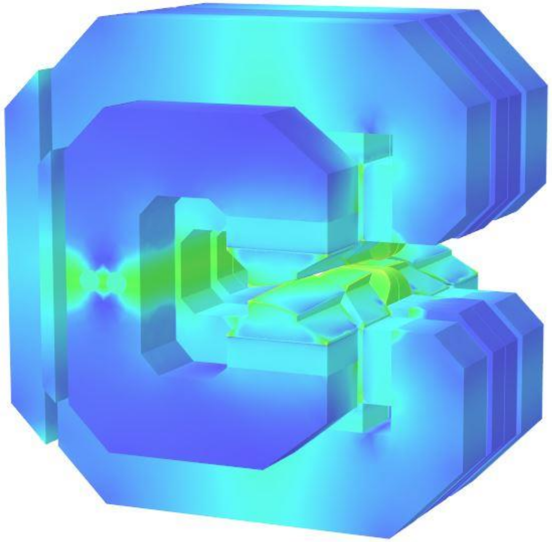
Field trimming

- Split yoke. Moving parts allow to adjust the magnetic circuit reluctance



- This solution could not reach the desired ±5% regulation

- Backup solution: Yoke holes will be filled with steerable permanent magnet rods if more regulation is needed

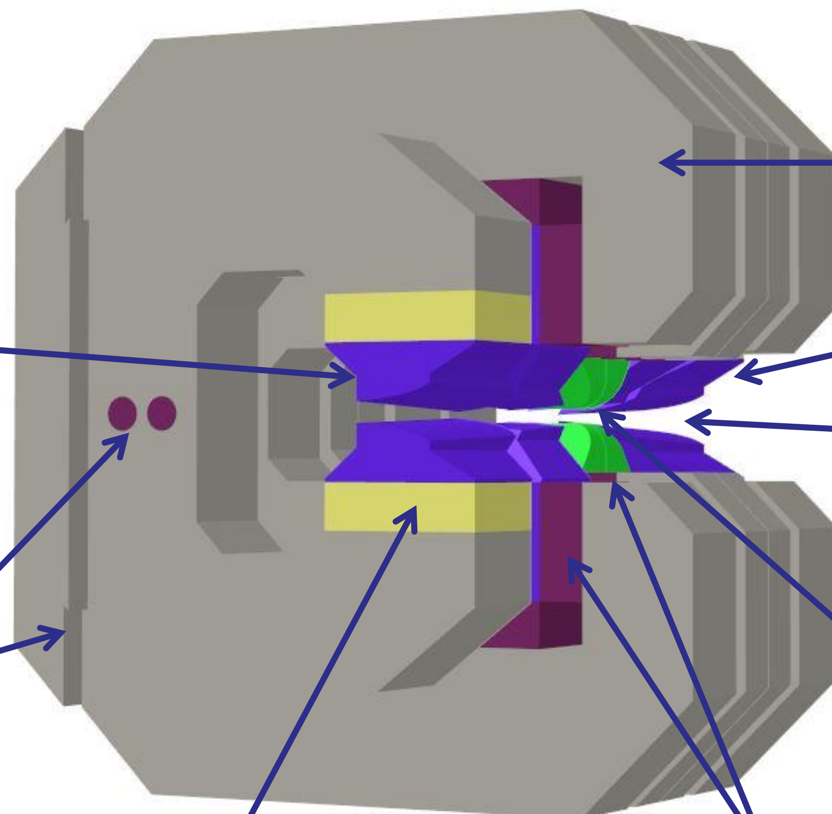


- It will reach the ±5% easily

Magnet Overview

Dimensions:
0.65 x 0.68 x 0.56 m

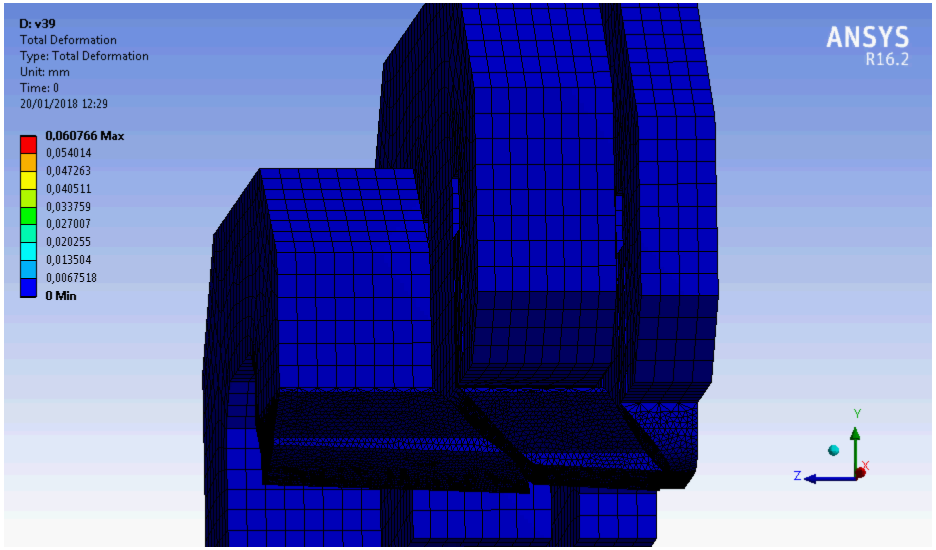
Weight: 1.1 T



Mechanical design

- Forces (analytically calculated with VW method):

