This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

VAriable Dipole for the Elettra Ring (VADER)

Low Emittance Rings' workshop 2025 – DESY, 09/10/2025

Y. Papaphilippou (CERN) for the **IFAST collaborators**

VAriable Dipole for the Elettra Ring - VADER

- **Task** within I.FAST **WP7**: High Brightness Accelerators for Light Sources (led by R. Bartolini, DESY)
- Partners and collaborators:

CERN

Y. Papaphilippou
(A. Poyet)

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

M. Dominguez
F. Toral

Elettra Sincrotrone Trieste

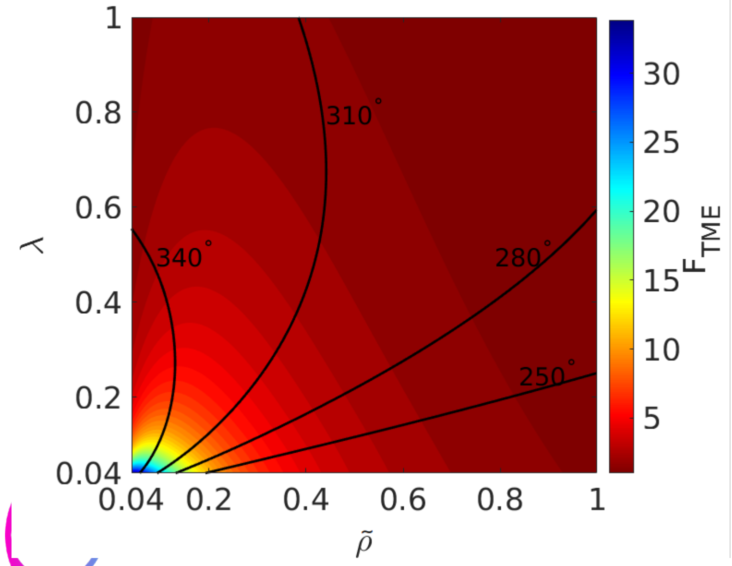
E. Karantzoulis
D. Castronovo

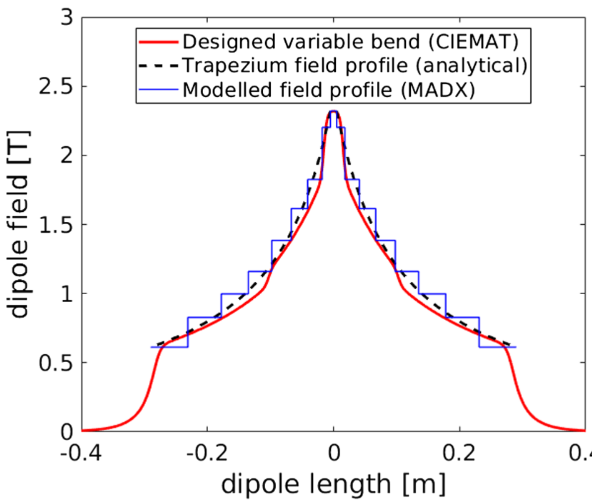
KYMA

R. Geometrante

VADER objectives

- **Fabricate** an innovative dipole magnet prototype with longitudinal varying dipole field, including a transverse gradient for the ELETTRA upgrade
- Permanent magnet **concept** with trapezoidal bending radius, **2.3 T** peak field and ~**10 T/m** gradient, already established (CERN/CIEMAT)
- Proved the **horizontal emittance reduction** to ultra-low levels of i.e. **~60 pm @ 2.86 GeV**, for the CLIC DR (M. A. Domínguez Martinez et al., IEEE Trans. Appl. Supercond. 28, 1, 2018; S. Papadopoulou et al, PRAB 22, 091601, 2019)
- First **demonstrator constructed/qualified** by CIEMAT





