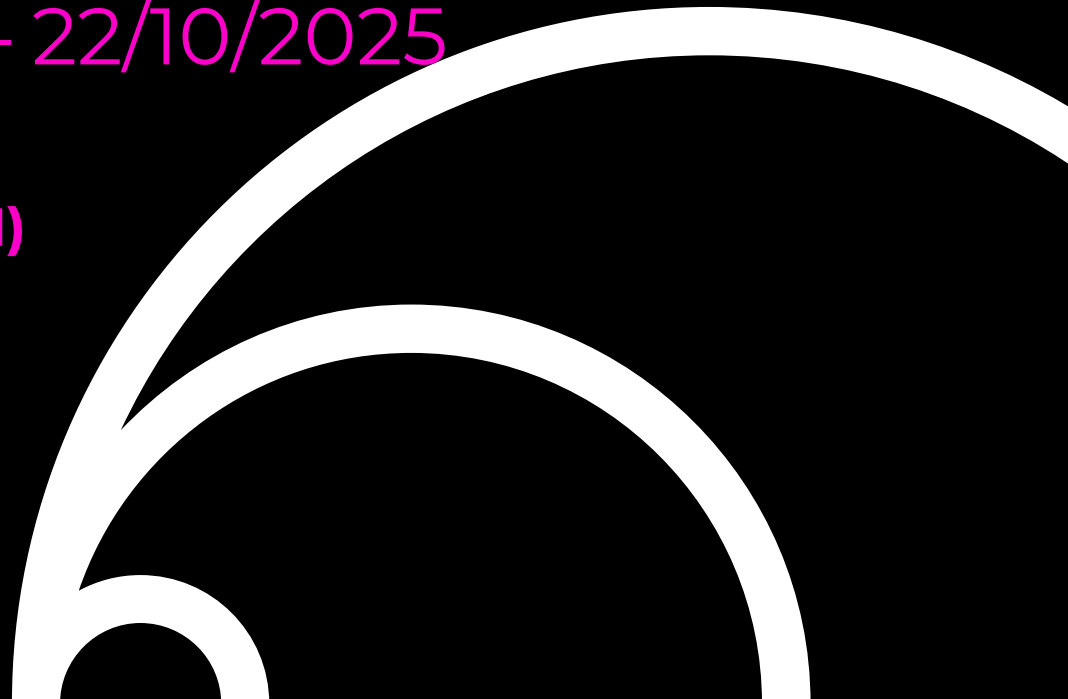
This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

Final Results of the Longitudinally Variable Dipole

I.FAST – 5th annual Meeting 2025 – 22/10/2025

F. Toral (CIEMAT) and Y. Papaphilippou (CERN)
for the **Task 7.3 collaborators**

iFAST



VAriable Dipole for the Elettra Ring - VADER

- **Task 7.3** within I.FAST **WP7**: High Brightness Accelerators for Light Sources
- Partners and collaborators:

Y. Papaphilippou
(A. Poyet)

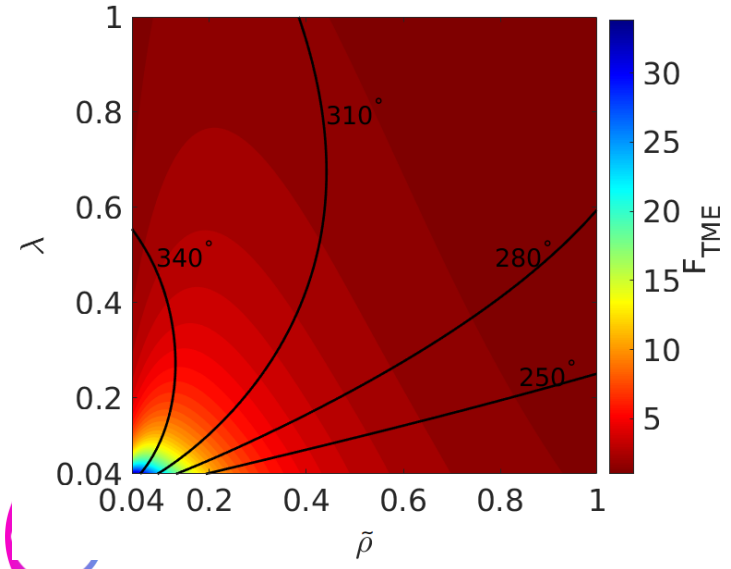
M. Dominguez
F. Toral

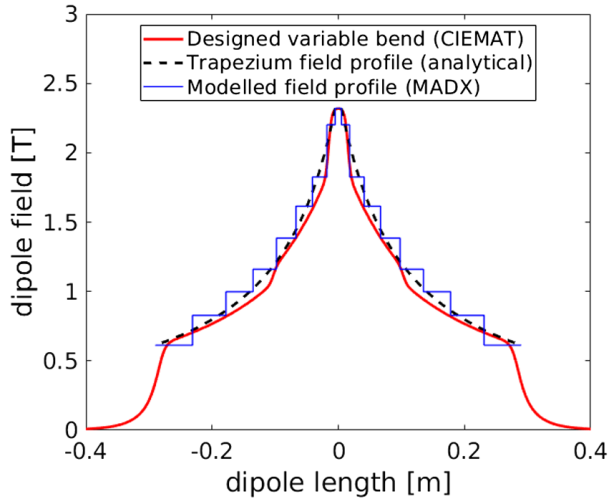
E. Karantzoulis
D. Castronovo
D. Caiazza

