

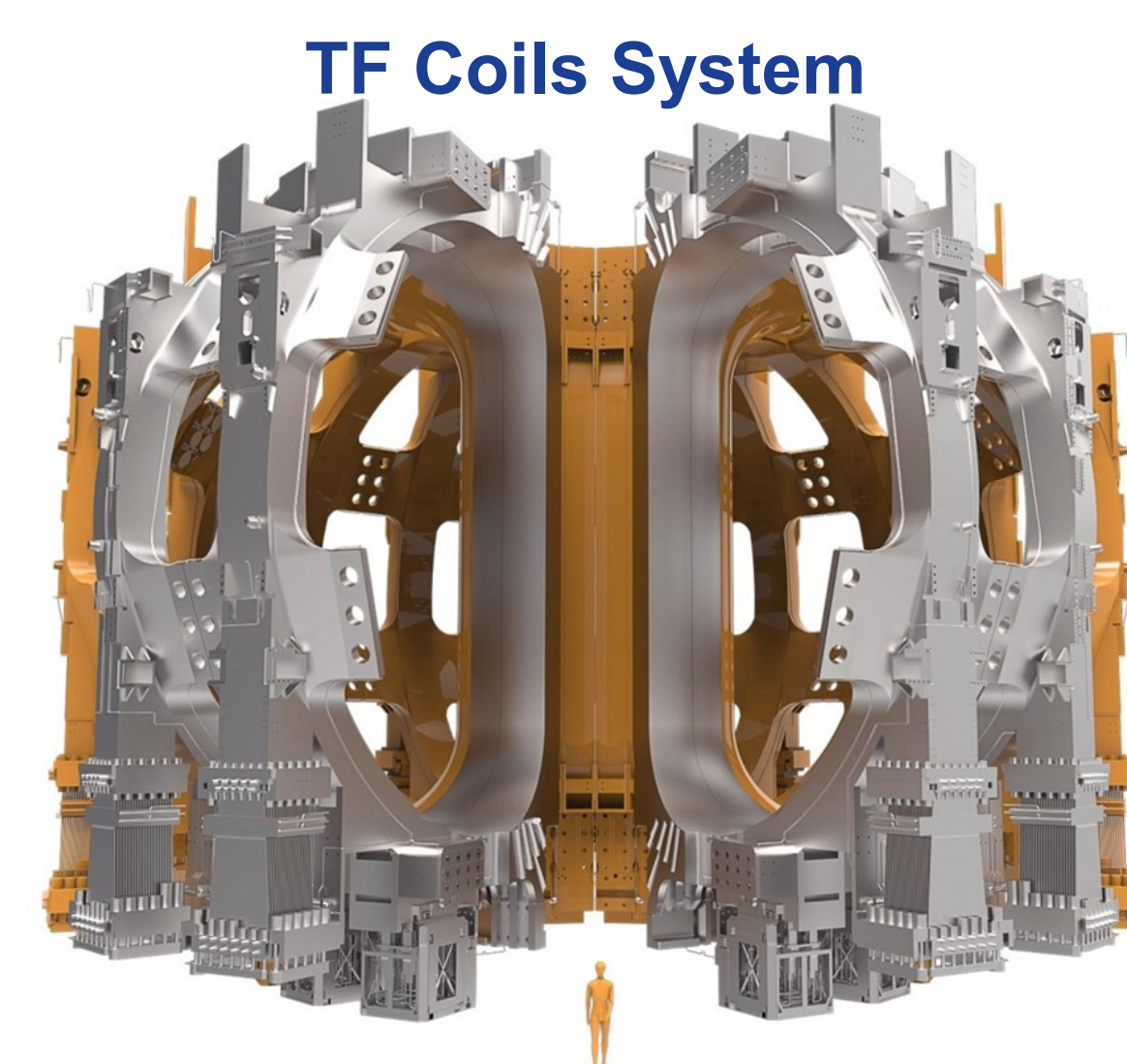
# Current Centre Line control, results and comparison after the manufacturing of the ITER Toroidal Field Coils