VADER objectives

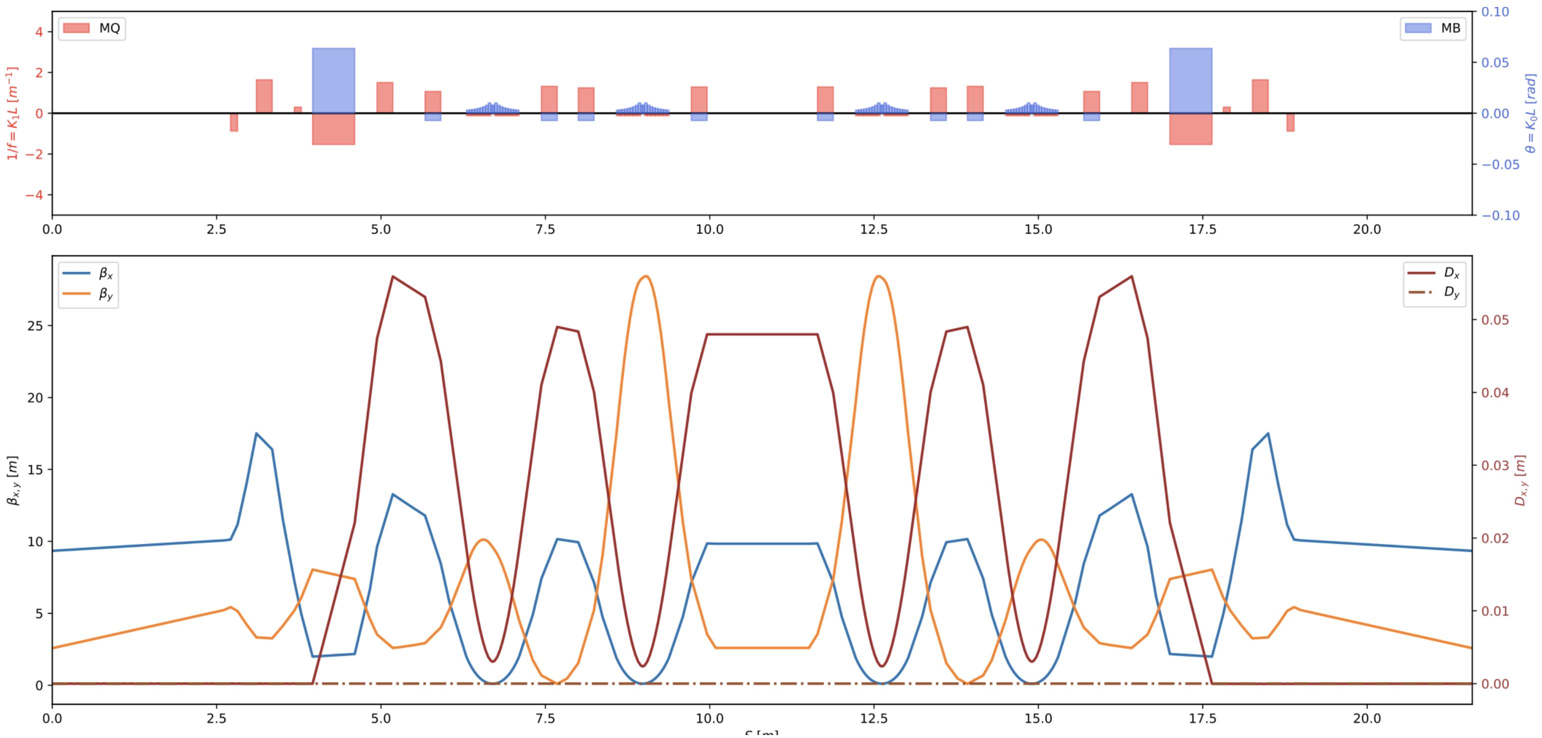
- Keep the same **S6BA-E** lattice for Elettra and replace the LG dipoles by VADER ones.
  - Implement a **trapezoidal profile in bending radius**
  - Observe a **clear emittance reduction**

- Some **constraints**:
  - Same **geometrical layout**
  - Same **total bending angle** for each dipole
  - Same **dipole length**

- But also some freedoms:
  - We set the dipole **peak field at 2.3 T** (as for the CLIC magnet) instead of the current 1.8 T

Lattice and optics design

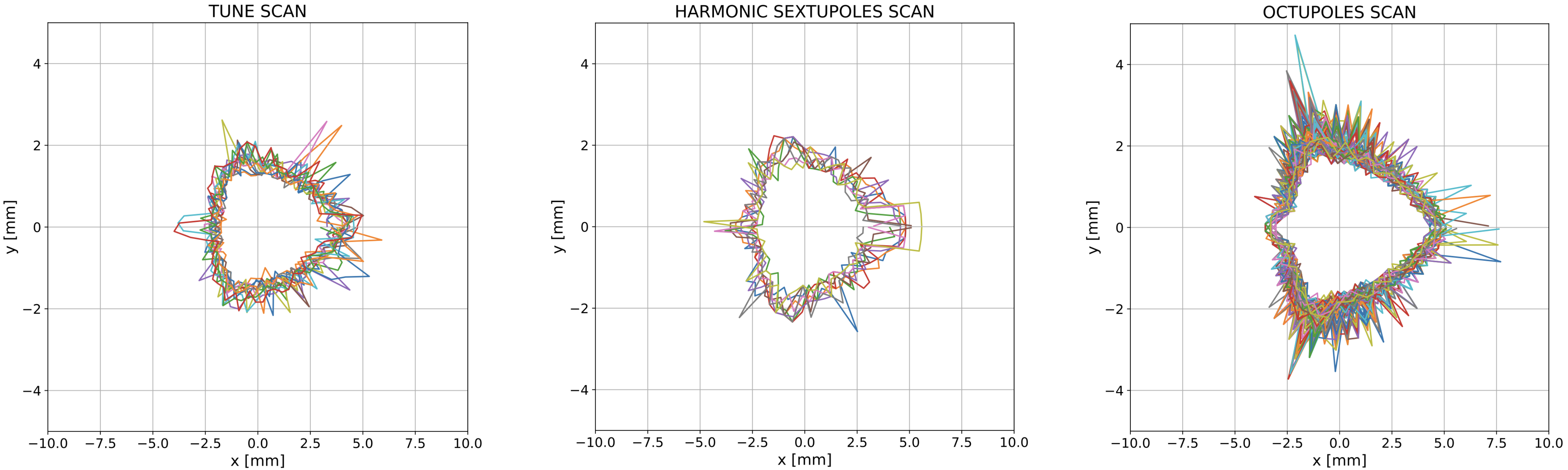
A. Poyet



- Optics constraints at the ID are **matched**
- **Horizontal emittance reduction from 212 to 100 pm (more than factor of 2!)**
- **Tunes: 34.706 / 22.852**
- **Chromaticities: -157/-125**