R. Geometrante
R. Righi
D. Topalovic

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

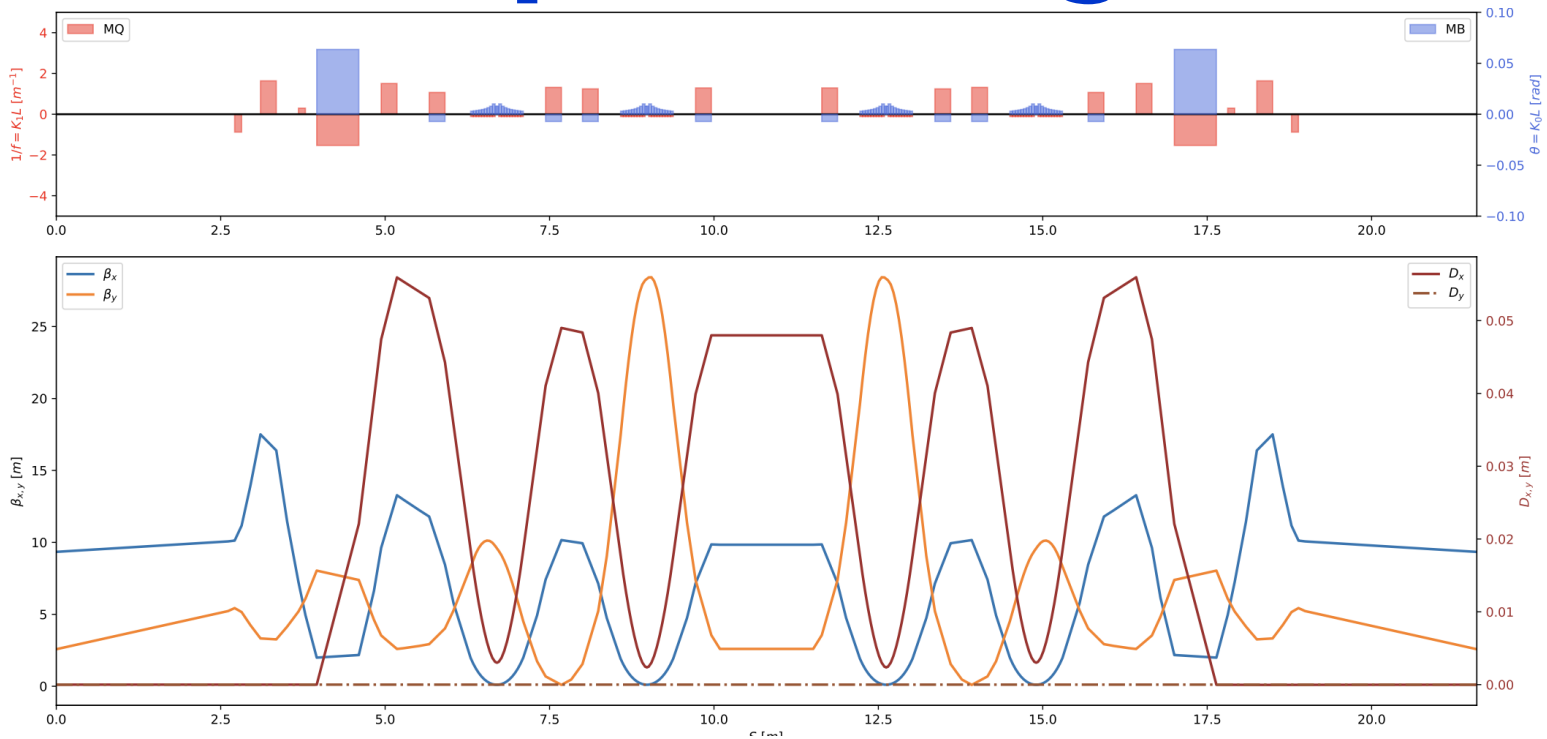
- Keep the same **S6BA-E** lattice for Elettra and replace the LG dipoles by VADER ones.
  - Implement a **trapezoidal profile in bending radius**
  - Observe a **clear emittance reduction**

