Tecnologias de radio-frequência no

Projecto ITER

Bruno Soares Gonçalves

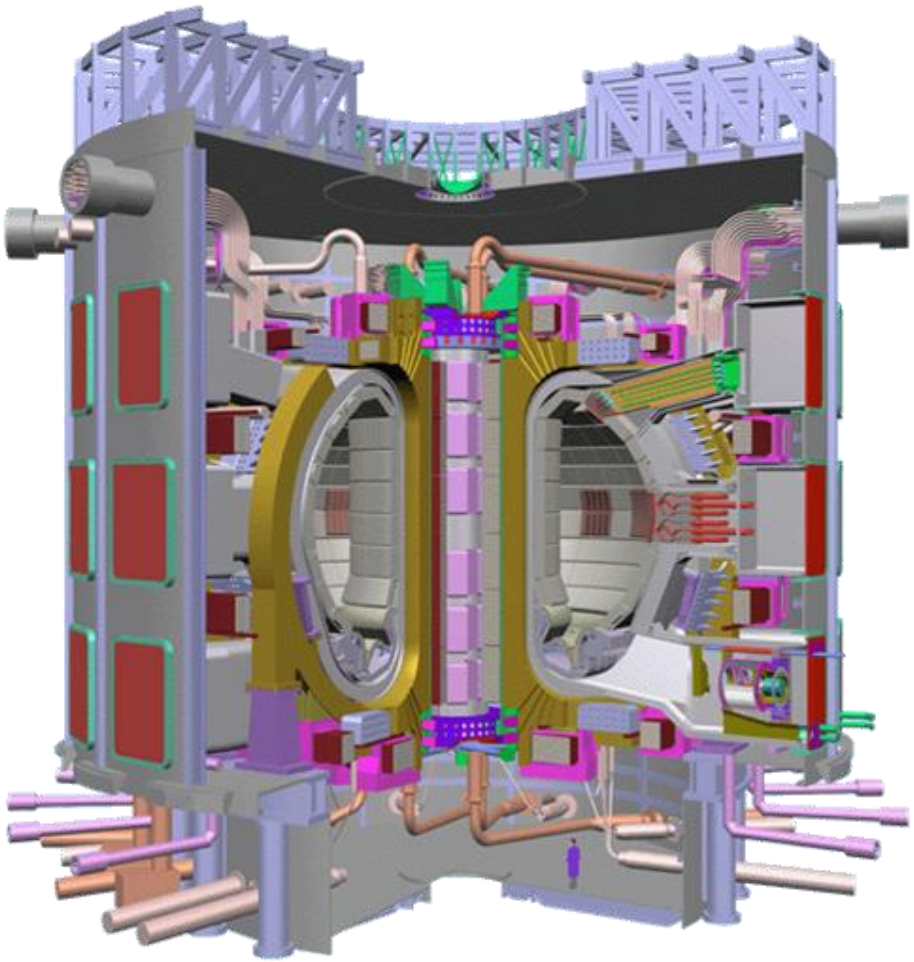
Instituto de Plasmas e Fusão Nuclear
Instituto Superior Técnico
Lisbon, Portugal
http://www.ipfn.ist.utl.pt

ITER | Mission

To prove scientific and technical viability of fusion

P = 500 MW, **D** = 300 s, **Q** = 10 – 20

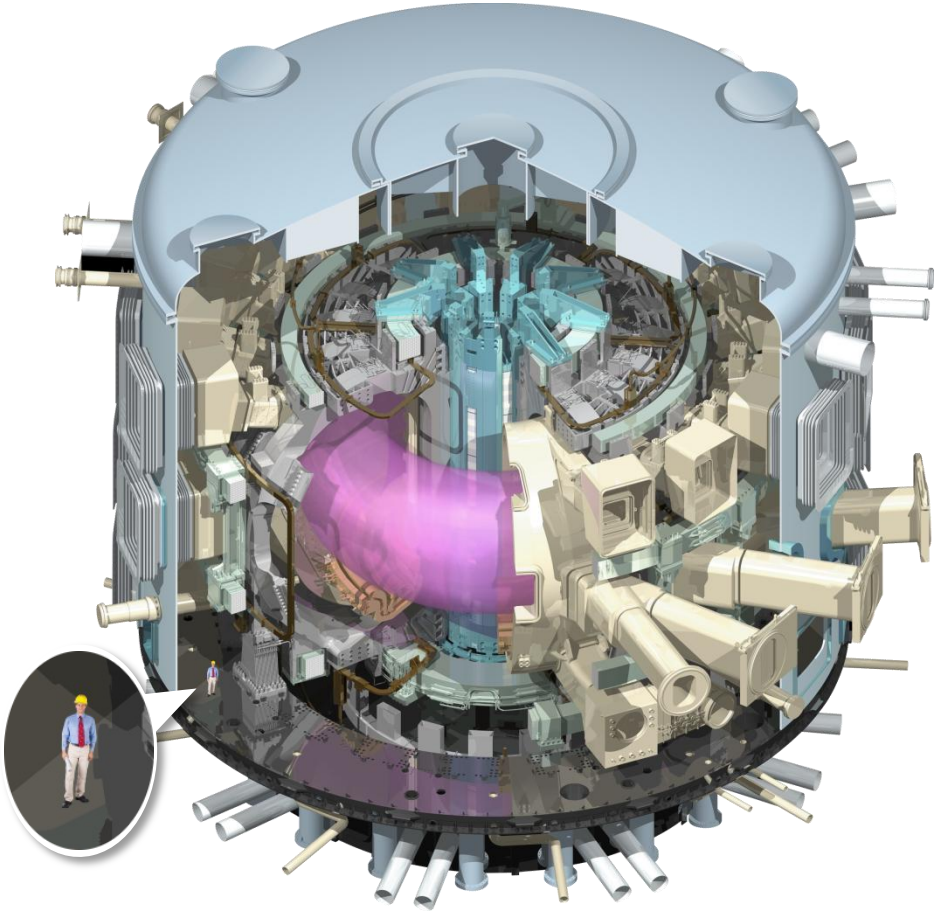
To test integration of all technologies required for a fusion power plant



ITER | Mega R&D project

16000 M€

(2010 budget)



30 years

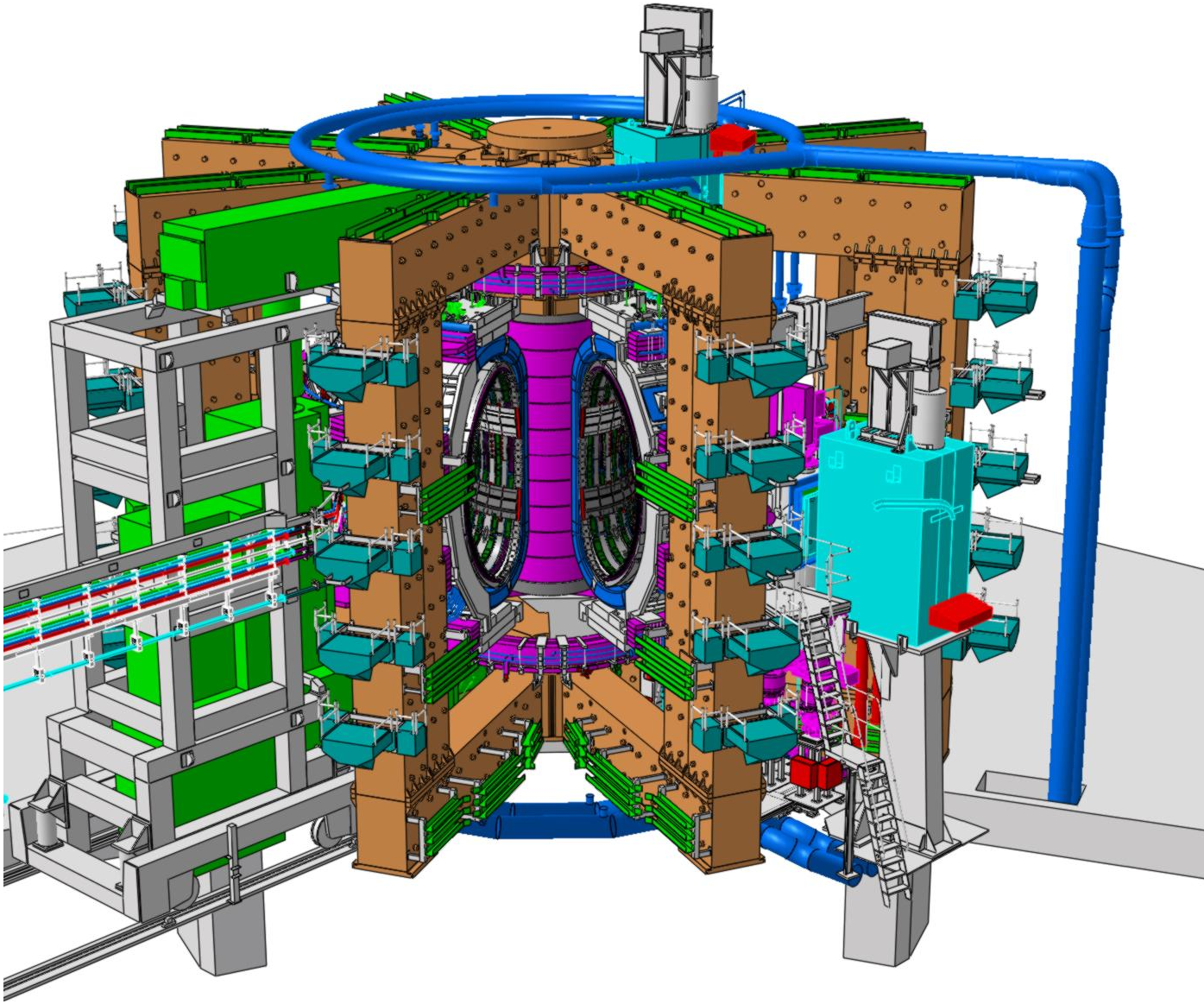
10 years construction
20 years operation