Non-linear Optimization

On-momentum, without error



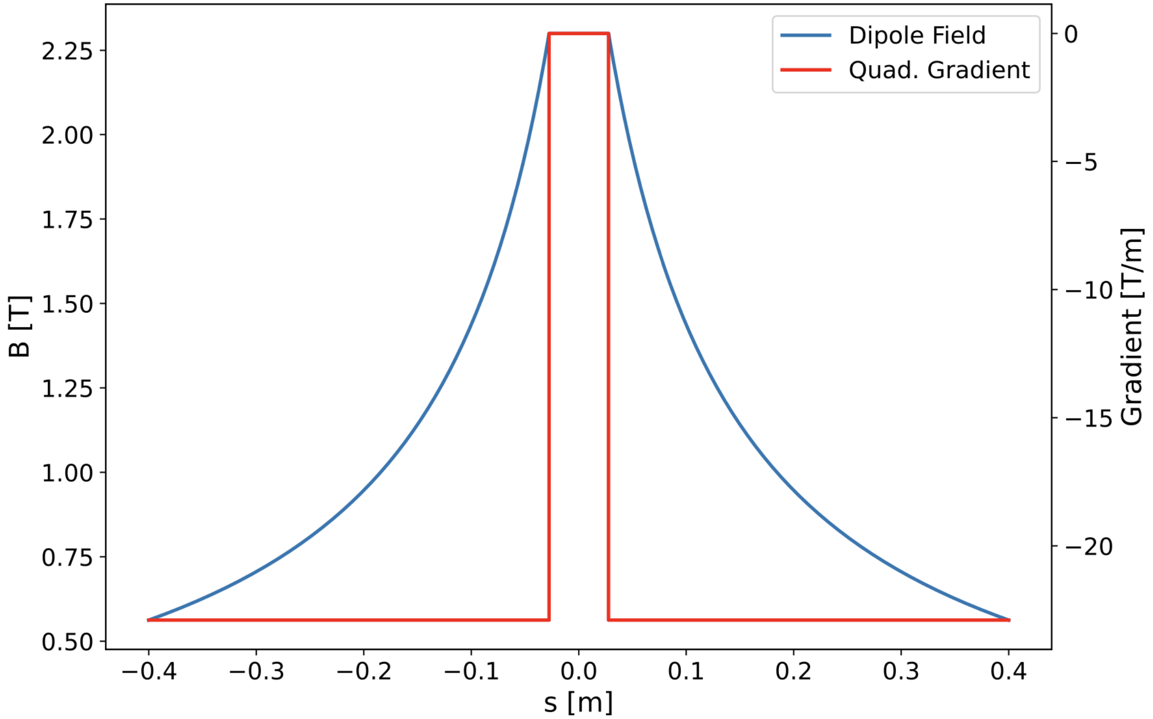
→ Up to ~ 6 mm DA in the horizontal plane, ~ 3 mm in the vertical one

→ Good starting point for further iterations, including errors/corrections, tune optimisation etc.

Profile Design and Magnet Specifications

- **Similar parameters as CLIC DR but…**
  - **Higher transverse gradient (> factor of 2)**
  - **Higher magnetic gap (~40%)**
  - **Longer magnet (~40%)**

Specifications	CLIC DR	VADER
Magnet Gap (mm)	**13**	**18**
Max Field (T)	2.3	2.3
Transverse G (T/m)	**11**	**23**
Field Quality (Units 1E-4)	≈ 1	≈ 1
Magnet Length (cm)	**56**	**80**



Magnetic design challenges

- Needed to satisfy field requirements for **curved trajectory**.
- **Curved trajectory** combined with **higher gap** and **low multipole content** for iron dominated magnet that works under saturation, extremely difficult objective
- **Sagitta** much **higher** than expected
- **Impossible** to perform required calculations with **Opera software** for **curved trajectory**
- This forced to **manually develop in-house code** (CIEMAT) to analyse field quality in both **Opera** & **Matlab**