	LF	MF	HF
Y axis	5272 N	5957 N	5425 N
Z axis	1047 N	1210 N	0 N (symmetry)



- Maximum Stress: 69 Mpa

- Max. Deformations:
  - Y axis: 0.06 mm
  - Z axis: 0,009 mm

- Including these deformations in the Opera model, the multipole values are still kept within the desired values:

	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10
Base	10000	-567.9	5.5	2.1	-0.1	-0.1	-0.0	0.0	-0.0	0.0
Def	10000	-567.7	5.6	2.0	-0.2	-0.2	-0.1	0.0	-0.0	0.0

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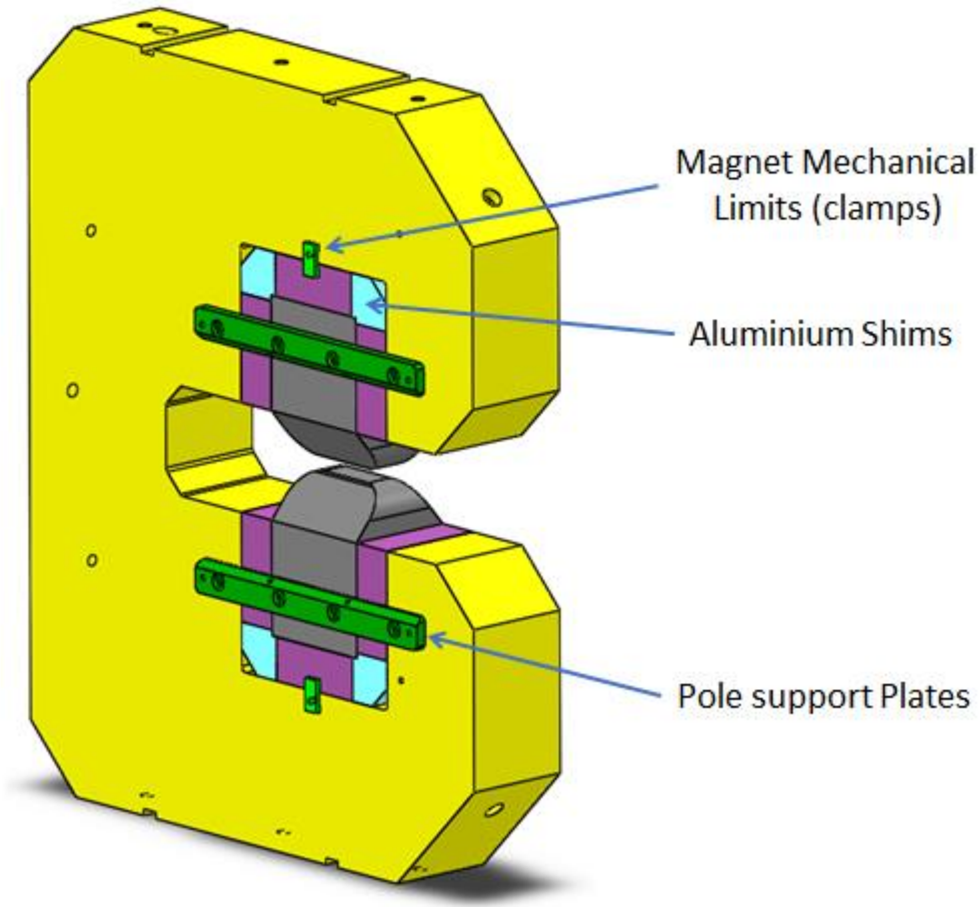
Mechanical design