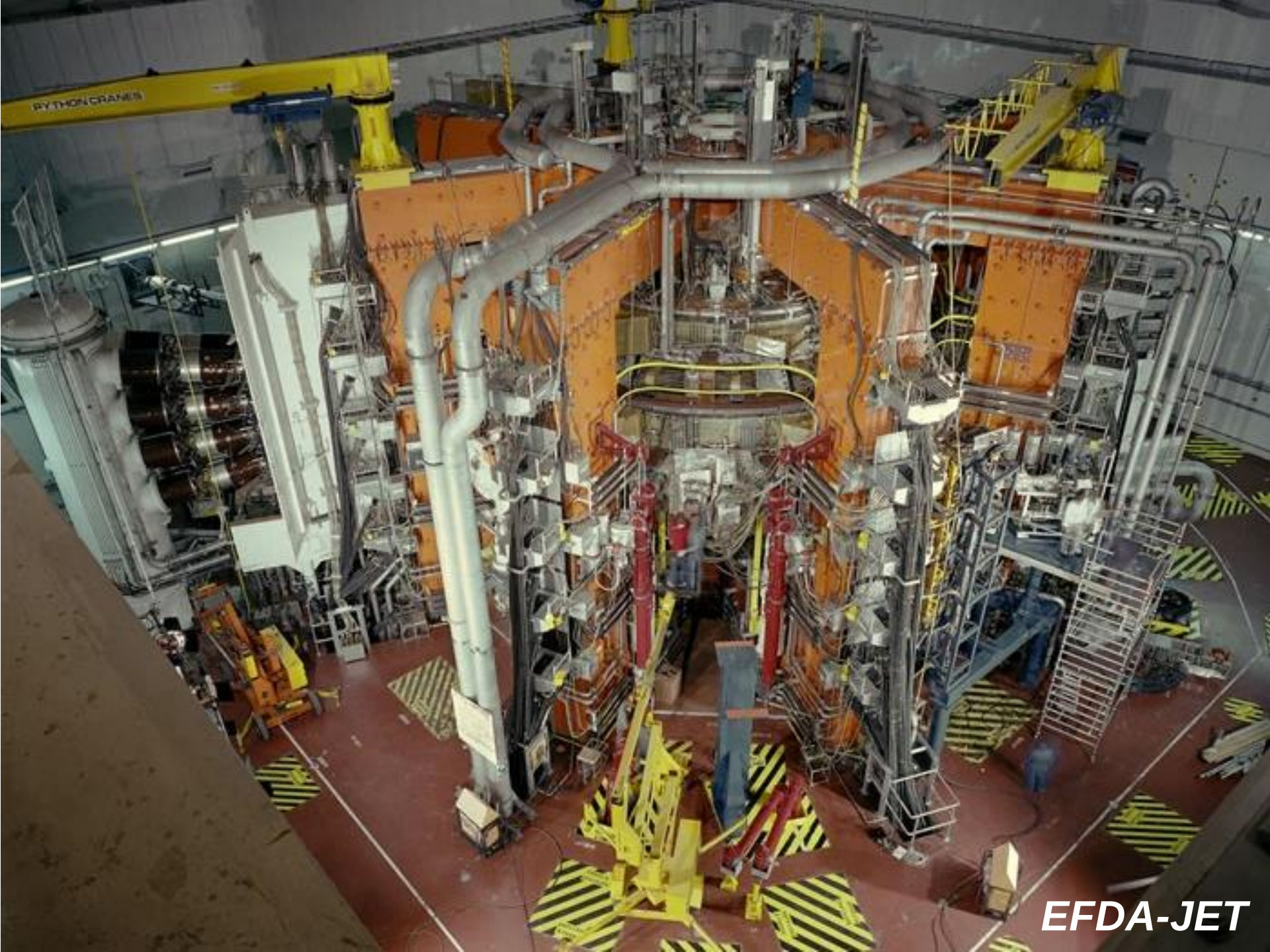
Anatomy of a tokamak | JET (as example)

TF coils create a *toroidal* field

- Confines plasma
- Helps avoiding instabilities.

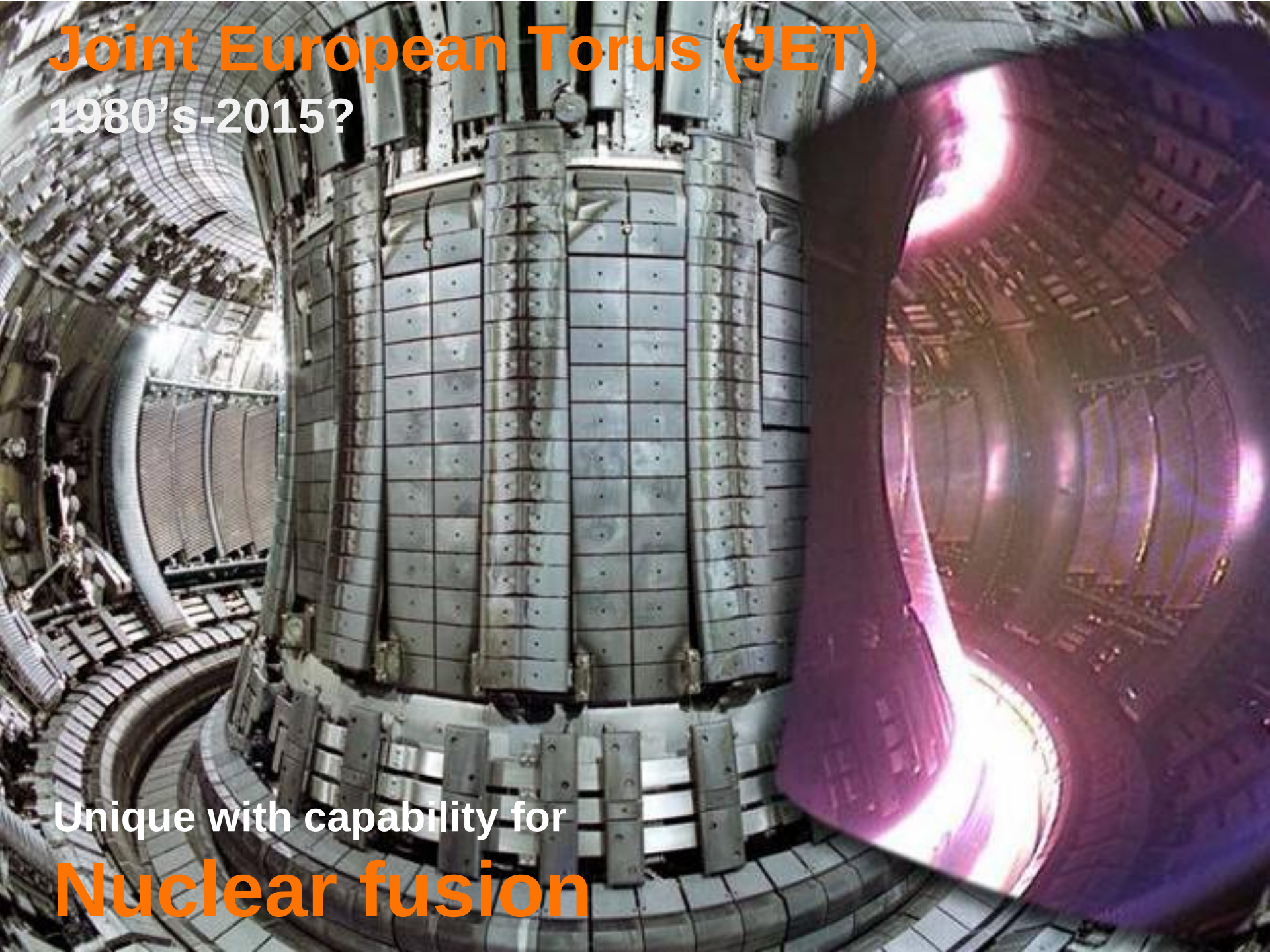
PF (*poloidal*) coils create and shape the plasma.