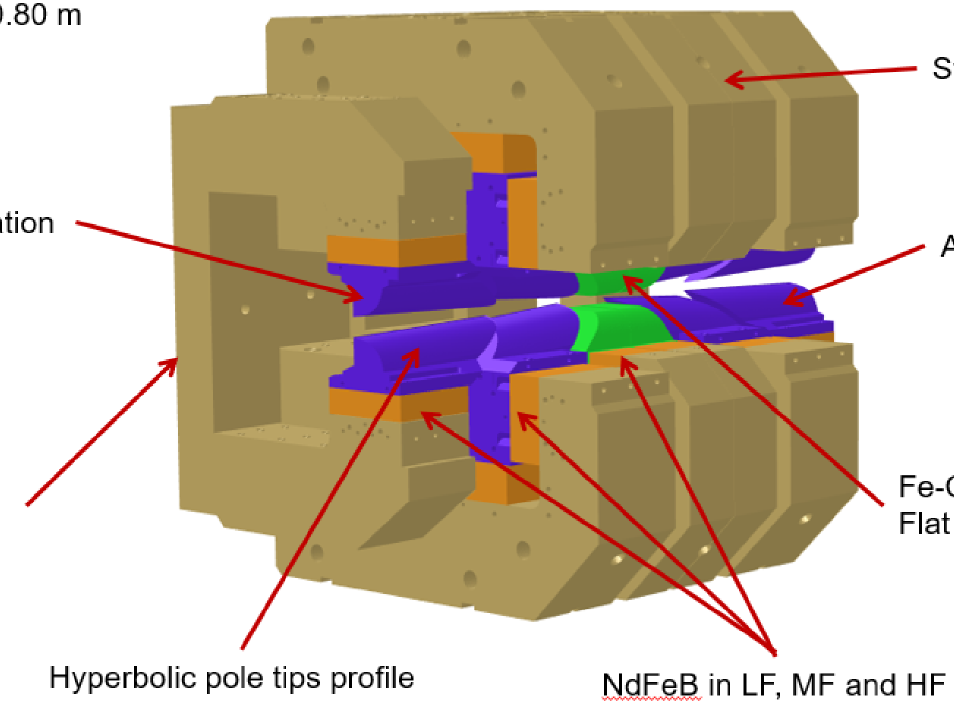
Magnetic Design @ CIEMAT

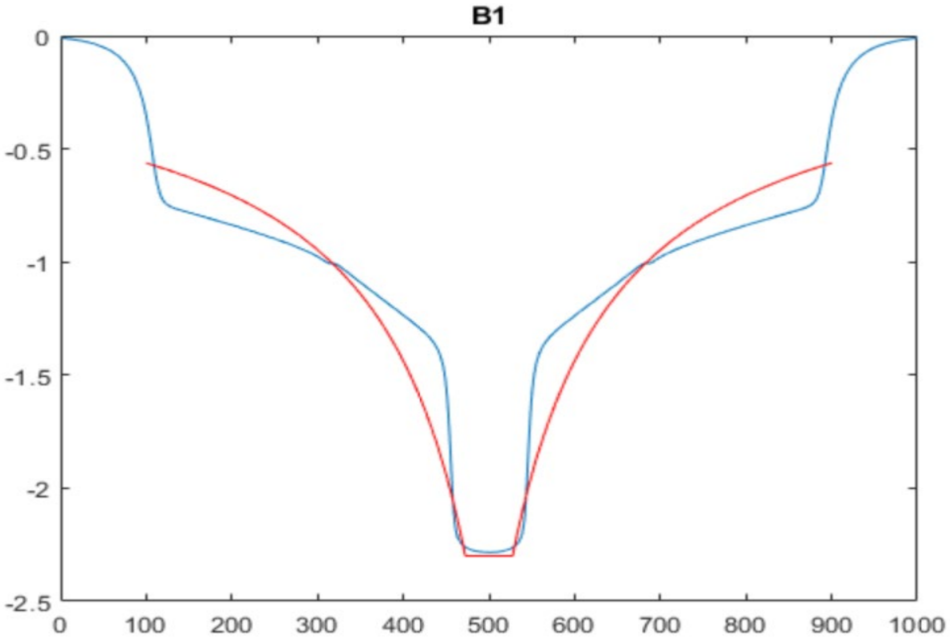
M. Dominguez,
F. Toral

Combined Function
Longitudinal gradient with trapezoidal shape (2.3 T Peak)
Transverse gradient 17 T/m

Dimensions:
0.65 x 0.68 x 0.80 m

Weight: 1.5 T

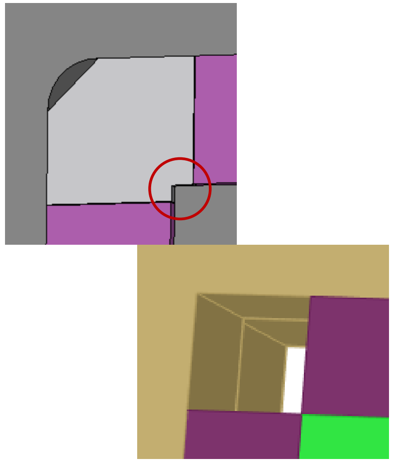




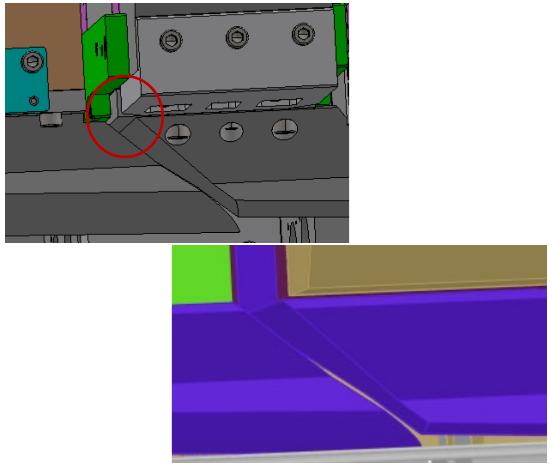
- **Longitudinal gradient** profile **achieved**
- **Integrated transverse gradient slightly below specs** but **ok for optics**
- **Field quality** looks reasonable
- **Mechanical design done**
- **Fabrication drawings communicated to KYMA**

B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
10000	-807.79	4.65	6.74	-1.09	0.21	-0.07	2.55E-05	-0.01	-0.03

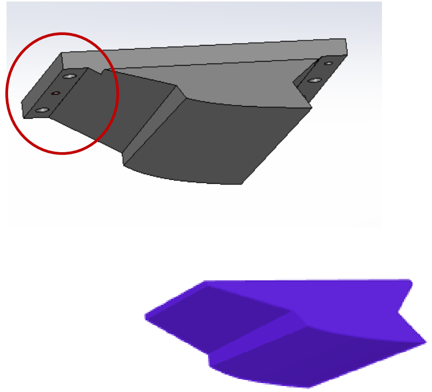
Resolving CLIC prototype issues for VADER