**FUSION FOR ENERGY**

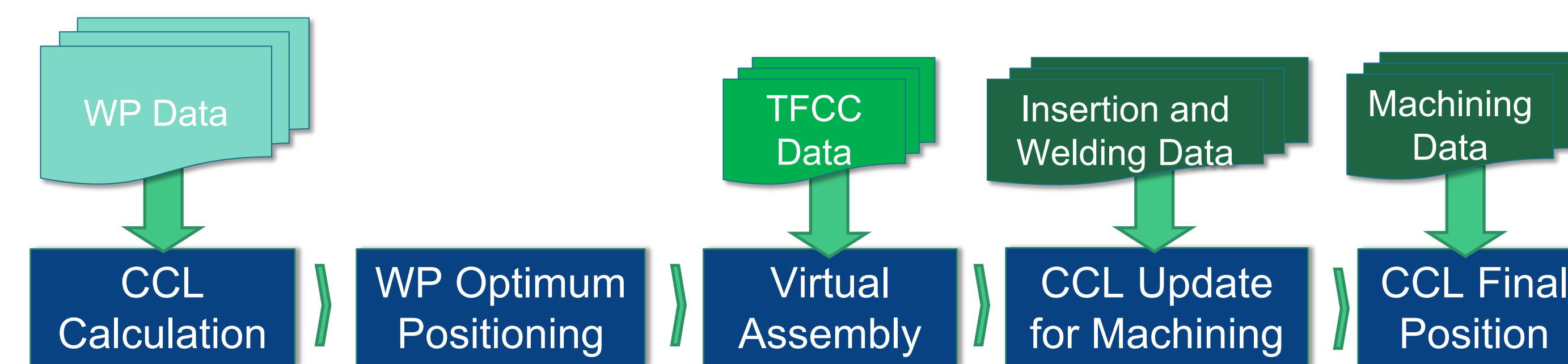
Marc Jimenez, Boris Bellesia, Piergiorgio Aprili, Alessandro Bonito-Oliva, Charalampos Kostopoulos, Robert Harrison, Alessandro Lo Bue, Guim Pallas, Narcis Pellicer, Eduardo Pozuelo, Eduard Viladiu, Alfredo Portone, Fusion for Energy. Marc Ferrater, ISQ. Edoardo Pompa, SETIS, Alessandro Formisano, Università degli Studi della Campania

## 1. Introduction



- The Current Centre Line (CCL) is defined as the **barycenter** of the 134 turns of **conductors**, and it represents **'As-built'** information of the magnet.
- Should be calculated in **30 sections** of the Toroidal Field (TF) coil and one of its uses is to **characterize the magnetic field** of the 'as-built' magnet.
- Manufacturing stages can be optimized to **recover previous deviations**
- Proper **CCL positioning** is key to **minimize Error Field** during operation.