PYTHON CRANES
EFDA-JET

Joint European Torus (JET)

1980's-2015?



Unique with capability for

Nuclear fusion

How to start a fusion plasma

Central solenoid creates an electric field

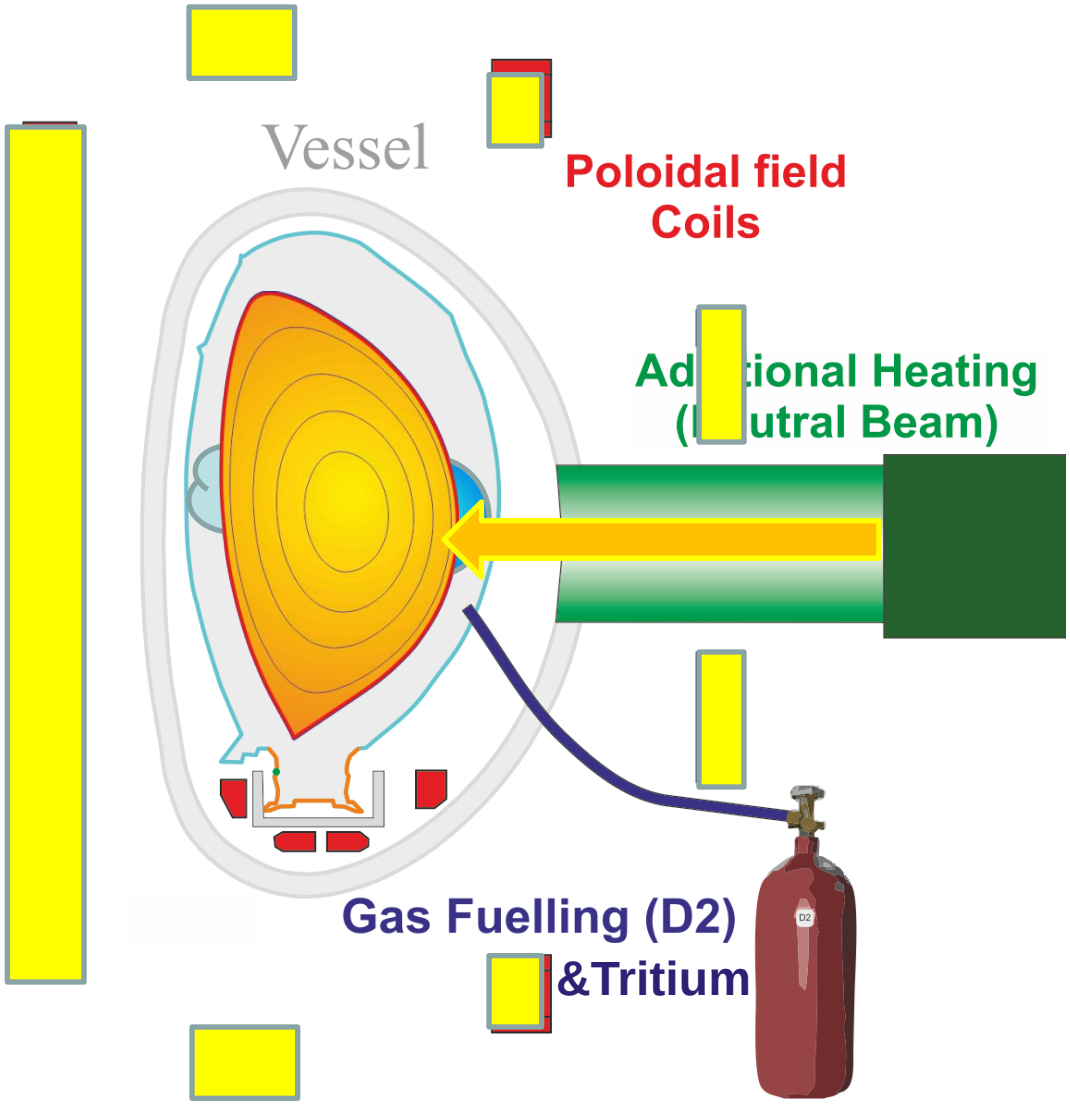
GAS is added and ionised plasma

During plasma growth PF coils control plasma radial position.

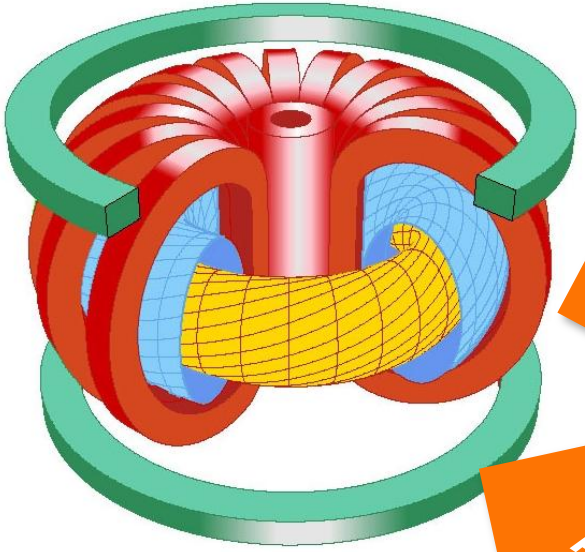
Other PF coils shape plasma into diverted shape

Additional heating heats plasma

Conditions for fusion are reached!



Thinking about control in fusion devices



Critical for safe operation and high performance

Diagnostics

Actuators

[redacted]

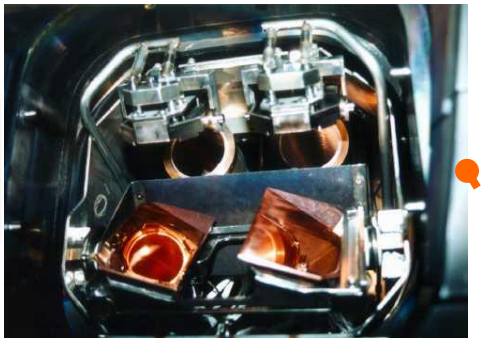
Ensures

- Reliability
- Reproducibility
- Plasma & Machine protection

Radio-frequency in fusion | actuators & sensors

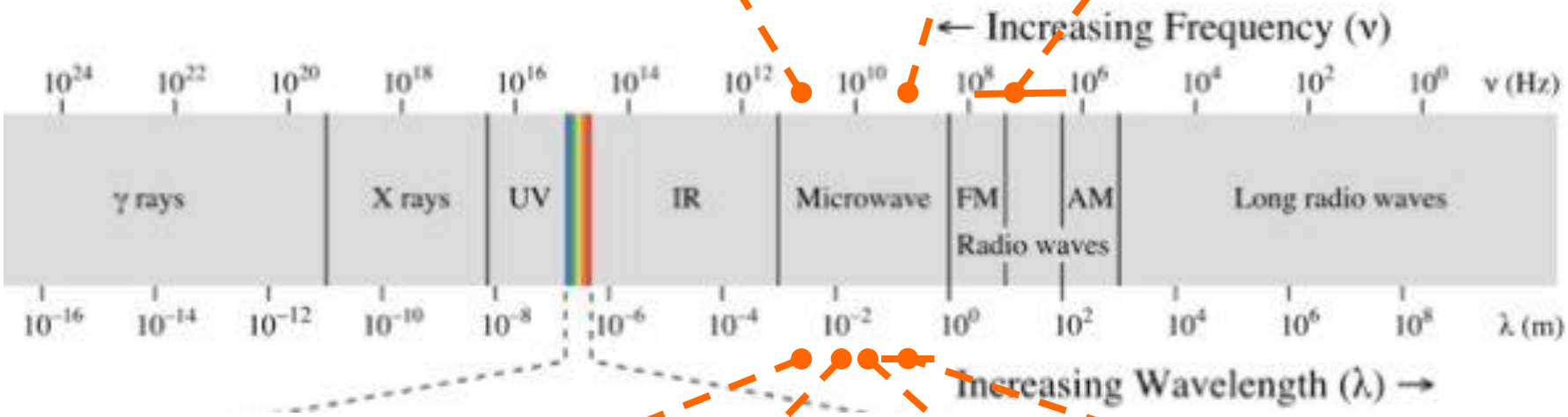
Heating Systems

ECRH | 100-200 GHz



LHRH | 1-8 GHz

ICRH | 30-120 MHz



Diagnostics

ECE

Interferometry

Collective Thomson Scattering

Reflectometry

Controller design is a nontrivial problem

Complex Models

High order

(> 100 states)