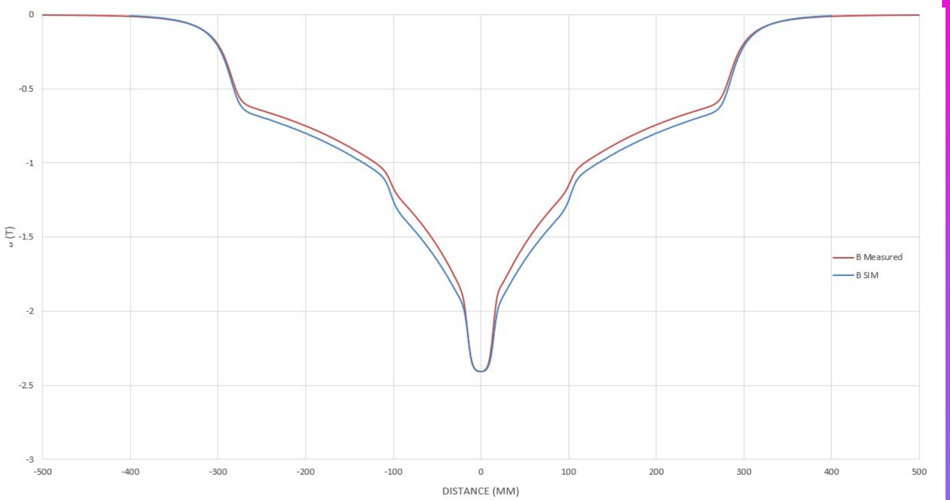
6 mm HF & MF pole base expansion



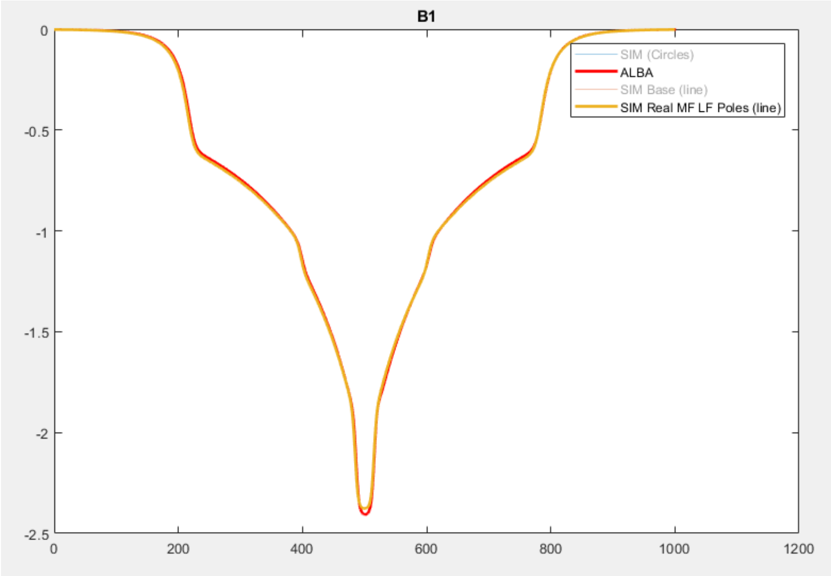
MF pole extrusion



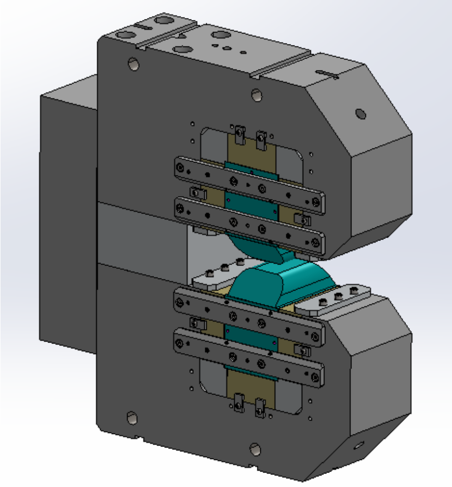
LF pole extrusion



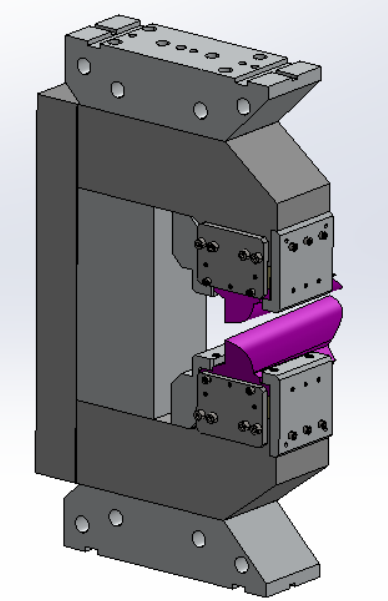
- **Discrepancy** in CLIC prototype between simulations vs magnetic measurements: **4% lower integrated dipolar field**
- **Various investigations**: missing Armco heat treatment, misalignment, hysteresis, simulation error, etc.
- Traced back to **3D mechanical model details** not reflected **Opera simulation model** due to **simplifications**
- All three simulated allow **model** matching perfectly **magnetic measurements: 0.641T simulated vs 0.638T measured**