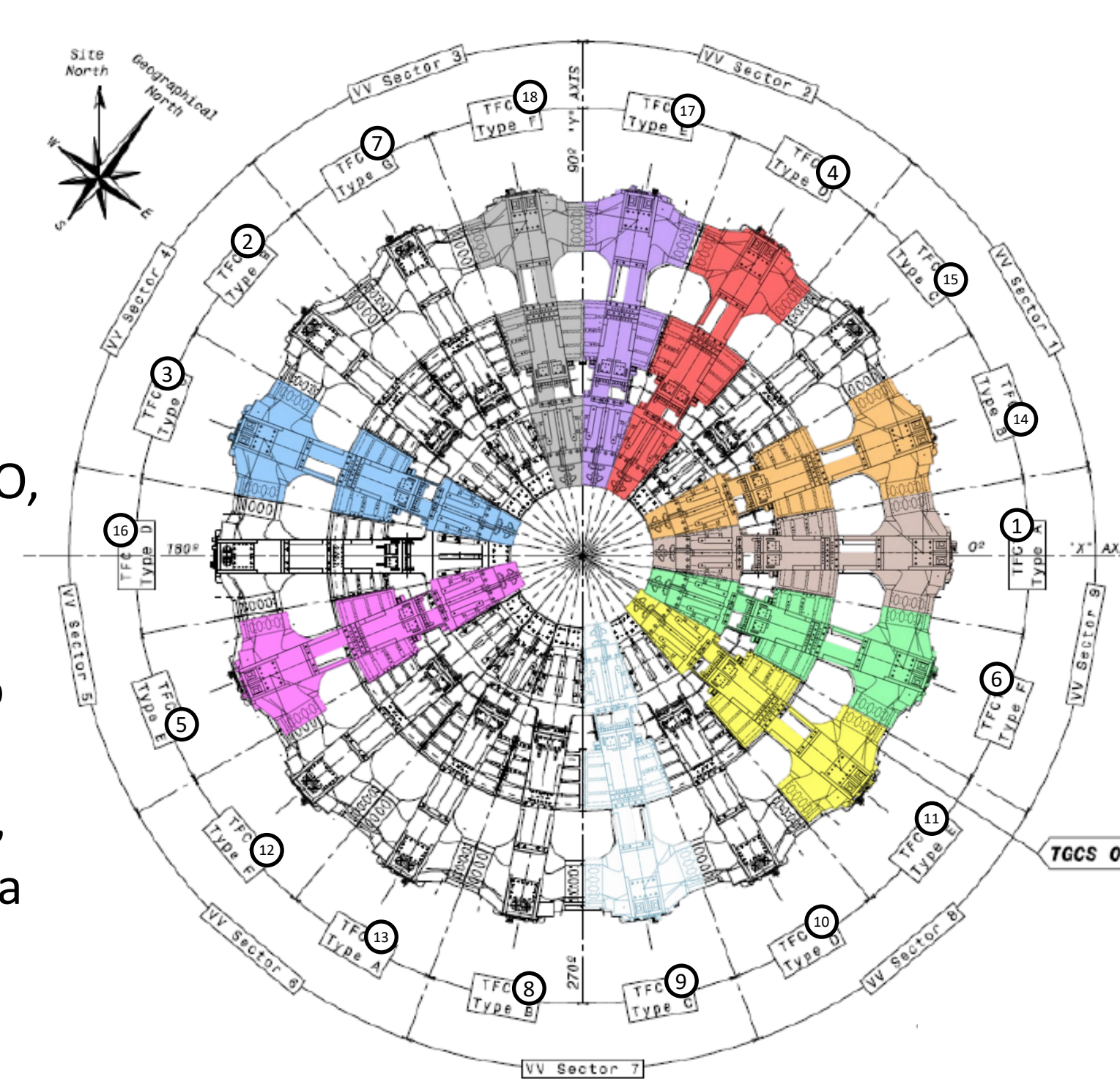
## 2. Process Overview



- The method is based in processing **dimensional measurements and manufacturing data** for the creation of Computer Assisted Engineering (CAE) models.
- It allows to **calculate, monitor and control the CCL** during the full manufacturing process: **WP construction, WP insertion, welding, machining and coil acceptance.**
- Final CCL data** is given to the ITER IO for the **machine assembly** and it is used by F4E to assess the **Error Field**.

### General Strategy

- TF coil system consist of **18 TFs** to be assembled by the **ITER Organization (IO)**, **10 from F4E and 8 from QST.**
- Harmonization** effort between ITER IO, F4E and QST to define **insertion and final machining**
- Procedure** established at F4E allows to execute CCL strategy harmonization while maintaining **Quality Assurance, Configuration and Control** of the Data