Strongly coupled MIMOs

Stability & robustness

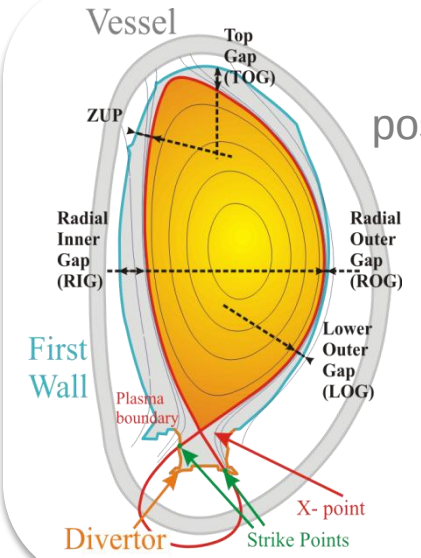
In large time variant operational space

Physical estimation of feedback variables

Control variables subject to physical limits due to

- Quality of measurements of physical phenomena
- Actuator constraints
  - voltage, current and power limits taken into account in design phase

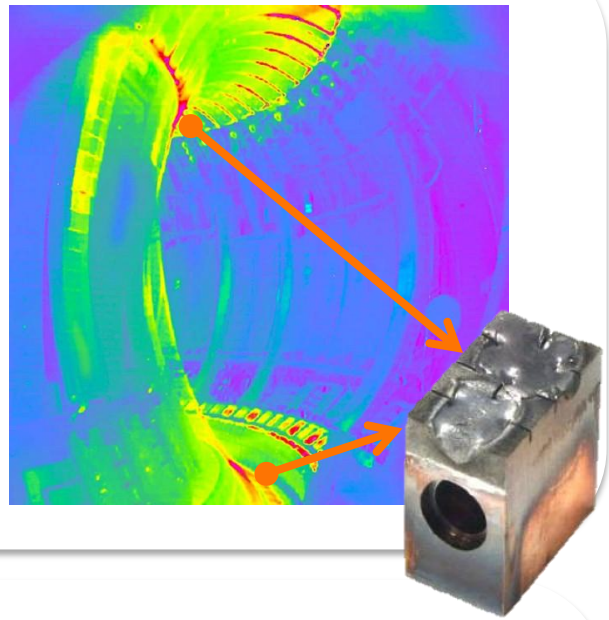
Control in fusion plasmas

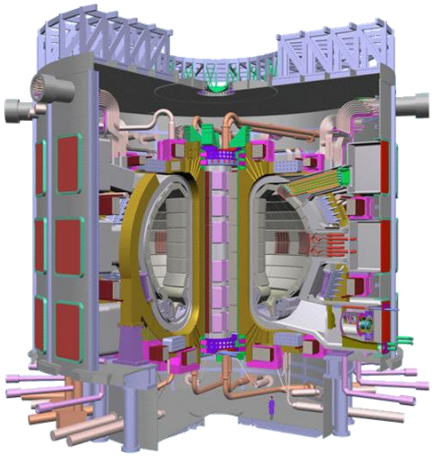


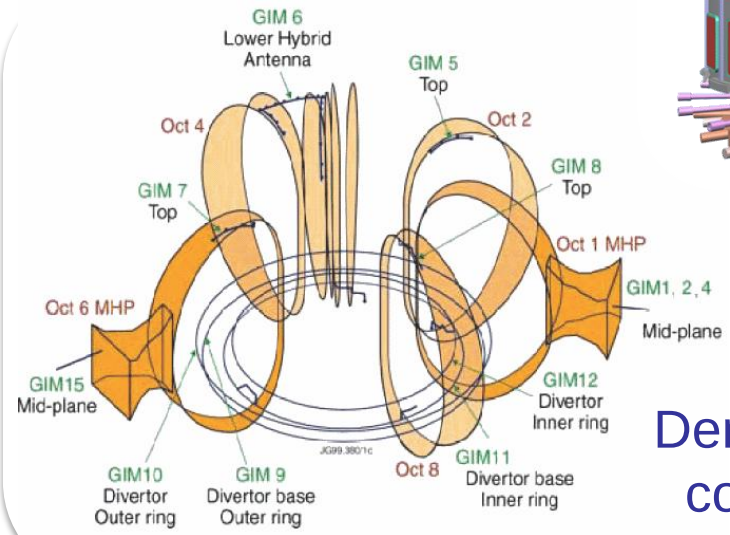
Magnetic control

position, shape & vertical stabilization

Wall protection

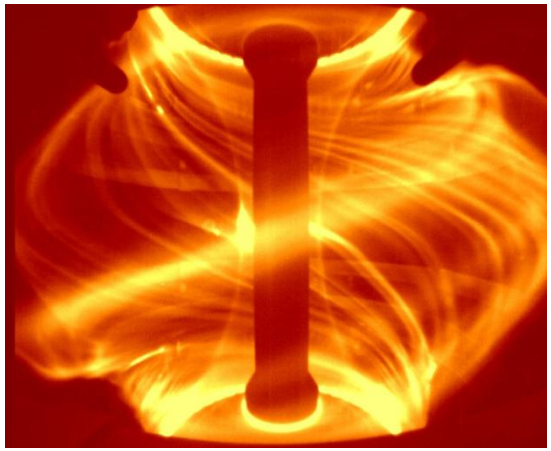






Density control

Instabilities mitigation & control

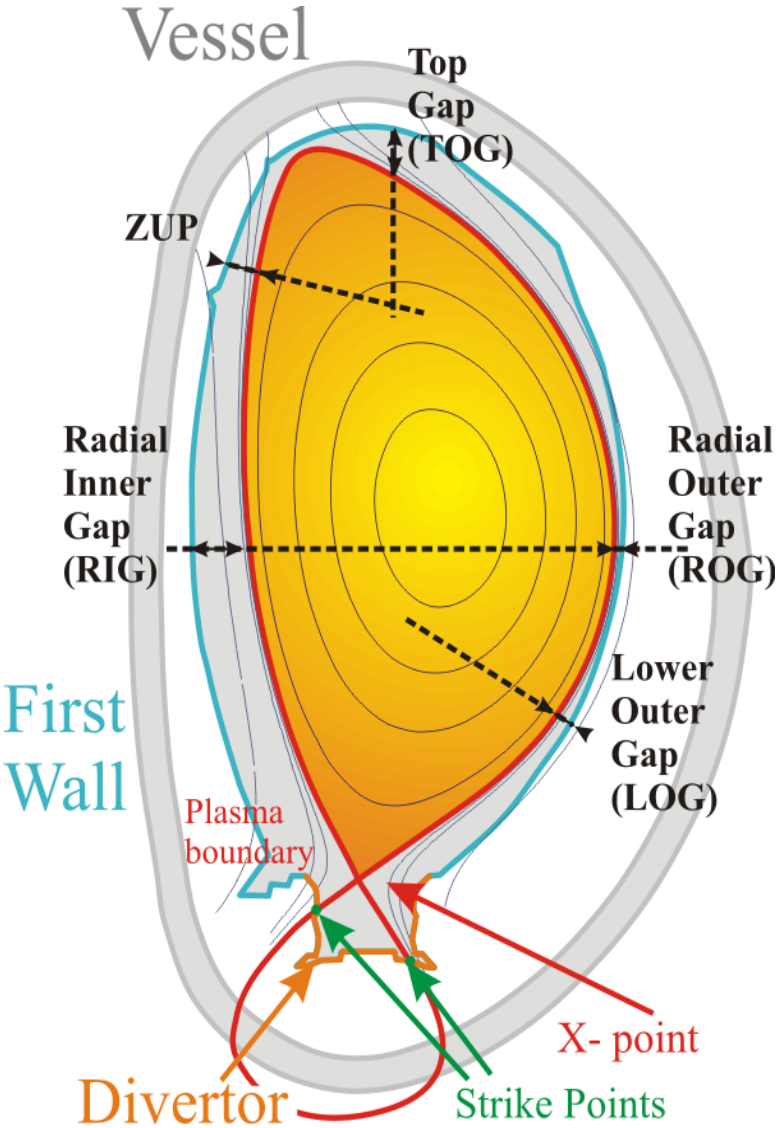


Control in fusion plasmas | Magnetic control

Maintain plasma equilibrium inside tokamak with prescribed position and shape of plasma ring