- 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

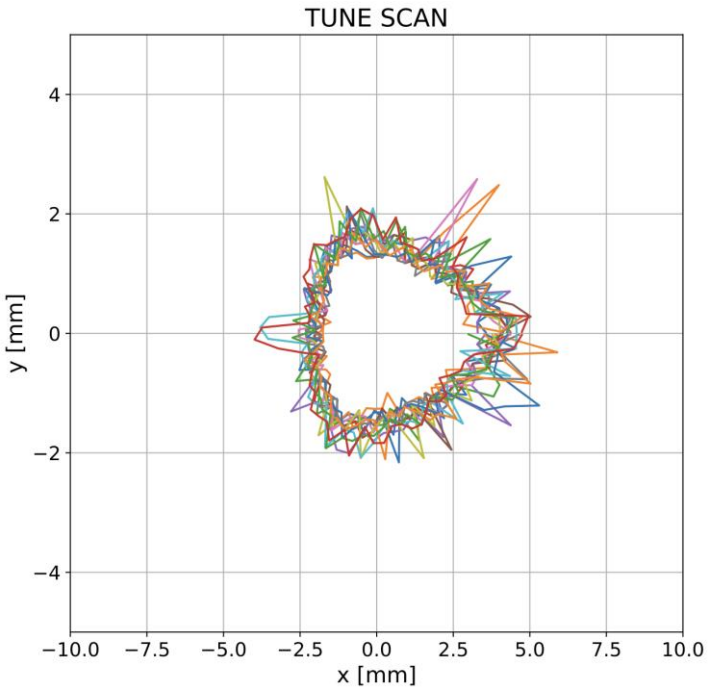
A. Poyet

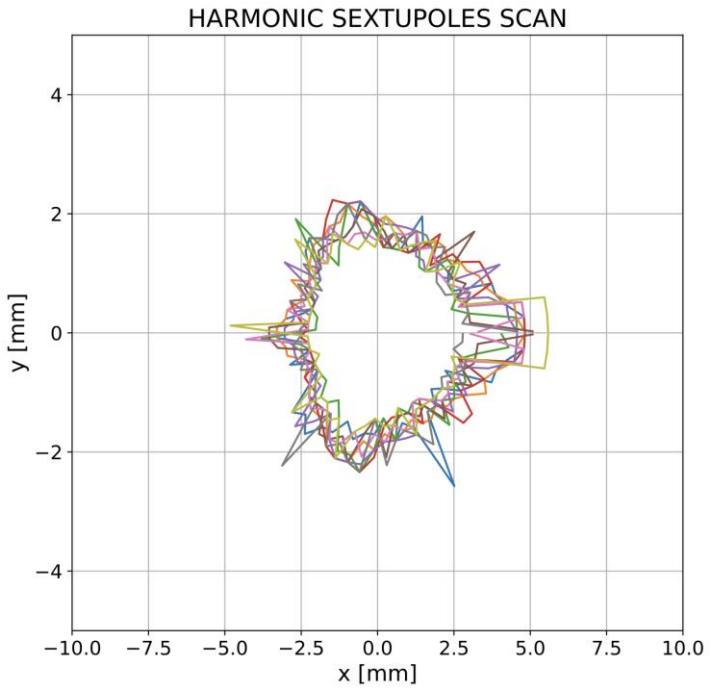


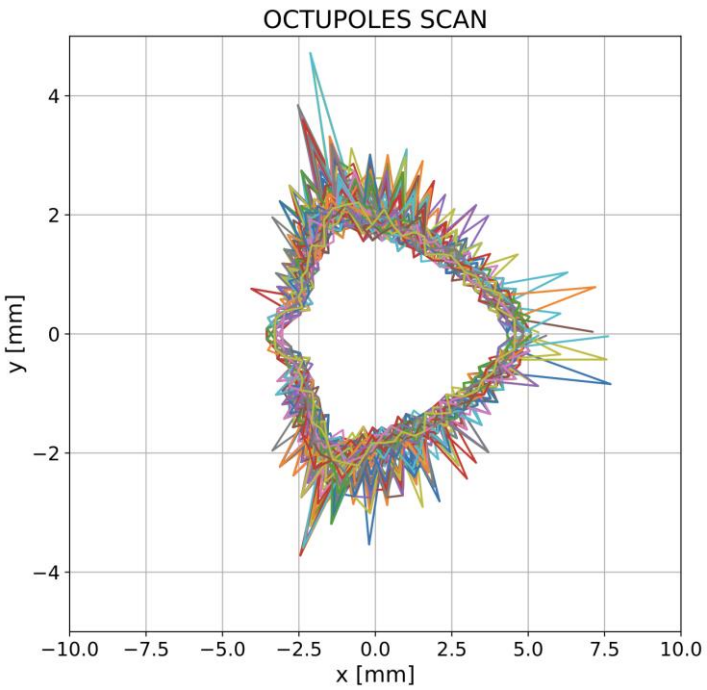
- Optics constraints at the ID are **matched**
- **Horizontal emittance reduction from 212 to 100 pm (more than factor of 2!)**
- **Tunes: 34.706 / 22.852**
- **Chromaticities: -157/-125**

Non-linear Optimization

On-momentum, without error





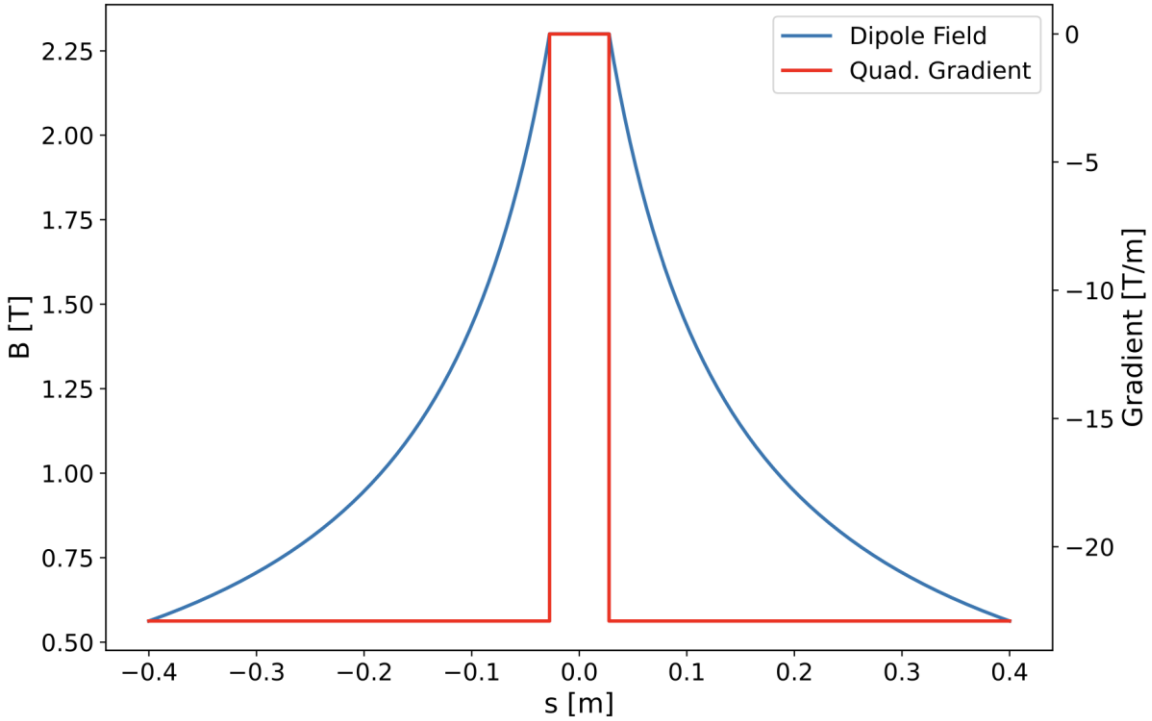


→ Up to ~ 6 mm DA in the horizontal plane, ~ 3 mm in the vertical one
→ Good starting point for further iterations, including errors/corrections, tune optimisation etc.