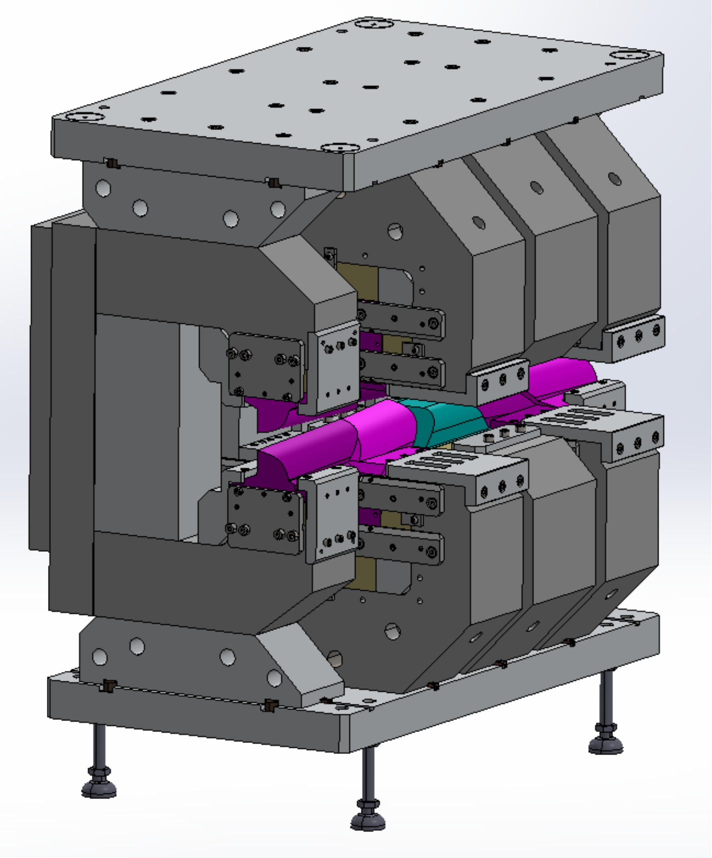
VADER: Final Mechanical Design



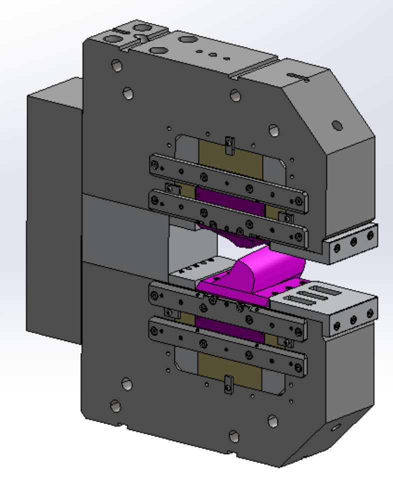
HF Module



LF Module



Final assembly



MF Module

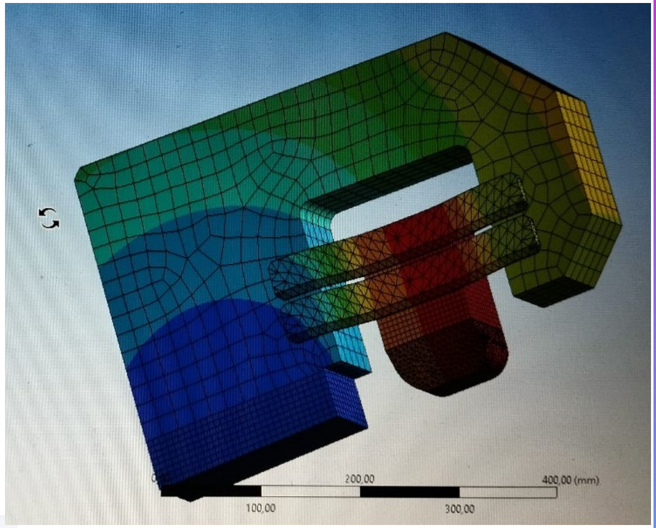
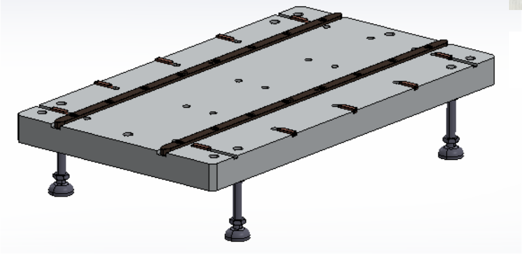


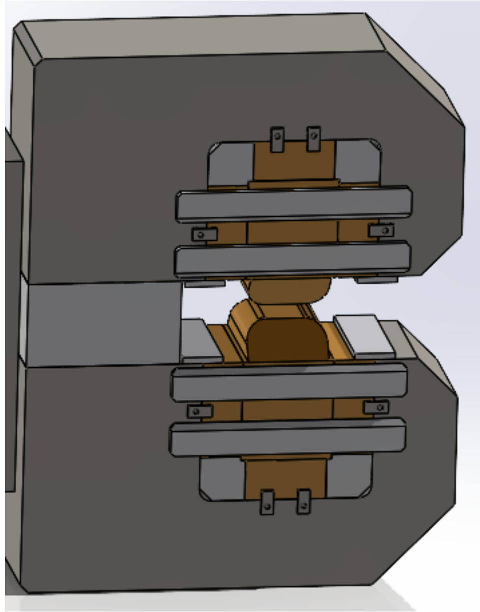
Fig. 6: Deformations in the HF module

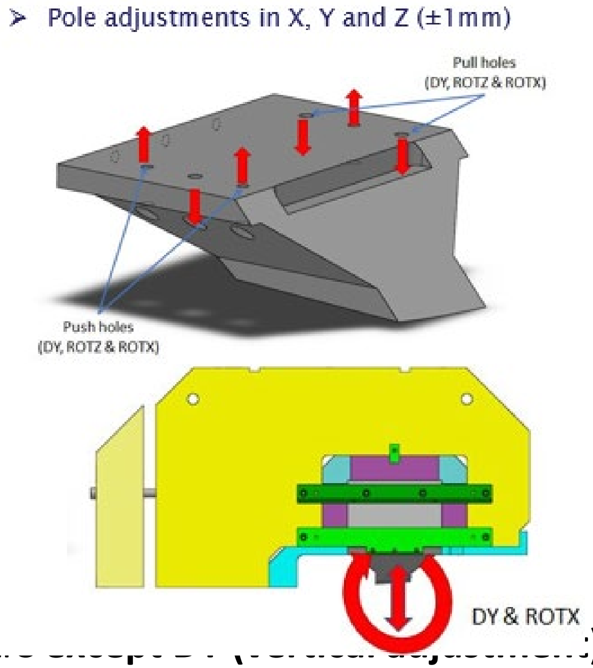


Base with guides

VADER vs CLIC Prototype: Main differences

- **Iron yokes** formed by **3 main pieces** instead of one, **screwed** from **iron to iron** across aluminium support block (before first assembly step)