Top view of TF Coils System, colored TFs are under F4E scope

## 3. CCL calculation, optimization and monitoring

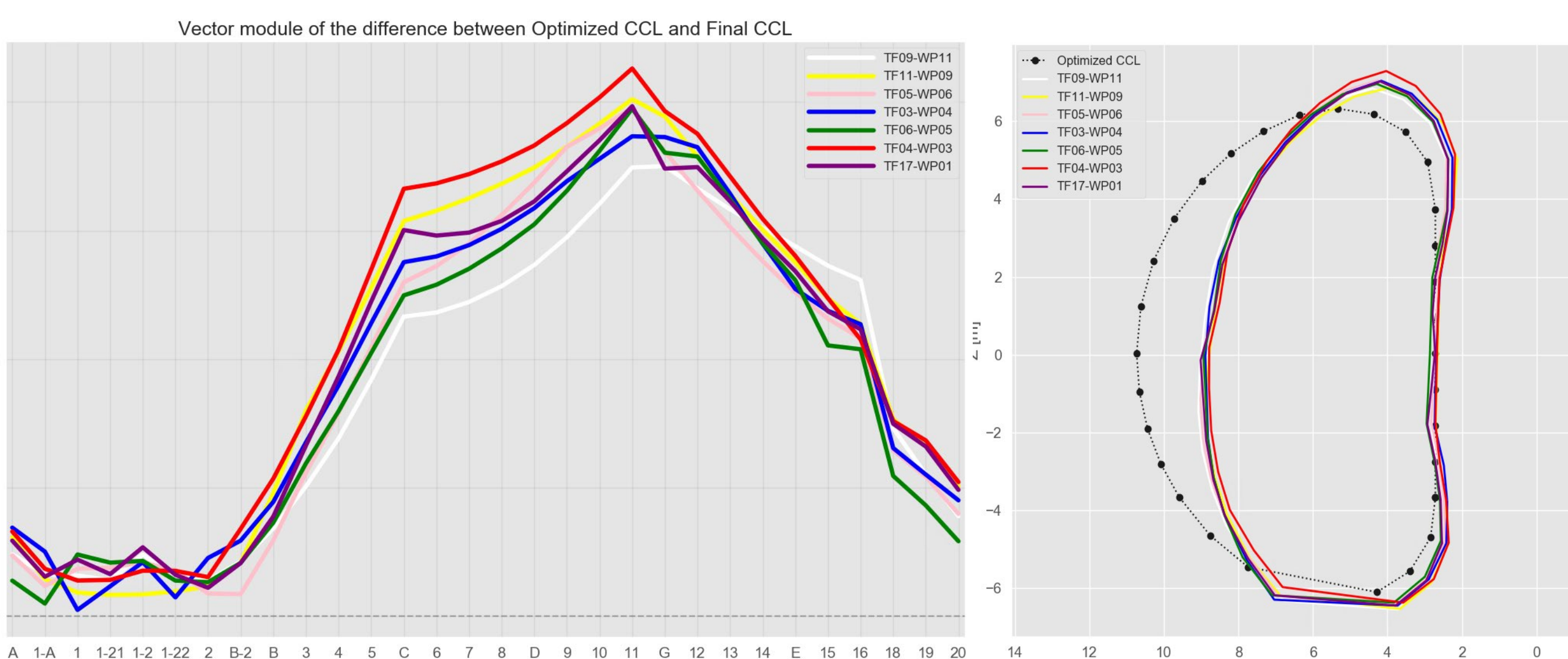
- WP in optimum position and CC data** is checked for **clashes and gap verification** for proper resin filling.
- All **gap check successful**, with similar gap values in different areas of the coils.

### VI Optimization and machining



The alignment is **optimized to minimize the CCL errors in inboard rea**, at the expense of **higher errors in other areas** of the coil (i.e. outboard features). After final machining, the **DI data of coil features and fiducial points** is processed to obtain the **deviation of internal WP fiducials**. These are then **interpolated to the CCL points** for final assessment.

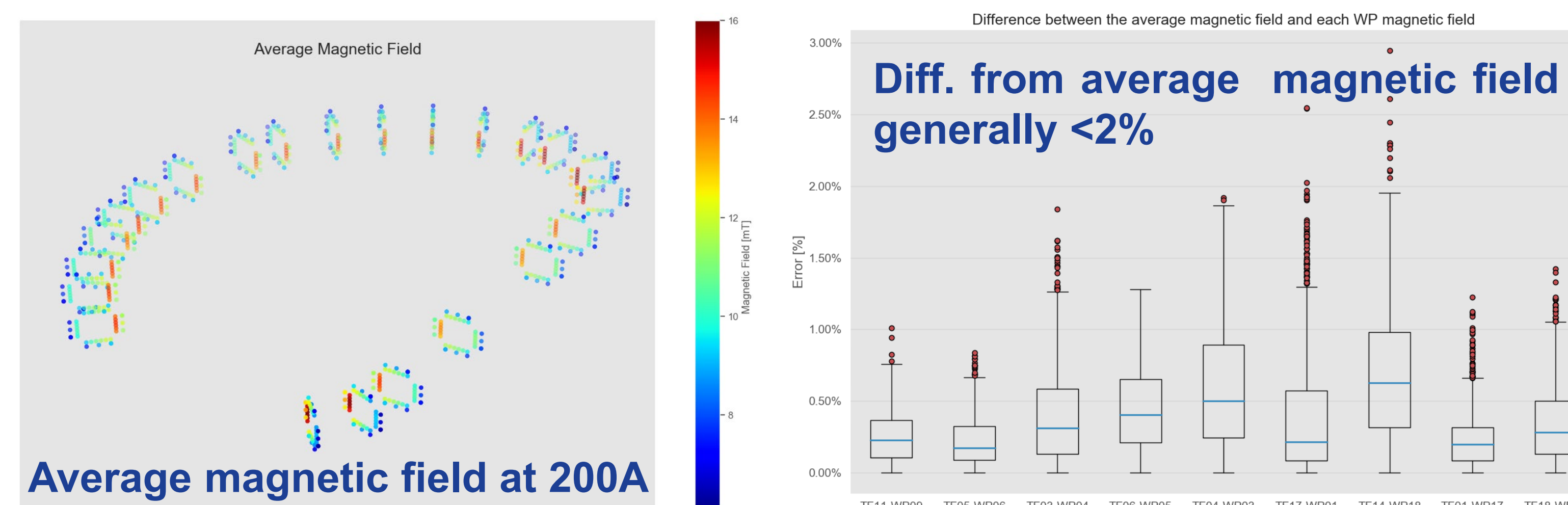
## 4. Production results (2020-2021)