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**

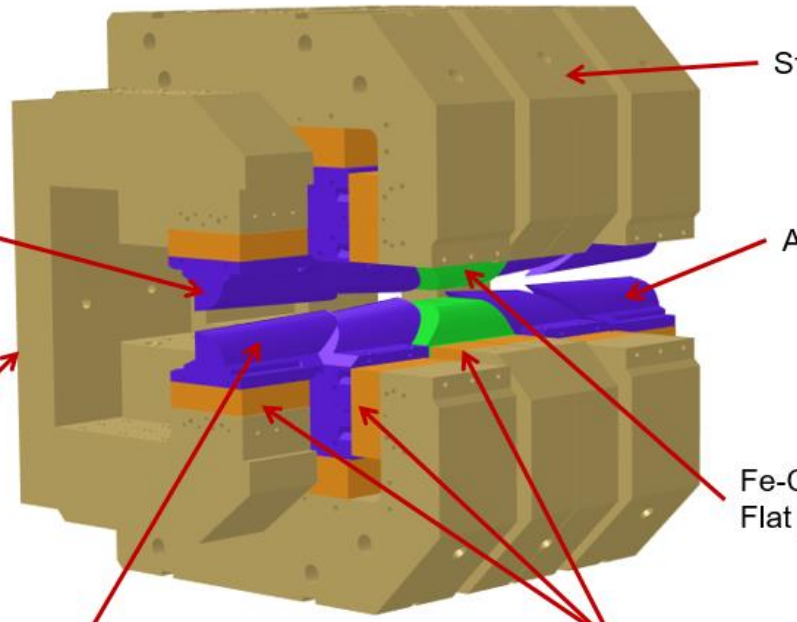
Magnetic Design @ CIEMAT

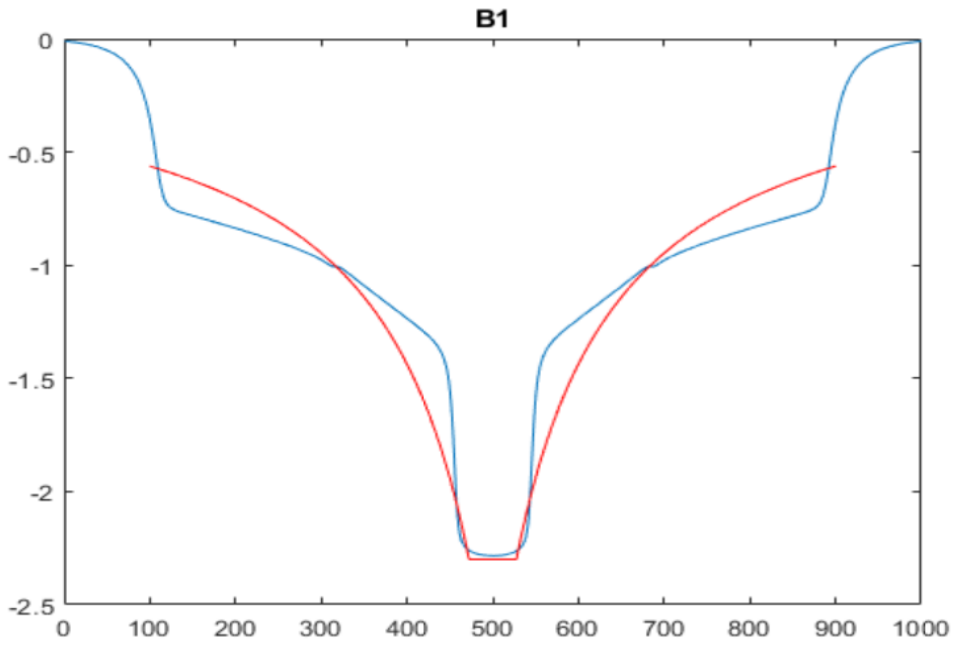
M. Dominguez,
F. Toral

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

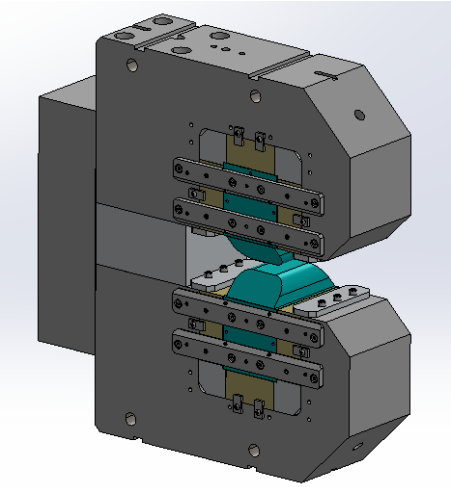




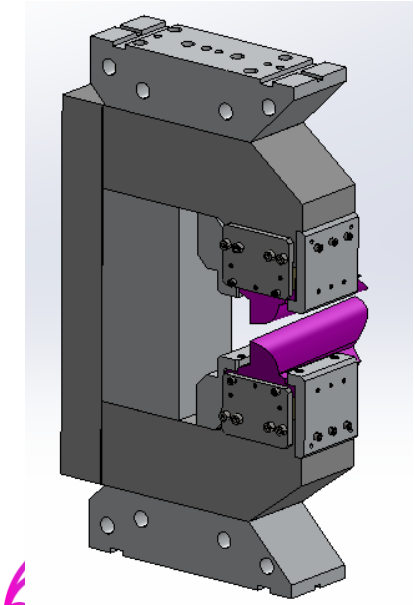
- **Longitudinal gradient** profile **achieved**
- **Integrated transverse gradient slightly below specs** but **ok for optics**
- **Field quality** looks reasonable
- **Mechanical design done**
- **Fabrication drawings communicated to KYMA**