Feedback system, sometimes divided into separate sub-systems

e.g. position control, shape control & vertical stabilization control



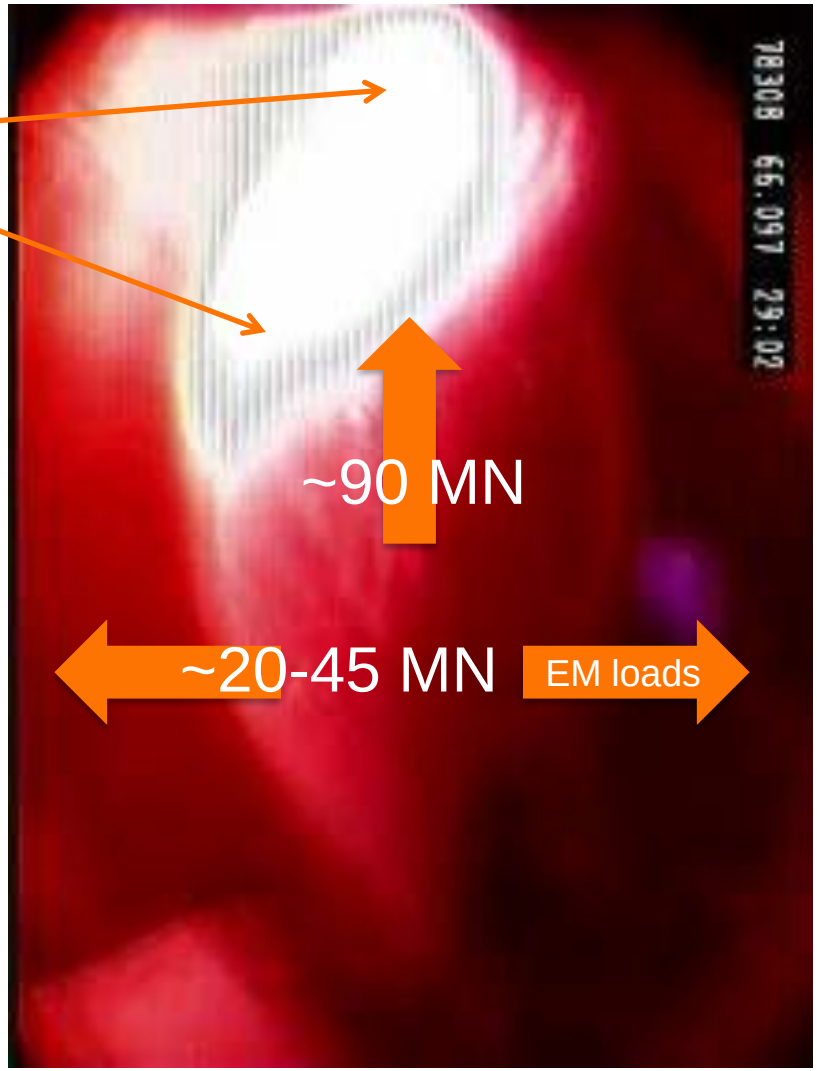
When something fails…

on position control

On ITER similar events will cause huge thermal loads on Plasma Facing Components

30-60 MJ/m^2 for ~0.1s

PFCs cannot be designed to sustain such (repetitive) thermal loads

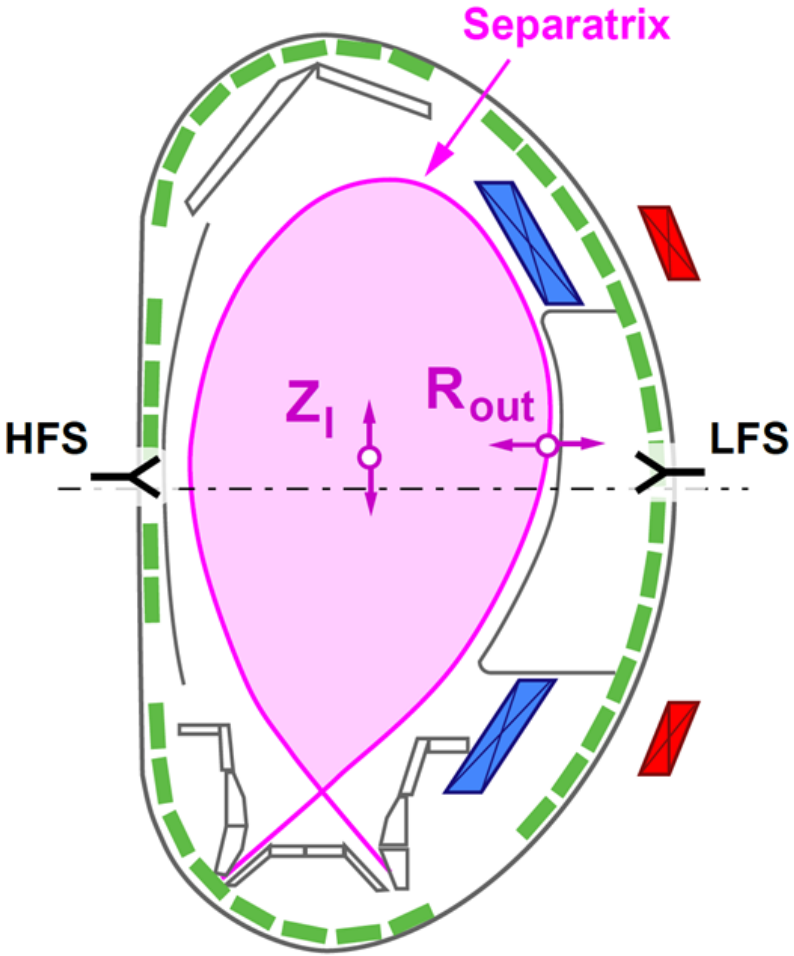


Will require a far higher level of availability and reliability than previous/existing tokamaks

.