- F4E coils present **similar CCL deviation**, showing a **robust manufacturing process** and CCL calculation method.
- Inside the most critical TFs **inboard region** deviations are **<1mm** for all coils, well below required tolerance ( $\Phi$  2.6 mm)
- In **TF outboard**, **out-of-plane deviations** are **<3mm**
- Outboard radial deviation** thought to be due mainly to effects linked to **weld deformation**.

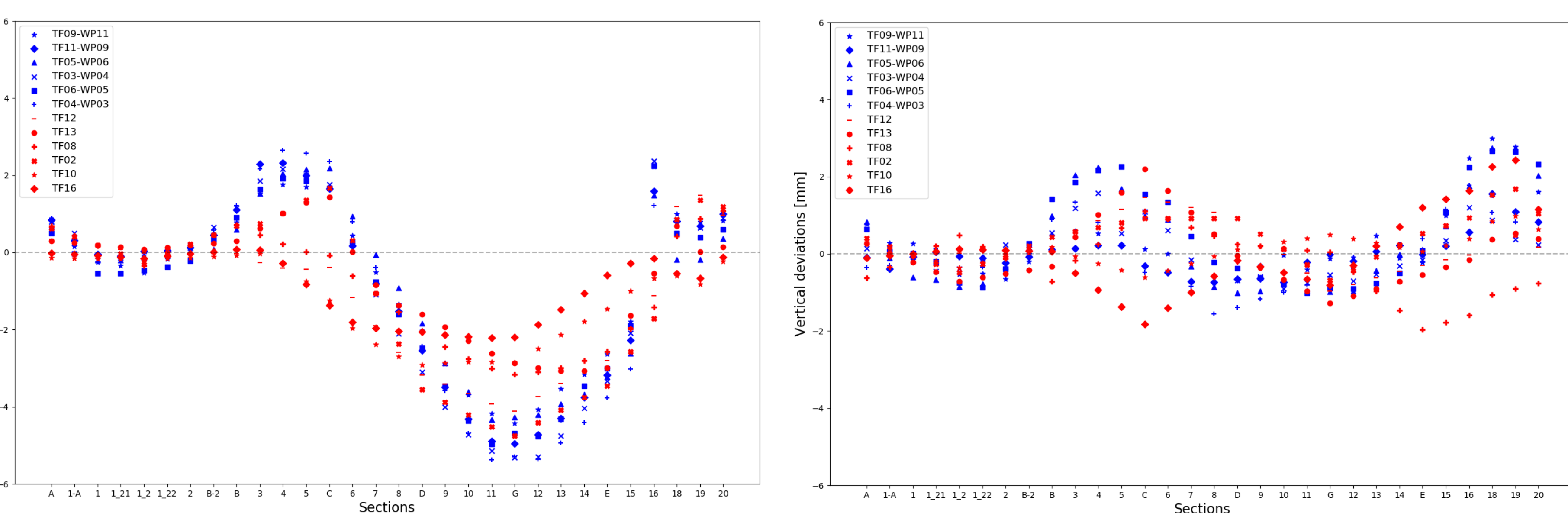
## 5. Conclusions and further activities

- F4E created **CAE models and methods** to manage the **CCL position throughout the TF manufacturing**, using suppliers' **DI and manufacturing data** from EU and Japan. **Same method has been adopted to PF Coils.**
- Standardized and controlled procedure** set up to collect, process and store all the technical data maintaining **configuration and traceability.**
- All **outputs obtained** so far suggest very **stable manufacturing** and allow to consider the **EU TF magnets** as a **set of components. Similarity** is also observed considering **Japanese coils**, even though the **different manufacturing process and CCL calculation method.**
- All **CCL related data** is further used for **Error field Analysis** and can be used during the **assembly phase**, and **relationship with other magnet's parameters** can be studied (e.g. warm magnetic measurements).