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

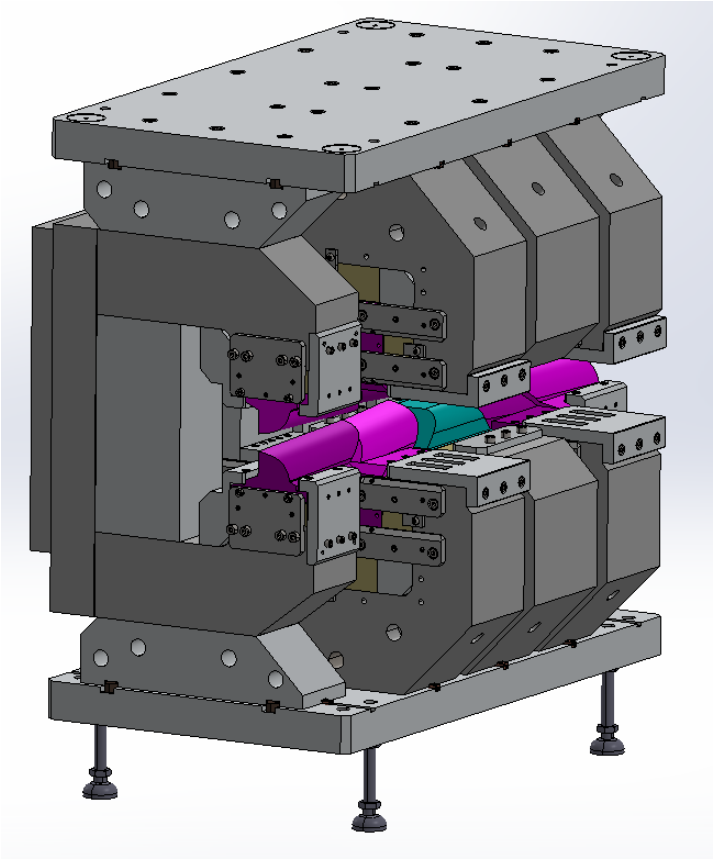
VADER: Final Mechanical Design



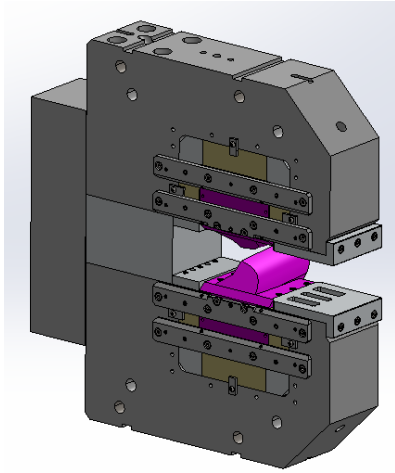
HF Module



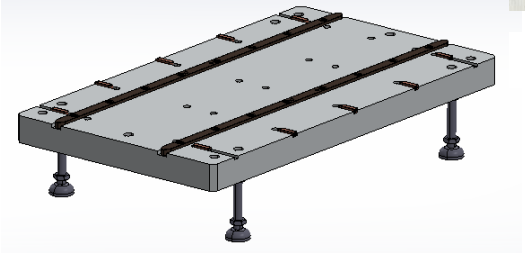
LF Module



Final assembly



MF Module



Base with guides

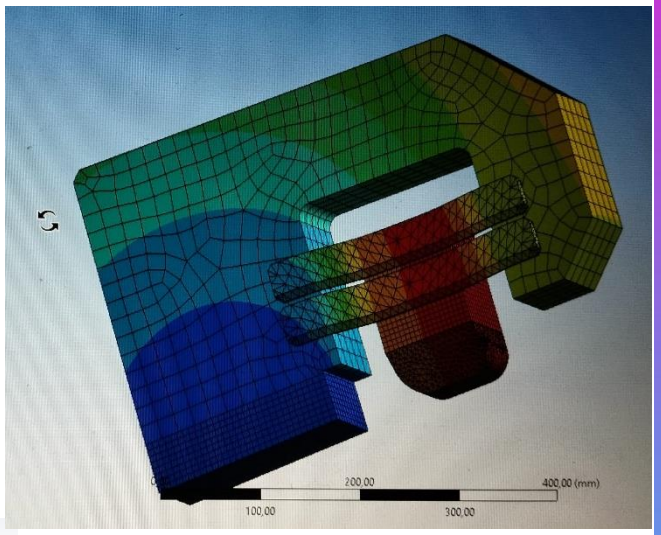
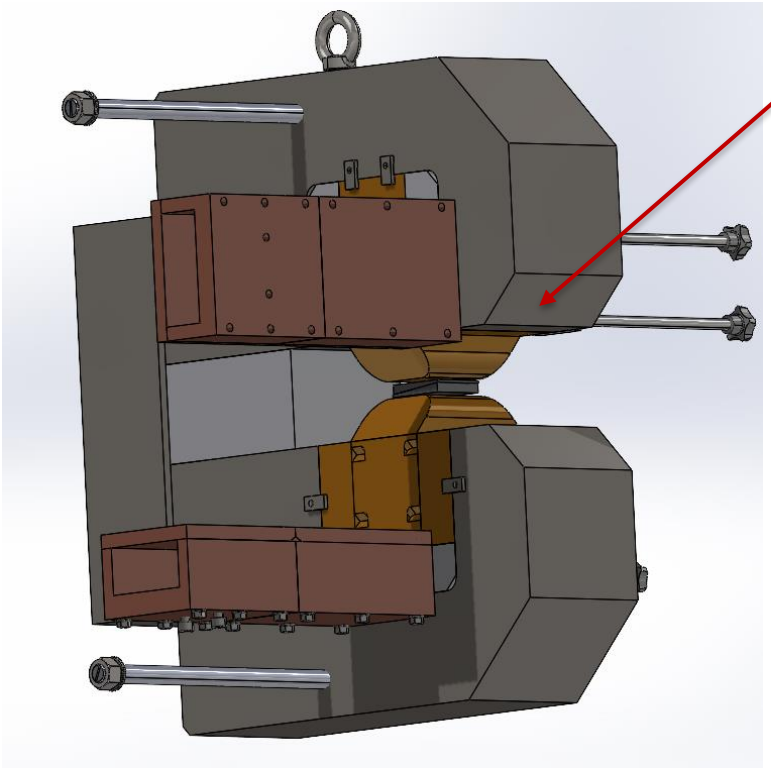
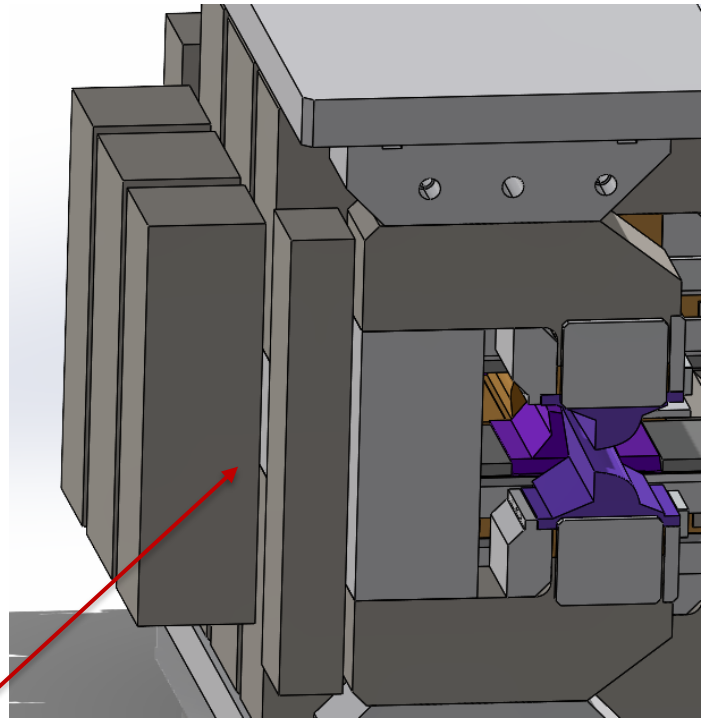