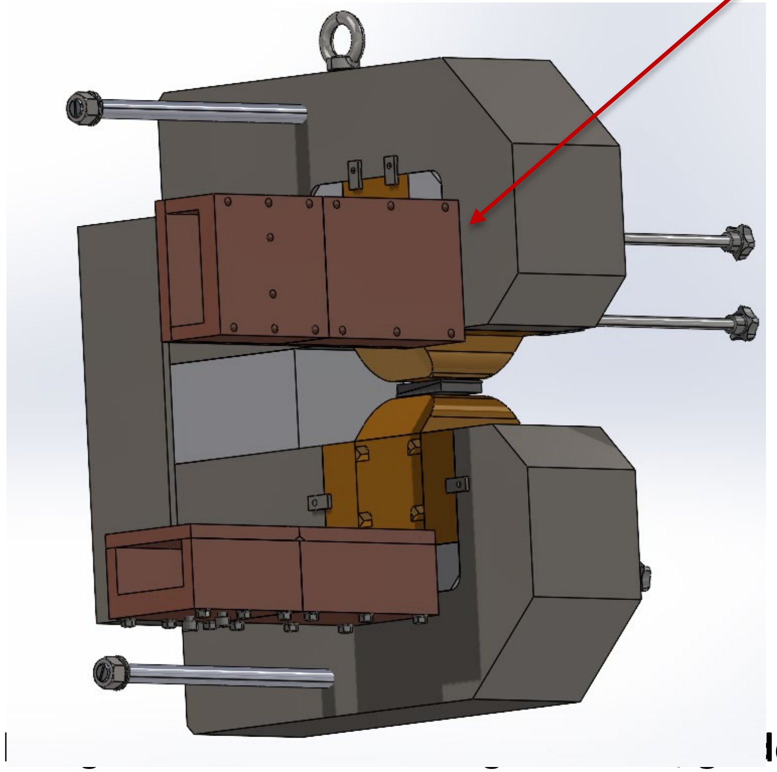


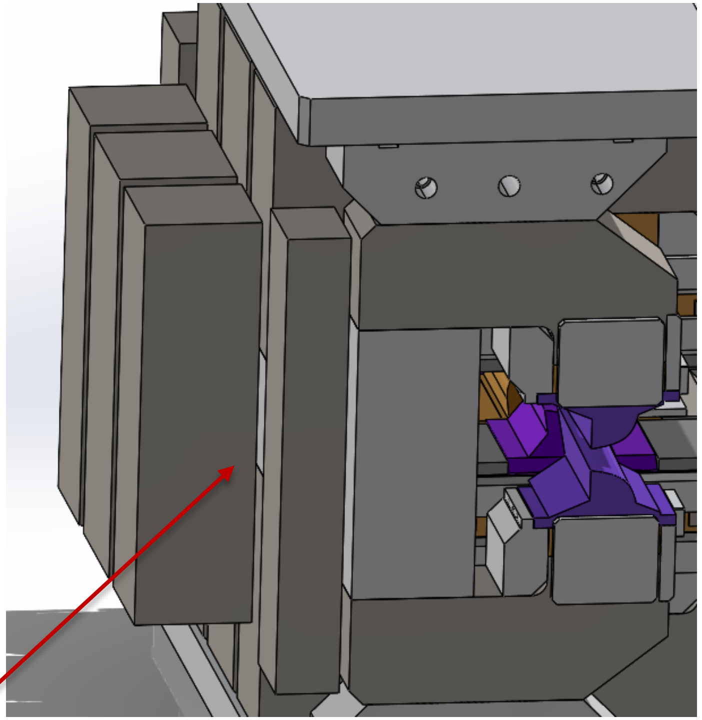


- In VADER, **same pole adjustments** in MF and LF modules present in CL[illegible]**)**

VADER vs CLIC Prototype: Main differences

- PM blocks bigger, meaning **higher forces**. **POM boxes redesigned** (longer) and **second one** to carry block **added**





- Moving parts of fiel … les **reinforced** and regulating screws include **bronze ending** to avoid fluency with time (instead of plastic in CLIC)

VADER: Timeline

- **Final manufacturing drawings** - done on **February 2025**
- Iterations for **magnetic material selections** during **March 2025**
- From **mid-April 2025**, Kyma proceeded with **procurement** of components (waiting for quotes)
- Magnetic material delivery (expected during summer 2025) **delayed** due to shipping issues to **September 2025**
- **All parts machined and sent to KYMA on early October 2025**
- **Assembly process** is estimated to take **~2 weeks** (procedure communicated by CIEMAT, based on CLIC prototype experience)
- **Estimated date** for **full fabrication: mid-October 2025**
- **Measurements** in **Elettra** for **acceptance tests** (**bench/mole procured**) end of **October 2025**

VADER: Achievements

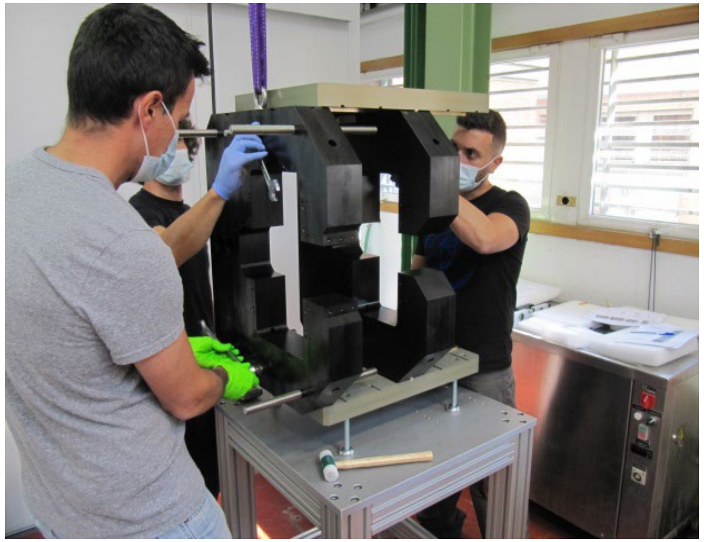
- Specified **longitudinally varying dipole** with **gradient** for reducing **horizontal emittance** of Elettra upgrade SR by factor of **2**
- Designed advanced **permanent magnet dipole** with **variable field** and **gradient** including mechanical **field trimming** reaching all **specs** **(sustainability!)**
- Adress various challenges/limitations with **present/previous** design
- Magnet is in the **procurement/fabrication** face in **KYMA** (industrial partner) reaching **TRL6** (Technology demonstrated in **industrially relevant environment**)
- Ready for **series production** and **industrialization**
- Technology to be used in **future low-emittance rings** (light source SRs, **damping rings for colliders** such as FCC, etc…)

Thank you for your attention!