Average magnetic field at 200A

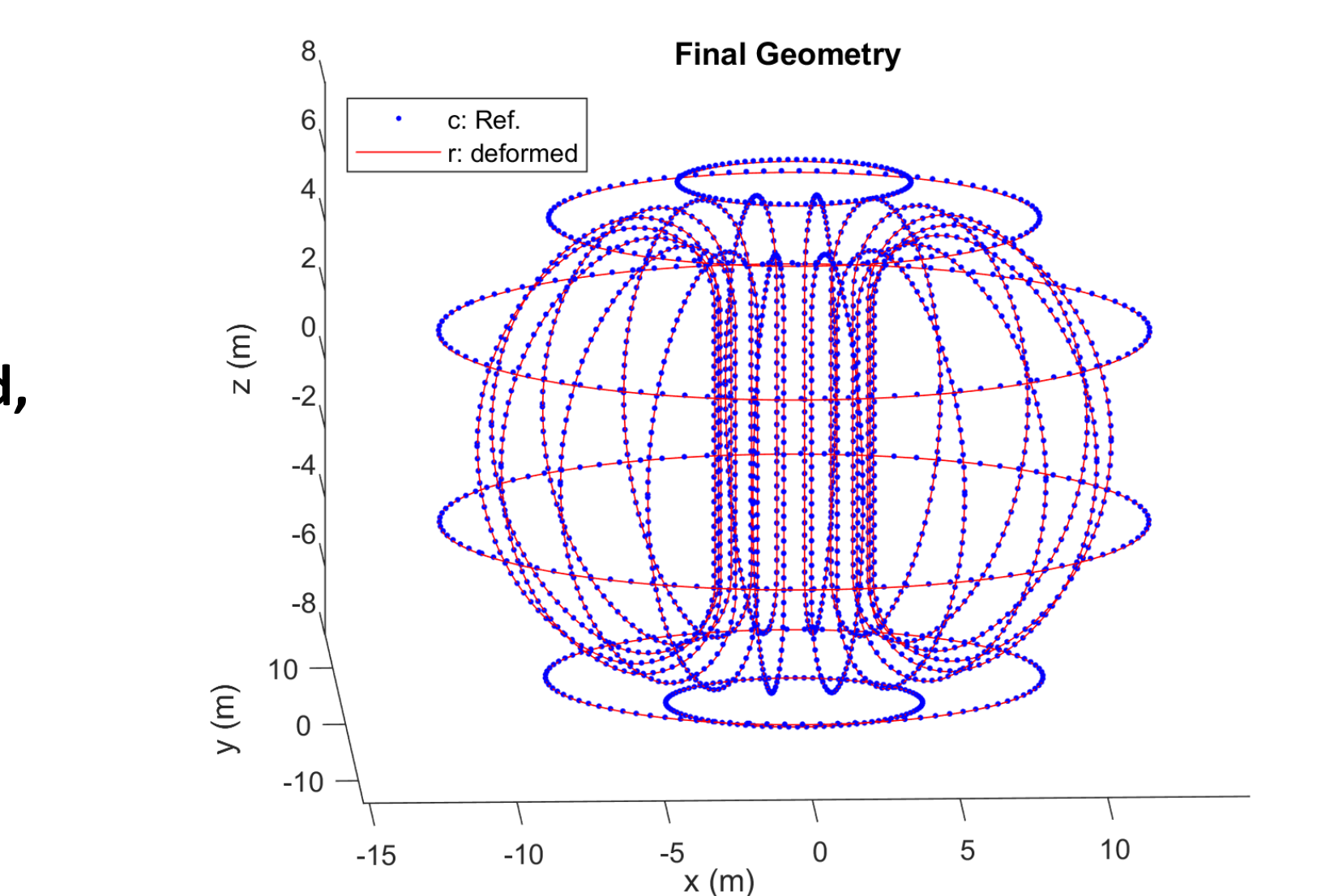
Diff. from average magnetic field generally <2%



CCL deviation of all TFs produced up to date with respect to nominal

### Error Field Analysis

- TF and PF** are included at **different manufacturing stages and load effects** applied after FEM analysis: **Gravity, Preload, Cool Down, Coil Energization**
- Three different plasma scenarios** are considered and **model is benchmarked** against independent analysis.
- Results suggest that manufacturing effects** contribution to Error Field are **well below required thresholds.**
- Work is ongoing** and will need CCL final results for whole ITER Magnet System



mT	Plasma Sc. 1	Plasma Sc. 2	Plasma Sc. 3
n=1	97.26	37.53	11.24
Limit	420	250	80