Fig. 6: Deformations in the HF module

VADER vs CLIC Prototype: Main differences

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



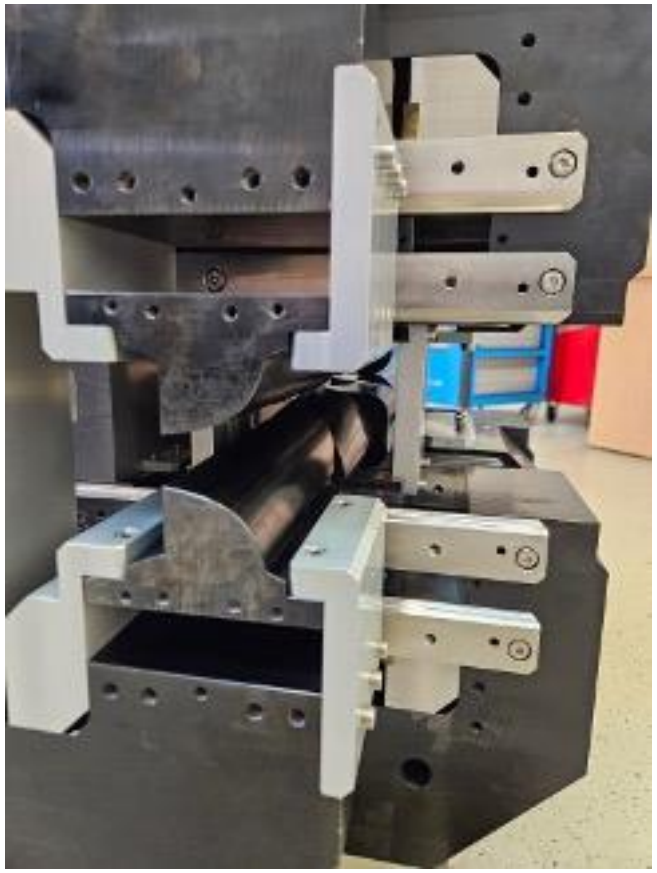


- Moving parts of field regulation under much higher forces, **guides reinforced** and regulating screws include **bronze ending** to avoid fluency with time (instead of plastic in CLIC)

VADER: Timeline

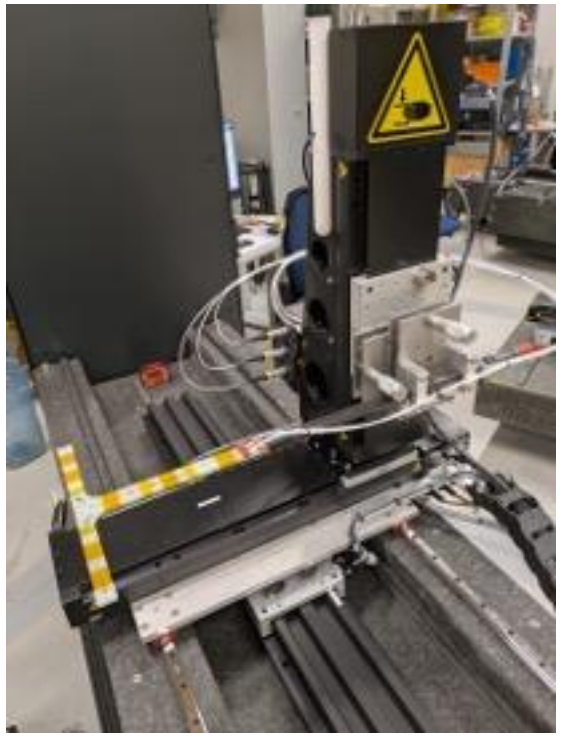
- **Final manufacturing drawings** - done on **February 2025**
- Iterations for **magnetic material selections** during **March 2025**
- From **mid-April 2025**, Kyma proceeded with **procurement** of components
- Magnetic material delivery (expected during summer 2025) **delayed** due to shipping issues 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 (end of this week!)**
- **Measurements** in **Elettra** for **acceptance tests** (**bench/mole procured**) end of **October 2025 (next week!)**