- HF Module:

  - This module will be fixed
  - No pole regulation
  - Reference



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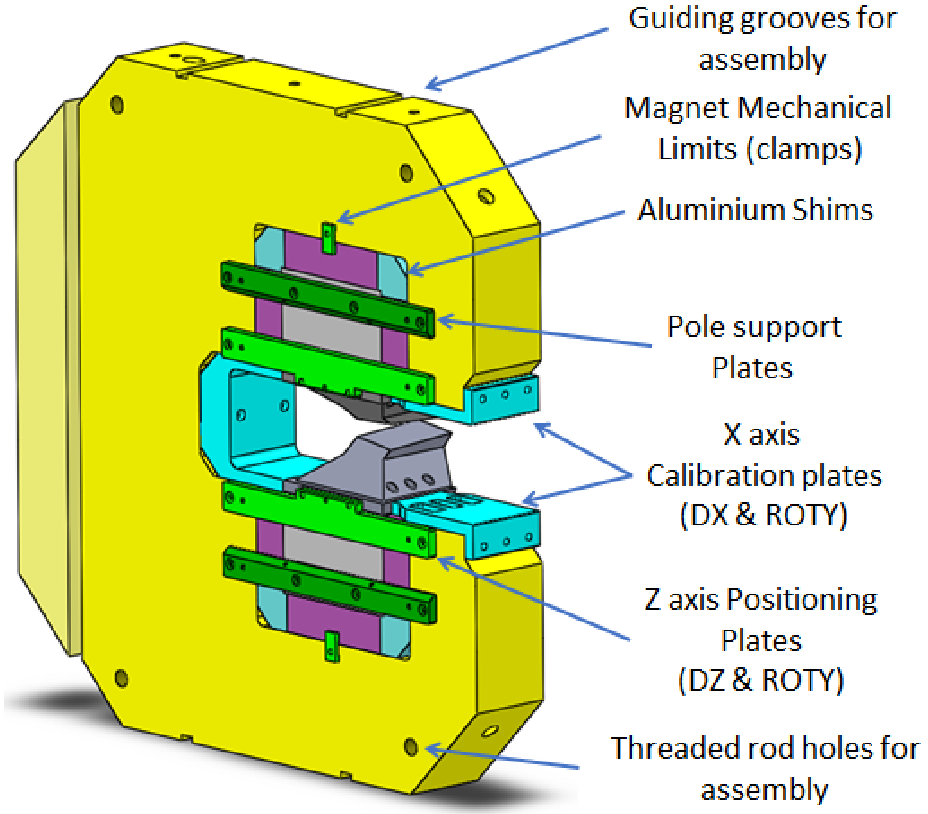
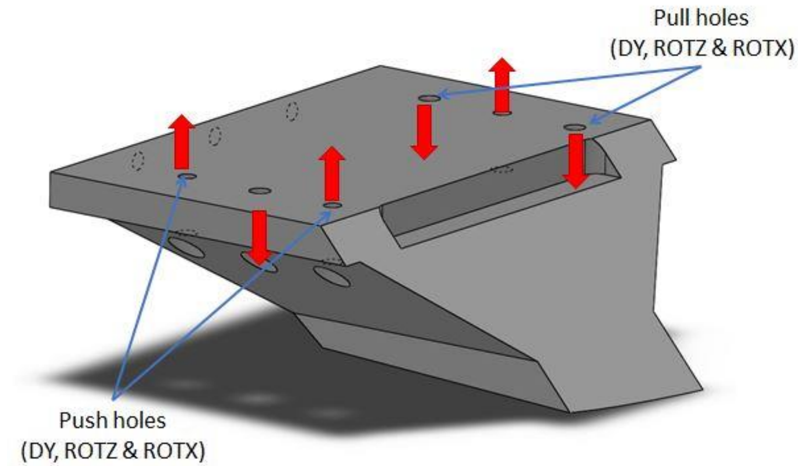
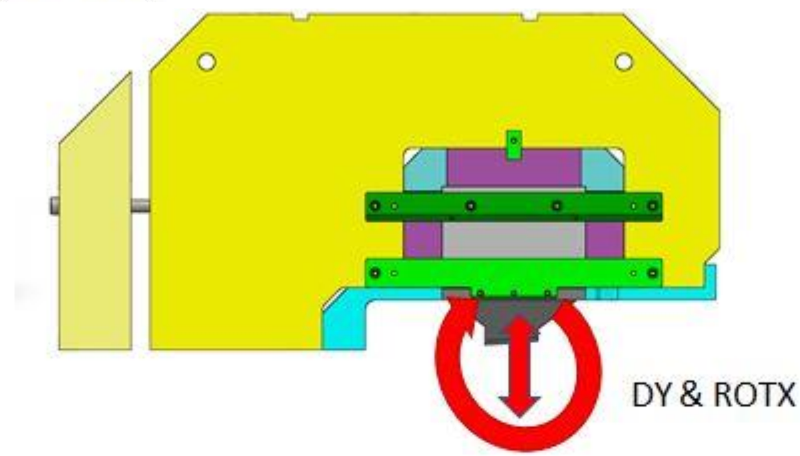
Mechanical design