Coping with faults in magnetic sensors | Solutions

Design for backup diagnostics to complement or replace primary diagnostics

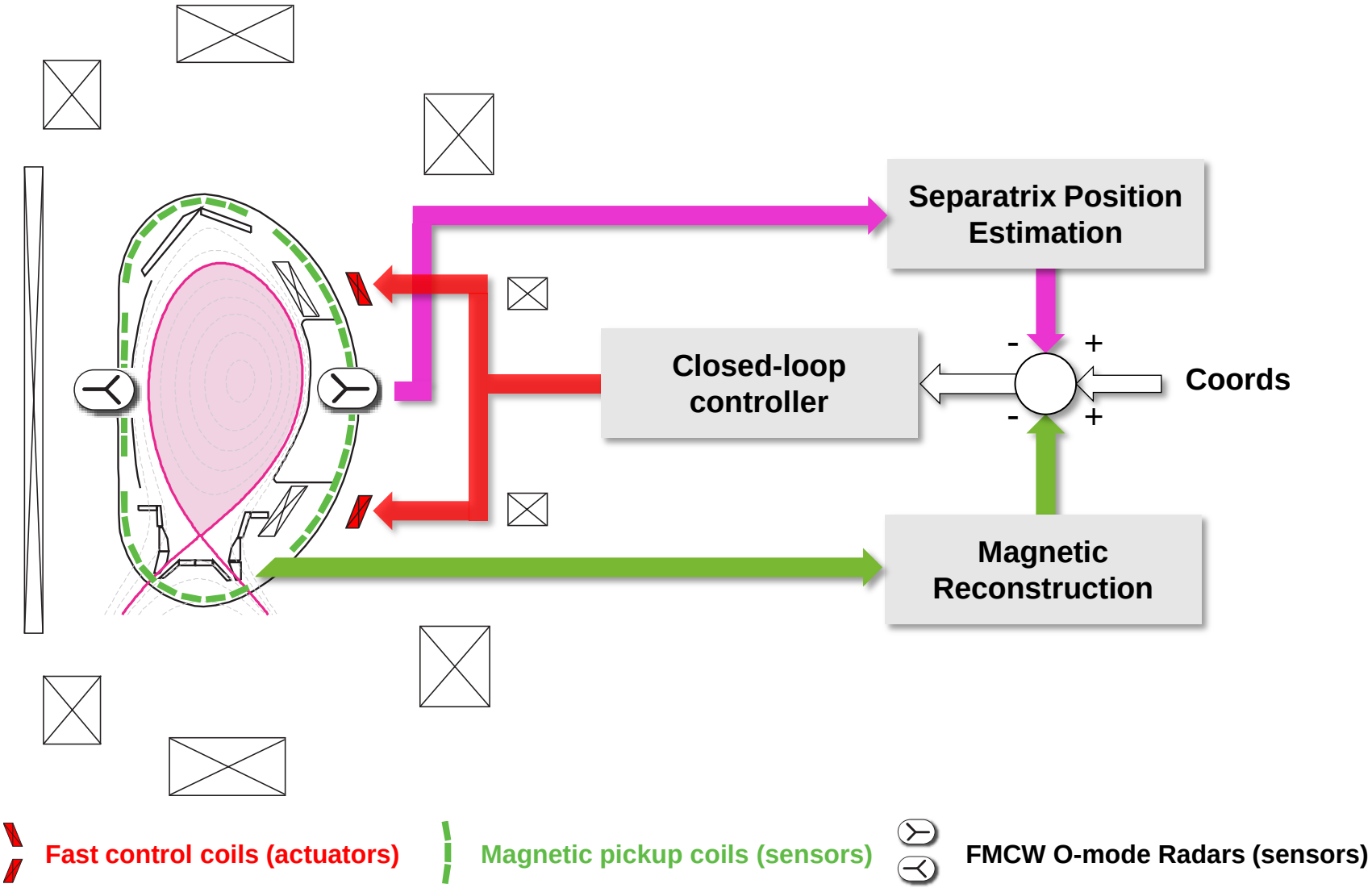


Plasma Position reflectometer

FMCW Radar capable of probing the **inner and outer** plasma edge

See J. Santos, URSI award

Plasma Position reflectometer

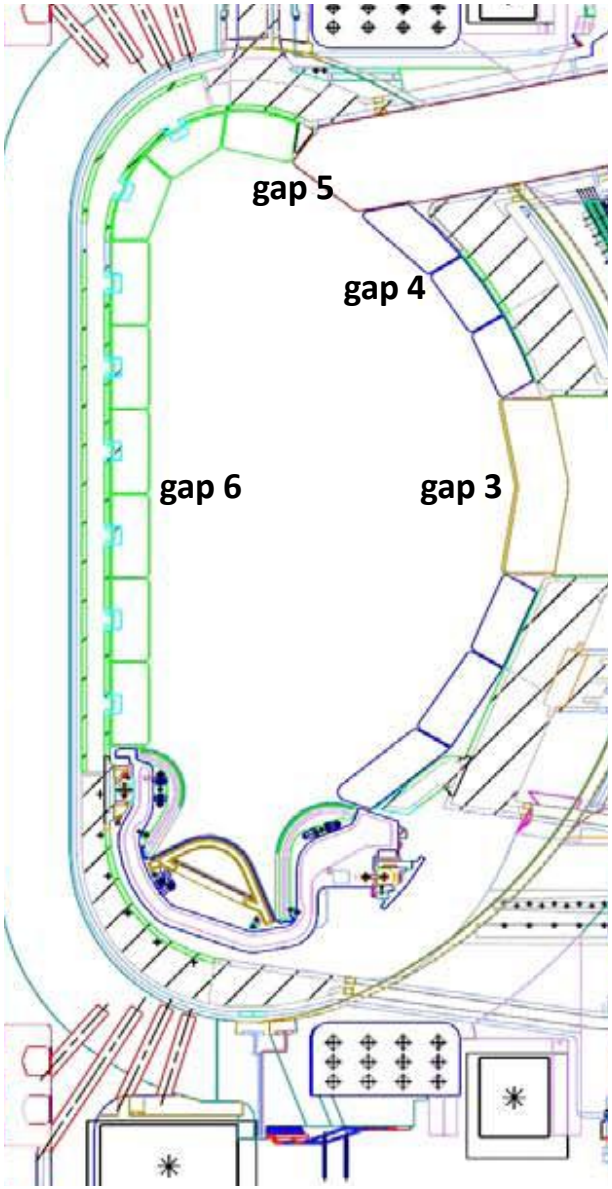


See J. Santos, URSI award

ITER | Plasma position reflectometer

Measurement of distance (gap) between plasma column and first-wall @4 poloidal locations