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

CLIC: Preliminary Assembly

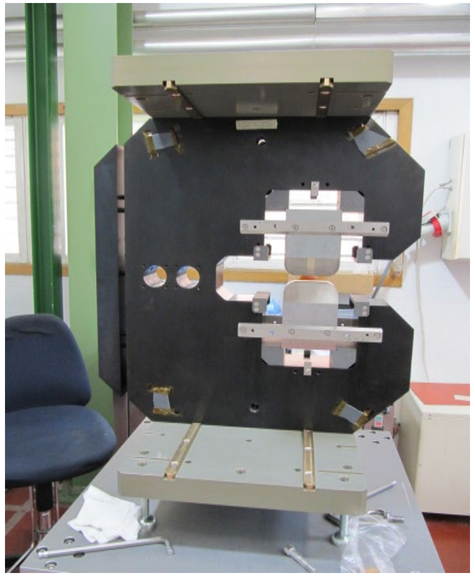
- A preliminary assembly without permanent magnets (PM) should be done to assure the correct manufacturing and adjustment of all the parts.



Testing the modules' approach system

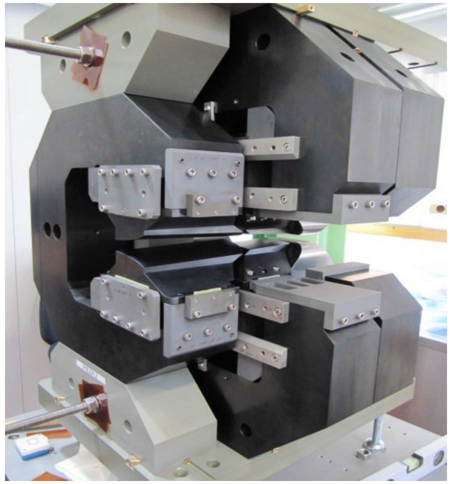
Each module is mounted separately, with all the parts except the PM

CLIC: Preliminary Assembly



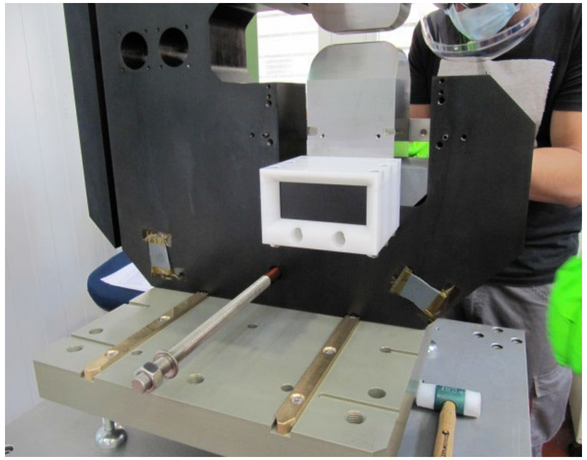
HF module is mounted first, with the top and bottom aluminium plates
Then each module is introduced following the bronze guides fixed to the plates

Detail of one pole and how they are fixed in their nominal position using fibre gauges

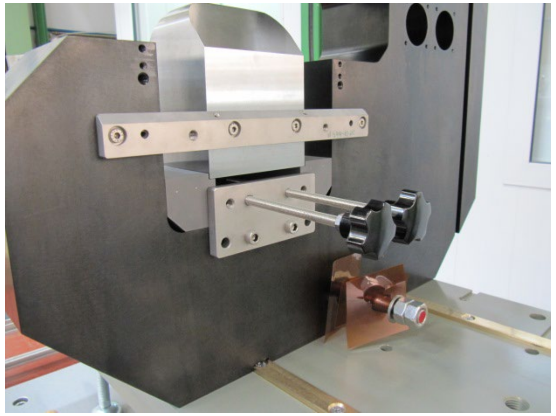


Full assembly without PM

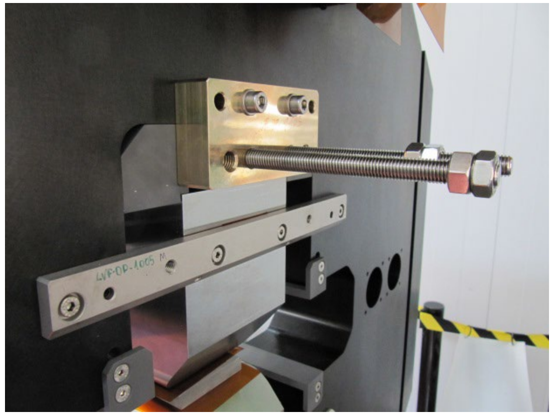
CLIC: Assembly with PM



The PM blocks are introduced using a POM box attached to the yoke



The insertion was controlled using these rods and plate…



…that have to be redesigned due to the huge forces involved
This is already implemented for VADER

CLIC: Assembly with PM

Magnetic measurements are done after each PM is inserted. Low precision but necessary to assure the correct PM assembly

Once each module has all the magnets in, the controlled approach starts

The process is repeated with each module until the assembly is completed