- MF Module:

  - Pole adjustments in X, Y and Z (±1mm)

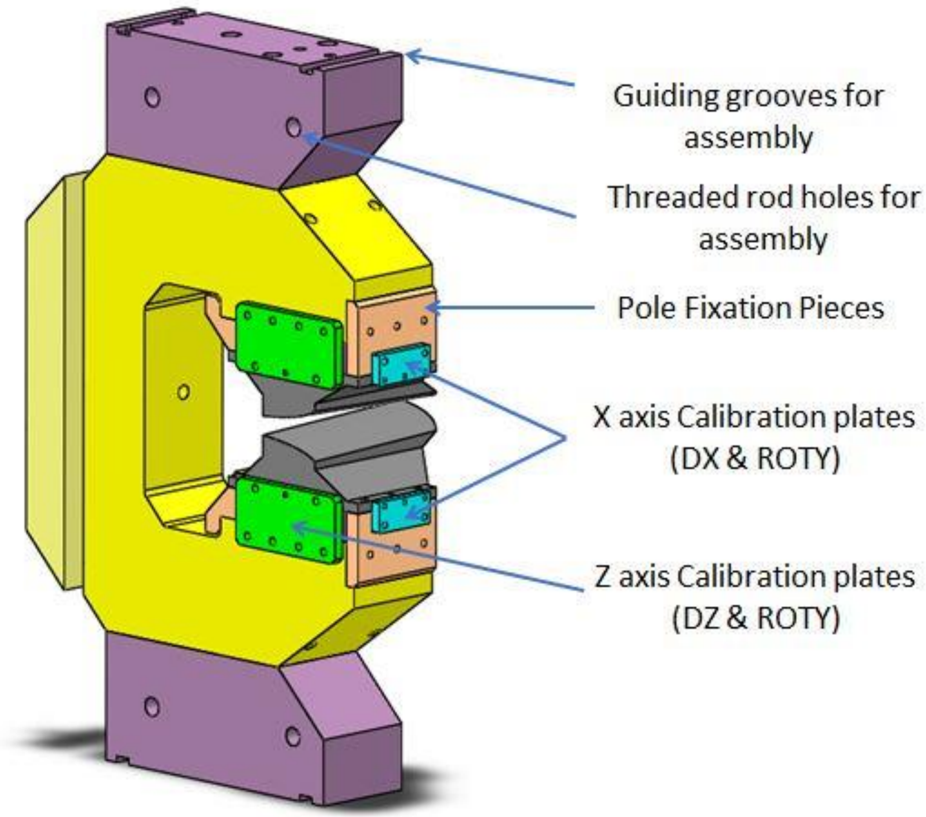




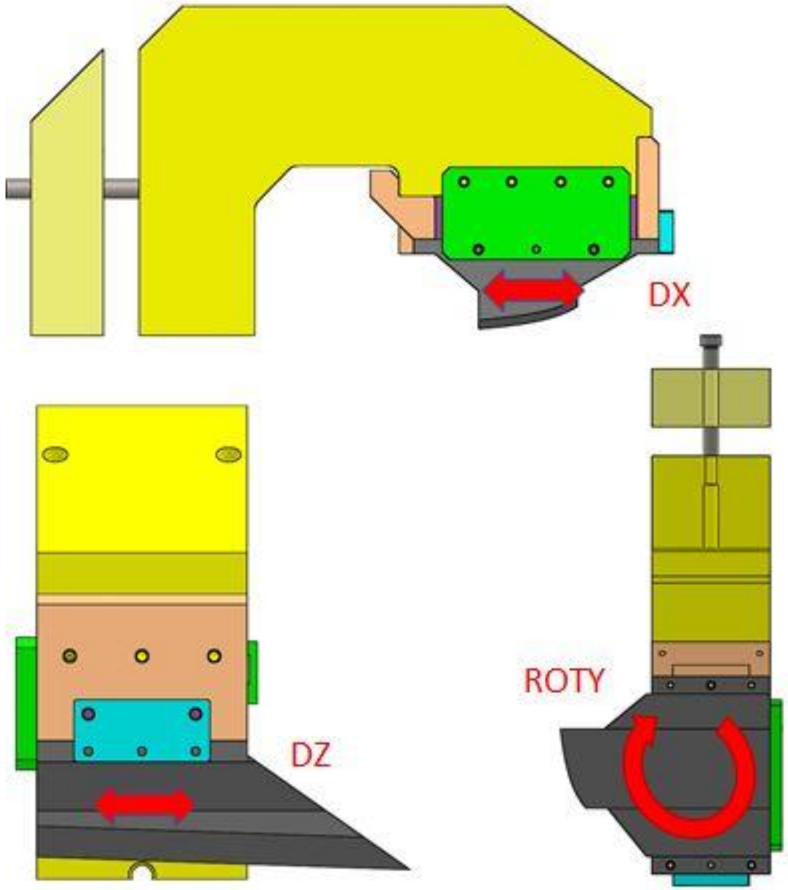


Mechanical design

- LF Module:

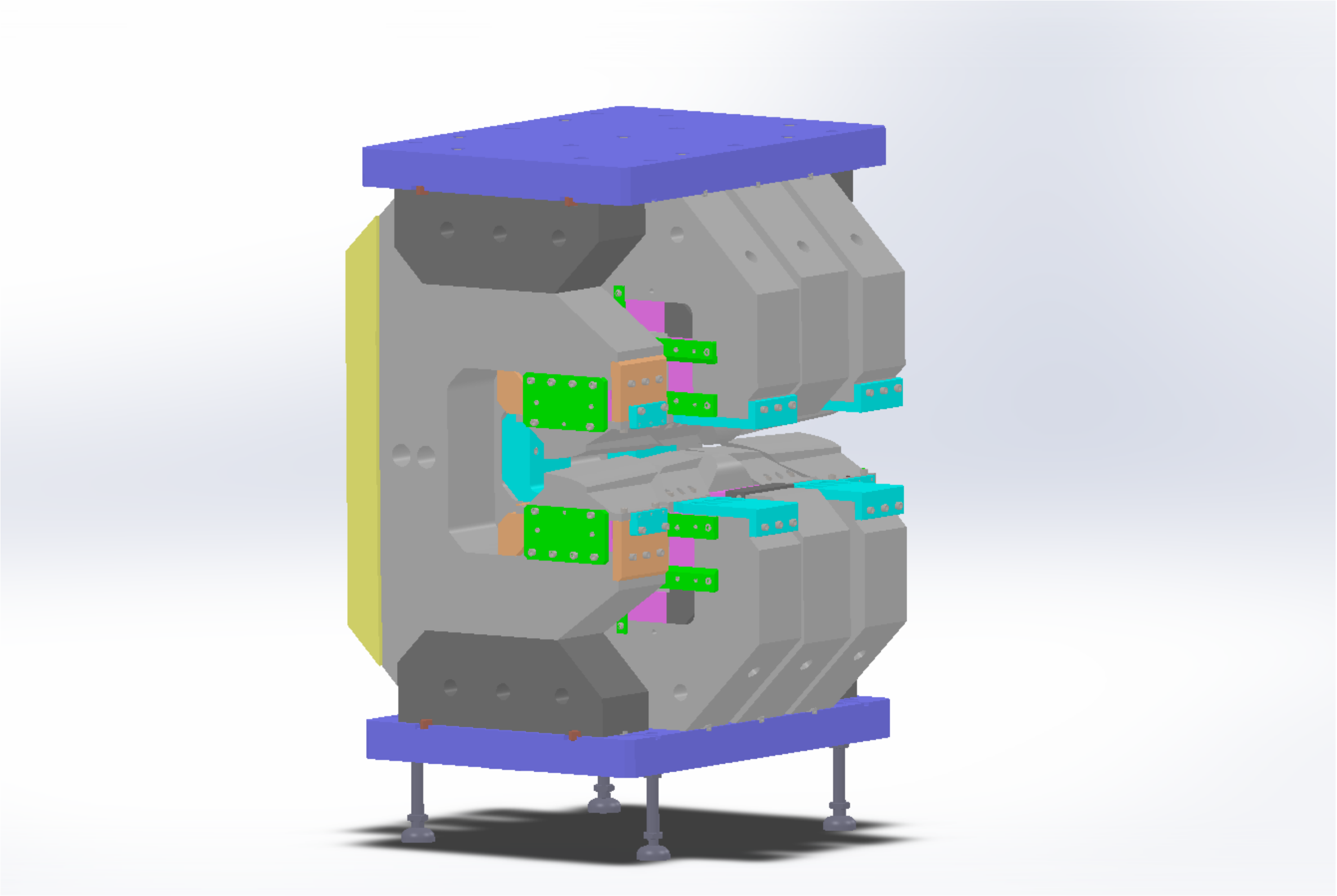


- Pole adjustments in X, Y and Z (±1mm)



Mechanical design

- Assembly:



Mechanical design

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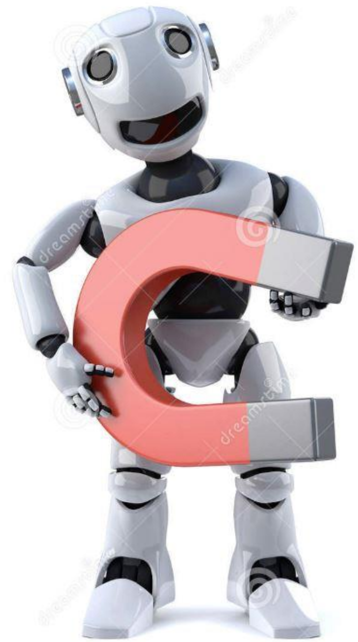
Conclusions

- PM based design: compact, no power consumption and no maintenance
- High peak field (saturation)
- Important challenge: **longitudinal gradient with trapezoidal decay.** Solved splitting the magnet in **three differentiated field regions**
- The final design **meets –and even exceeds** in terms of beam emittance reduction- the specifications. This achievement is due to the trapezoidal field profile, which has been implemented **for the first time in an accelerator magnet**
- Multiple backup solutions and adjustments implemented to achieve the desired field quality and specifications

Ongoing work

- 98% of the pieces produced, received and checked!
- Remaining 2% already under production
- Based on this magnet, a proposal was sent to Horizon 2020 Innovation Pilot Project for Particle Accelerators, and finally awarded with the third position in the prototypes category
- A new version of these magnets will be used in the Elettra new upgrade (*)

> (*) For further information, see Emanuel´s presentation: https://agenda.infn.it/event/20813/contributions/110196/



Thank you for your attention!

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