4 O-mode reflectometers operating in frequency range 15-60 GHz



8.5 M€

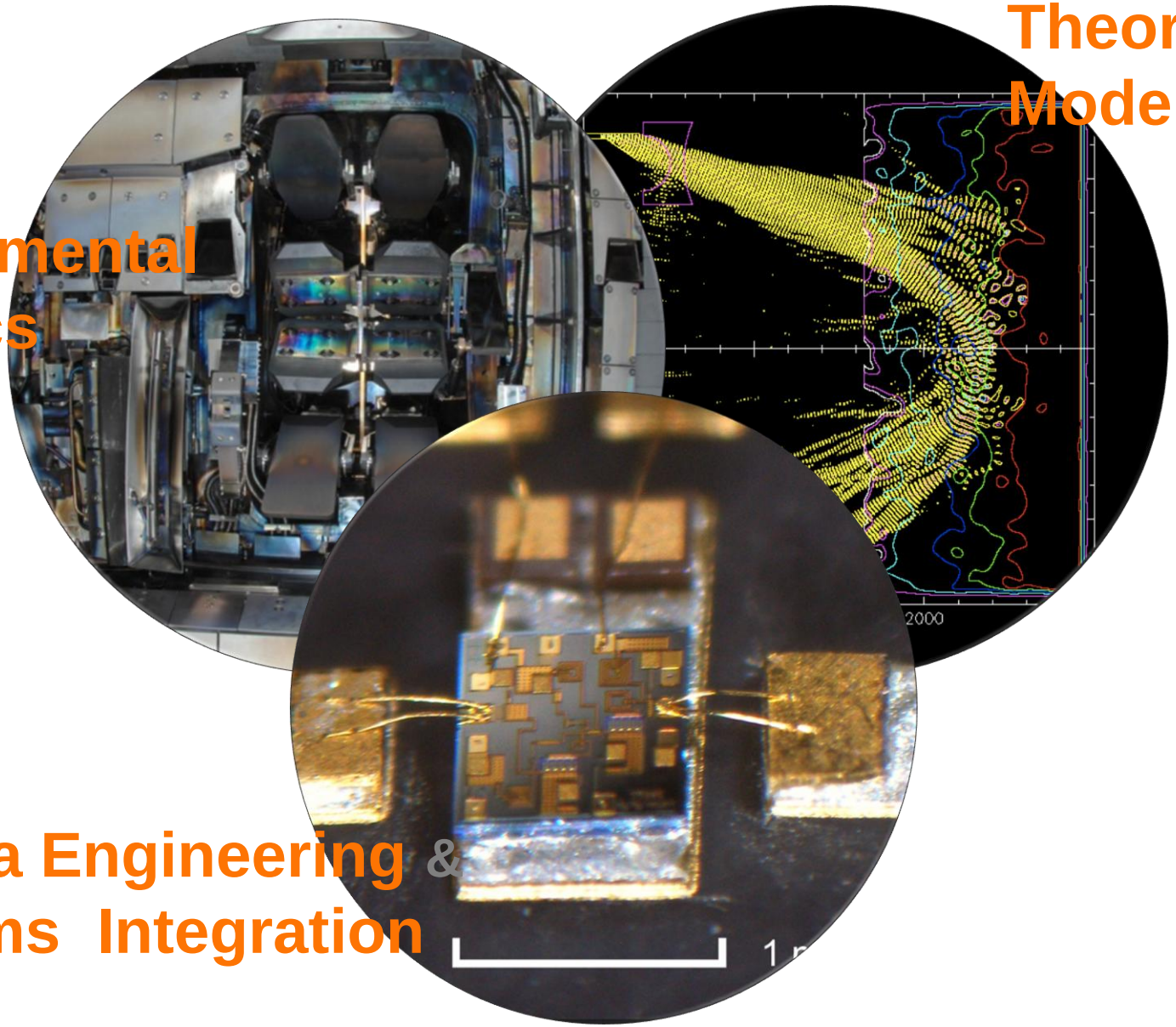
Consortium led by IST/IPFN

ipfn INSTITUTO DE PLASMAS E FUSÃO NUCLEAR

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

IFP

Key areas for microwave diagnostics



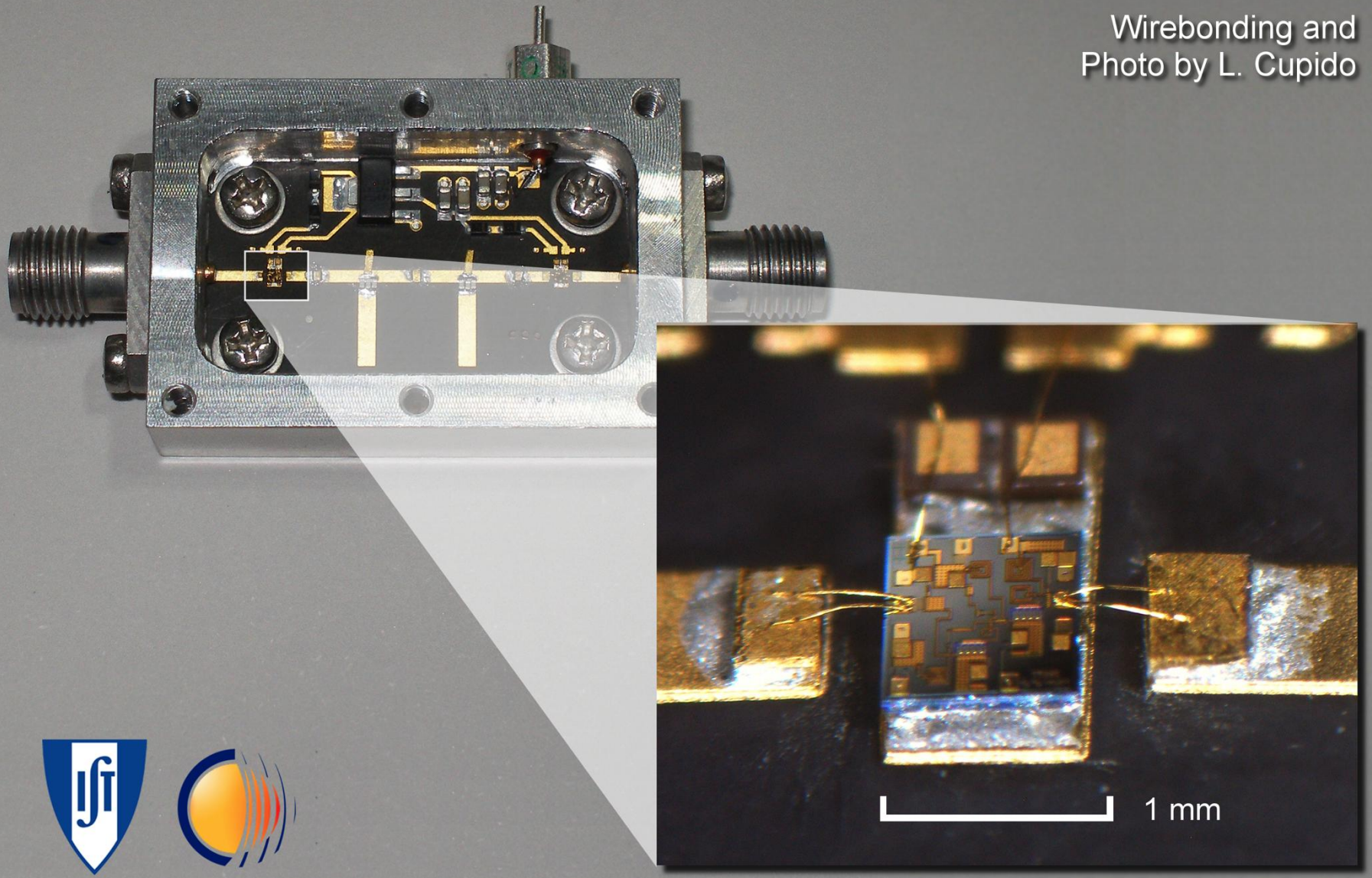
Theory & Modeling

Experimental Physics

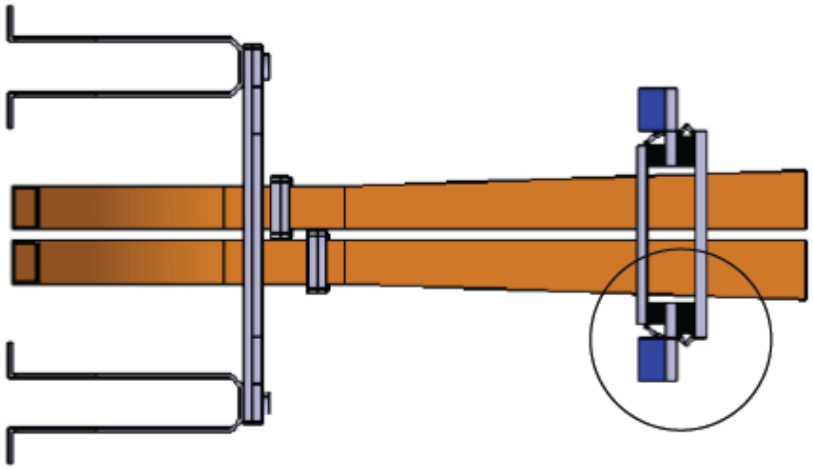
Plasma Engineering & Systems Integration

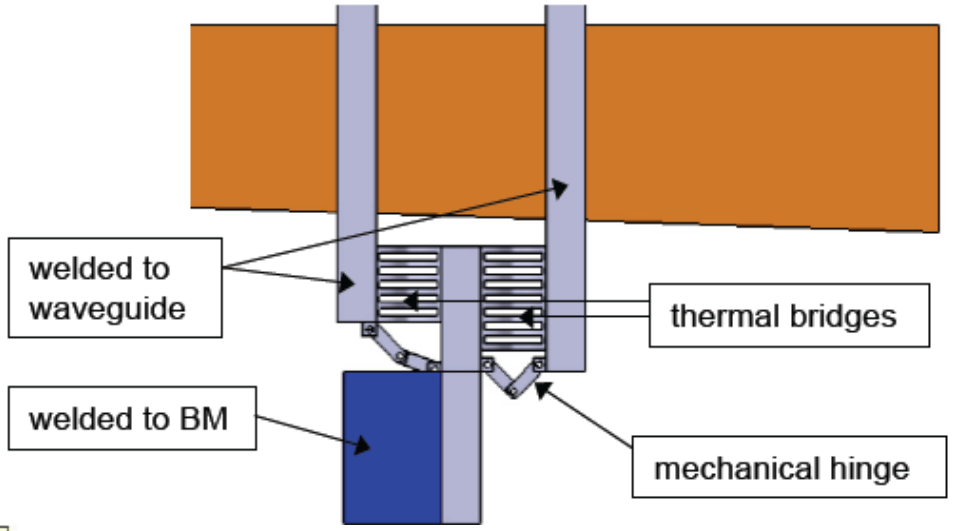
State-of-art engineering | development of microwave electronics