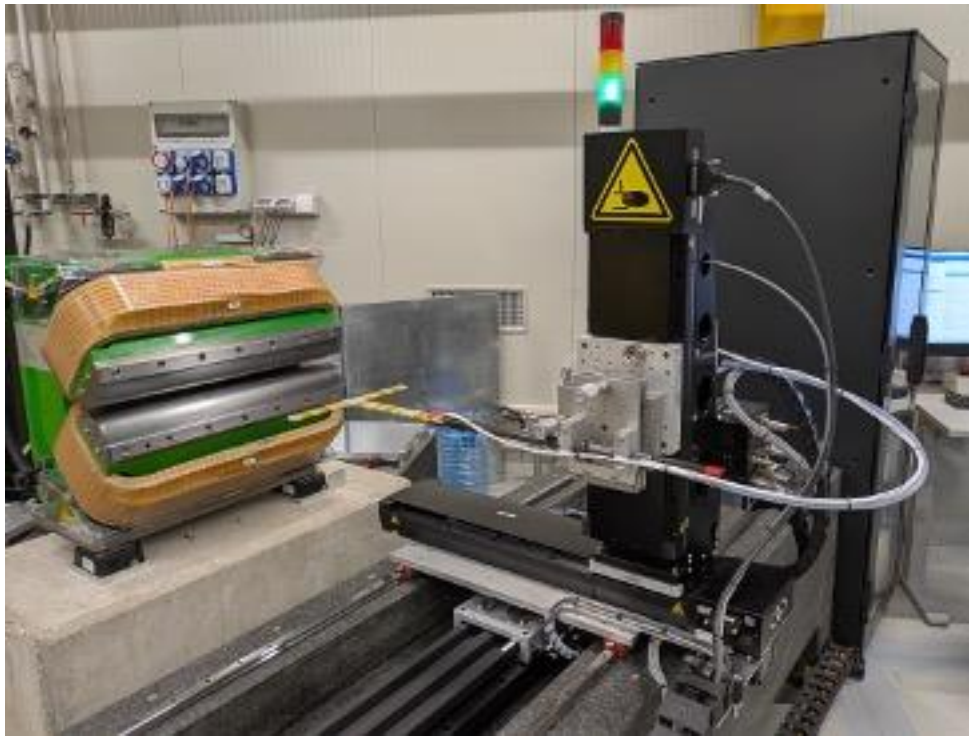
VADER: Assembly at KYMA



- **Mechanical assembly** finished **last week**
- **High-field and low-field part assembled** with **magnets**, will be followed by mid-field part, to be finalised end of **this week**

VADER: Measurements at ELETTRA





- **New Hall probe** procured and delivered to ELETTRA
- **Measurement bench** ready to receive magnet for measurements (next week)

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**)
- **Outcome:** Ready for **series production** and **industrialization.** Proposal included in EPITA to work on a wiggler for FCCee injectors.
- **Impact:** Technology to be used in **future low-emittance rings** (light source SRs, **damping rings for colliders** such as FCC, etc…)

iFAST

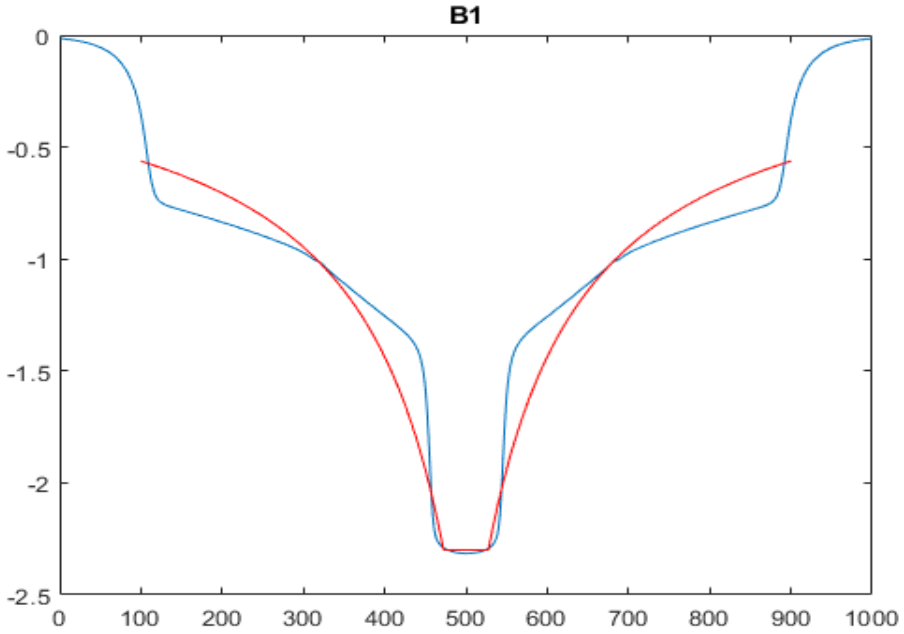
Thank you for your attention!

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

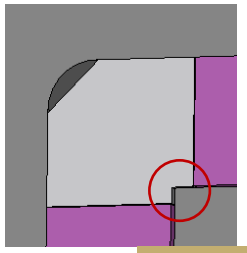
VADER: Final magnetic design

	Tech Specs	Design
Magnet gap (mm)	18	18
Peak field (T)	2.3	2.3
Transverse grad. (T/m)	17	15.2
Field quality (units, 10^{-4})	< 5	< 7
Integrated field B1 (T.m)	0.91	0.91
Field Trimming		+1%,-4%

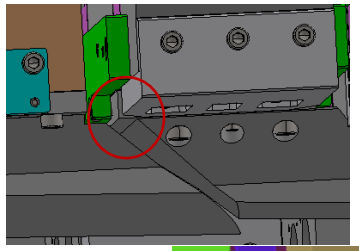
Longitudinal gradient:

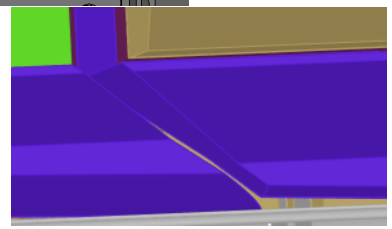


Resolving CLIC prototype issues for VADER

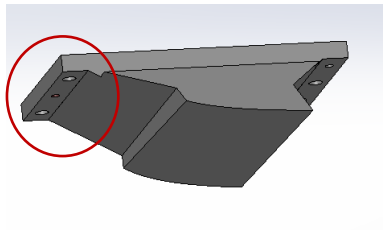


6 mm HF & MF pole base expansion

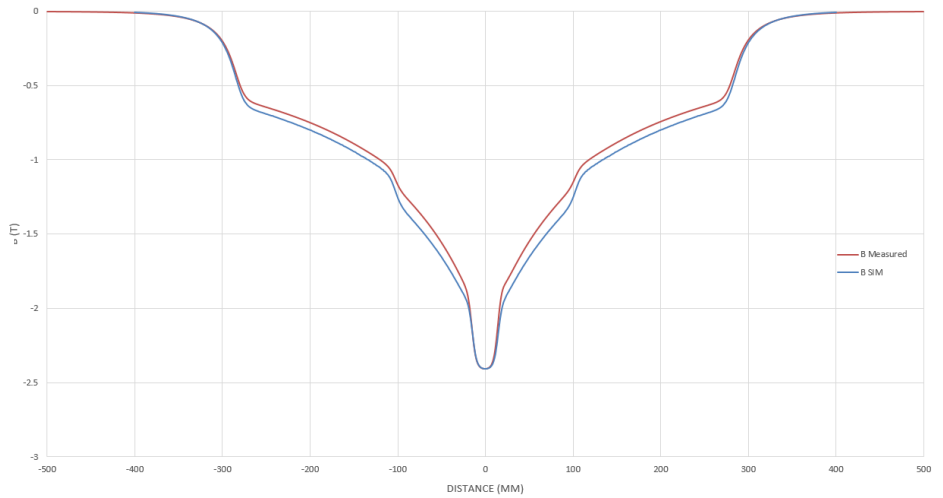




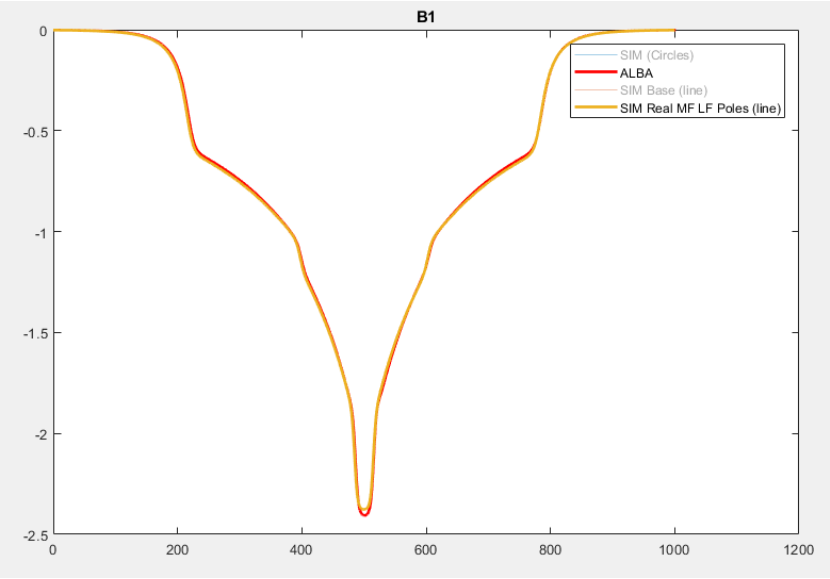
MF pole extrusion



LF pole extrusion

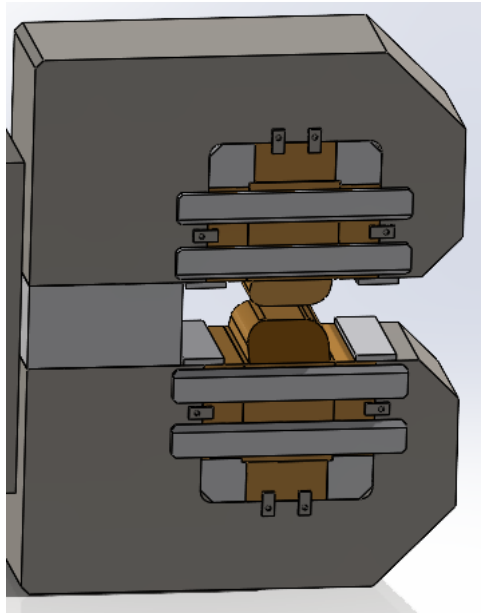


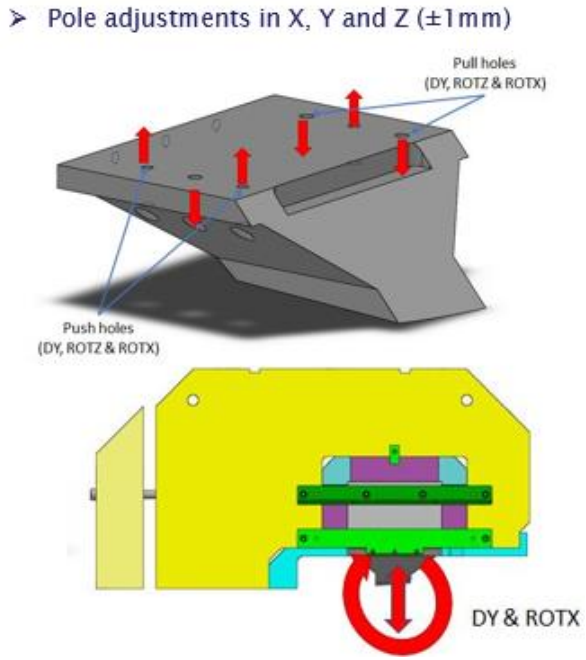
- **Discrepancy** in CLIC prototype between simulations vs magnetic measurements: **4% lower integrated dipolar field**
- **Various investigations**: missing Armco heat treatment, misalignment, hysteresis, simulation error, etc.
- Traced back to **3D mechanical model details** not reflected **Opera simulation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



VADER 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 CLIC **except DY (vertical adjustment)**