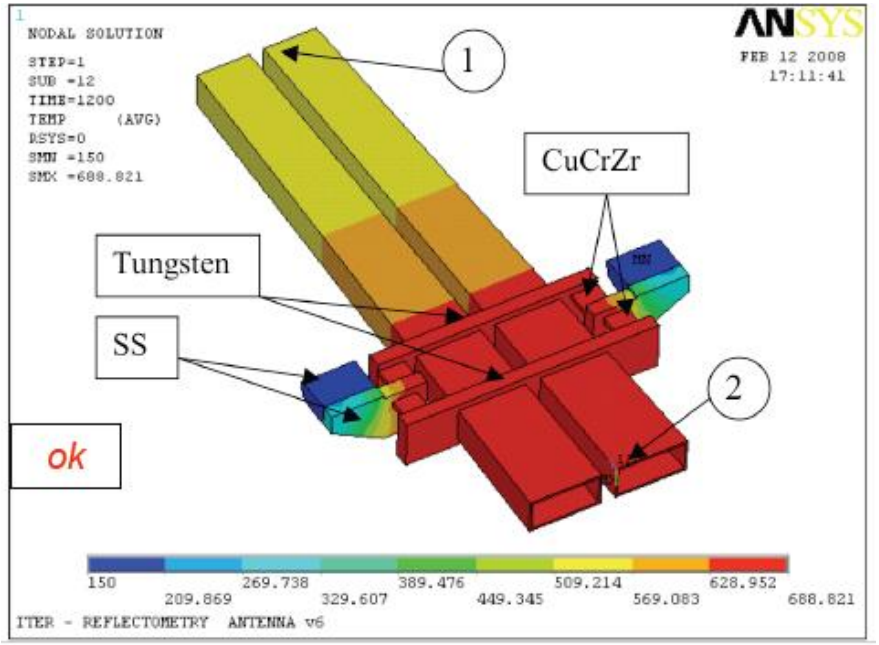
Wirebonding and
Photo by L. Cupido

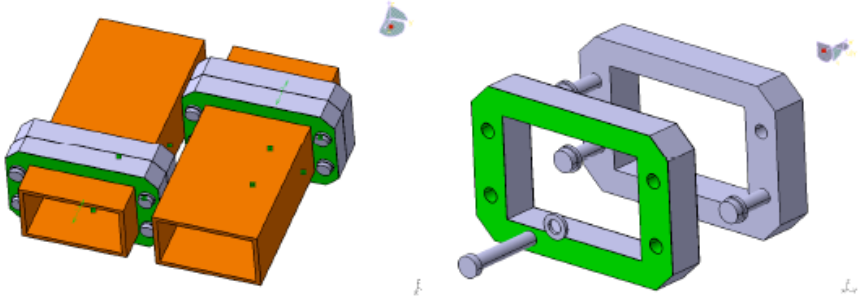


Engineering | antenna design & integration

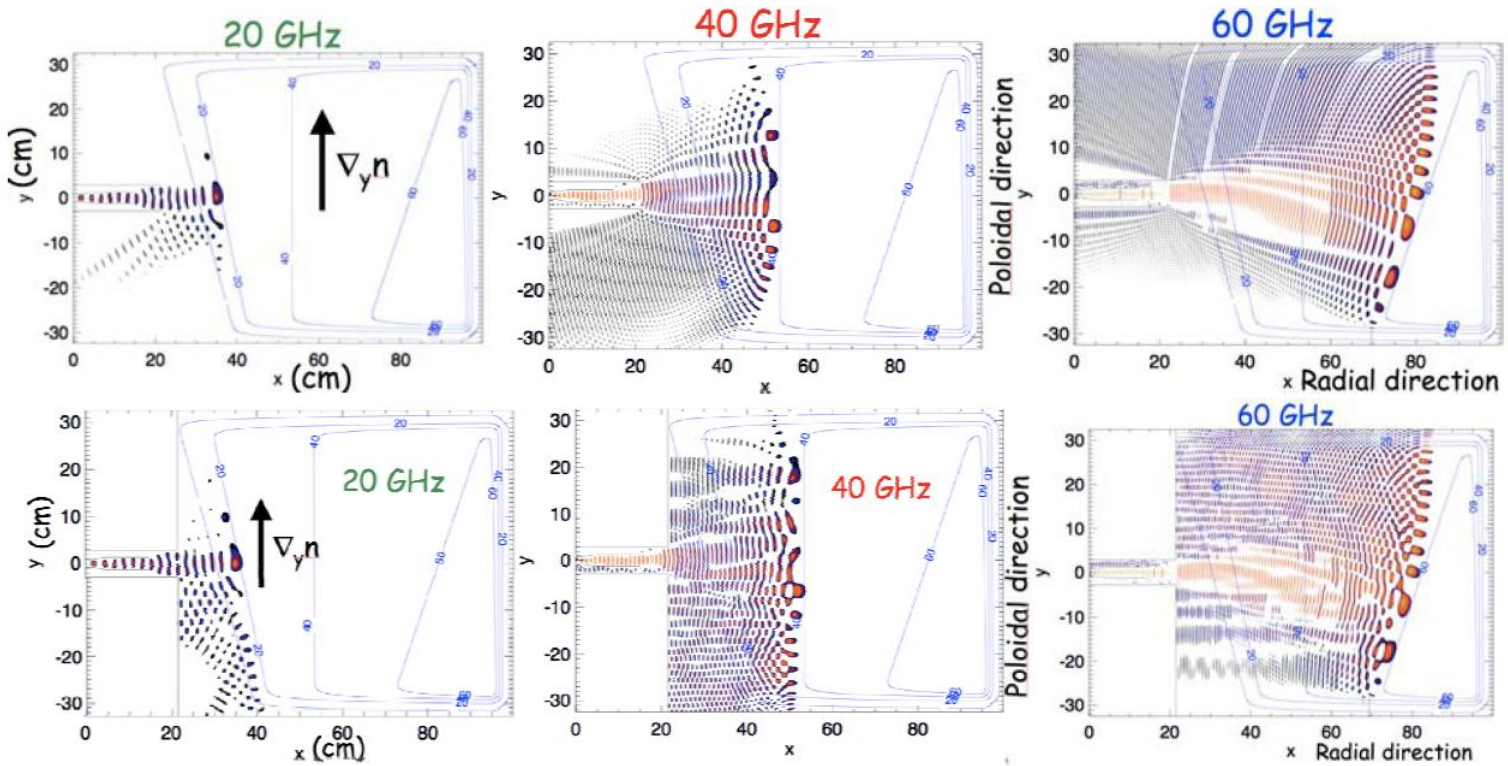








Theory & Modelling | wave/plasma interaction



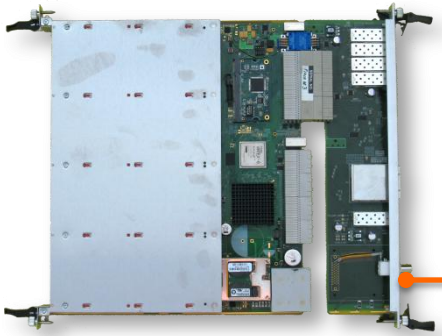
- 2D full-wave simulations of first-wall effects
- Multiple reflections between plasma wall can only be fully assessed with a 3D code
- Beam bending, particularly visible at 60 GHz (not shown by ray-tracing simulations) enhances the sensitivity to density fluctuations and Doppler effects

Further challenges…

Providing robust, fault tolerant, reliable, highly available, maintainable and radiation tolerant control systems

Requires using robust instrumentation standards designed for high availability!

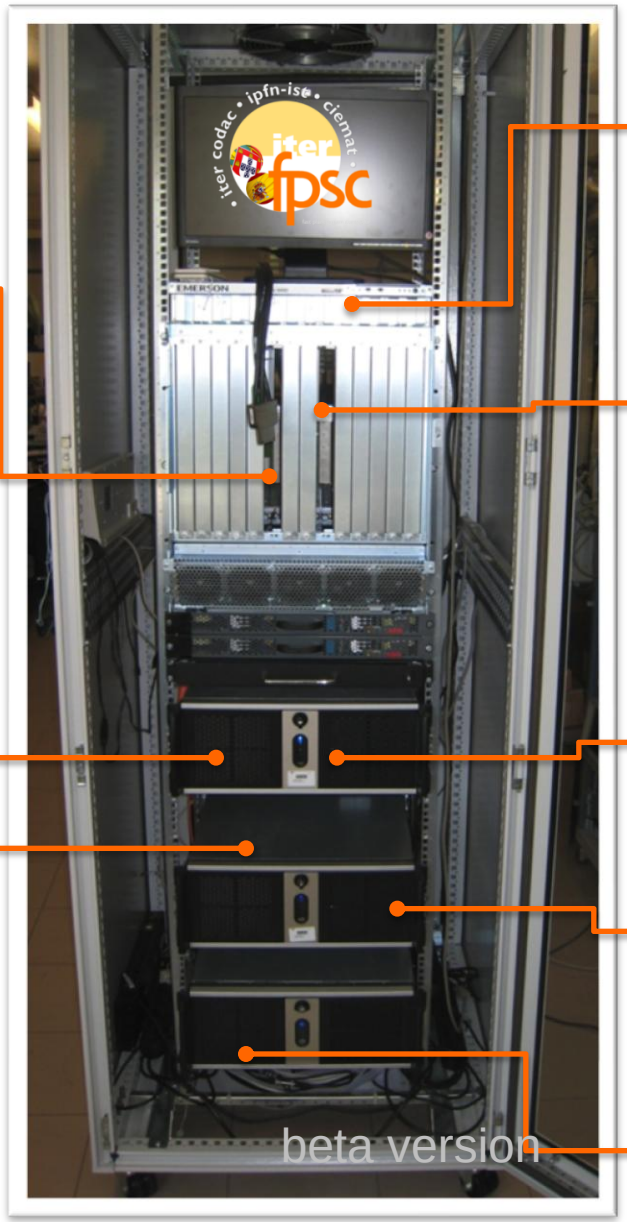
FPSC | ITER Prototype (Funding: ~1.5 M€)



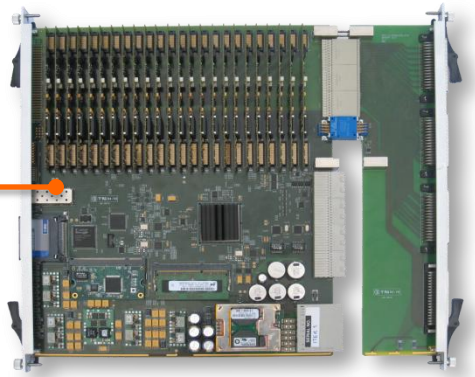
ATX-AMC4-PTP

Dolphin PCIe cable card

Dolphin PCIe switch (DXS410)



Shelf Centellis 4400
(ITER Catalogue)



ATCA-IO-Processor
(MIMO mk2)

Controller/PSH

Mini-CODAC & archiving server

HPC

Role of Nuclear Fusion on radio-frequency R&D

Vast field for development for applications of radio-frequency (up to 270 GHz)

- Radar (reflectometry)
- Fast digital electronics
- Signal processing
- Numerical simulation of wave propagation and interaction with the plasmas

Including high power applications

- New generation girotrons working at very high frequencies (up to 270 GHz)
- High power transmission lines
- Mode converters
- Mirror systems for creation of Gaussian beams

Privileged field for advanced education in radio-frequency engineering

- Several PhD & Master thesis, collaborations with IST DEEC, IT Lisbon, Univ. Stuttgard,…

Ground for research/innovation leading to contracts involving industry

Lots of work and R&D are still required in coming years!!

Spin-offs

Beyond state-of-art μw/mmw components and electronics

with applications to instrumentation for telecommunications, radars, material engineering, etc

Biological & medical applications

a) μw/mmw imaging diagnostics with enhanced detection and discrimination capabilities for early detection of tumors

b) μw/mmw equipment for hyperthermia treatment of cancer.

Leveraging IPFN knowledge

- Microwave and Millimeter Wave Instrumentation
- FDTD code for electromagnetic modeling
- Advanced Data Processing Techniques
- Optimized Antenna Design