Technology and Physics Advances for the Ignitor Program

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M.I.T.

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From JET to the reactor

P.H. Rebut, Alfvèn Prize Lecture

33rd EPS Conference, Rome (2006)

http://eps2006.frascati.enea.it/invited/post.htm

In a reactor, the energy produced by fusion reactions only matters, not the record on some of the non dimensional parameters.

The real gain has to be proven in tritium operation.

Having superconducting coils adds to the complexity and the cost of a machine; in my opinion it was premature to do it on ITER on the program leading machine which is still far from a reactor.

Taking into account the **efficiency of the conversion** from heat to electricity, and the **efficiency of the auxiliary heating** and **plasma control**, a **Q of 50** for the fusion reactor is required

To achieve such a Q of 10, ITER must operate in the **H mode**, The H mode appears in presence of a divertor, over a power threshold. It is not possible to **maintain** it for a **long time**.

The X point limiter

P.H. Rebut, cont’d

We may take advantage of the **H mode physics** by installing a limiter in the vicinity of the X point rather than a standard divertor.

The advantages are in a given machine:

- **Better plasma performances**

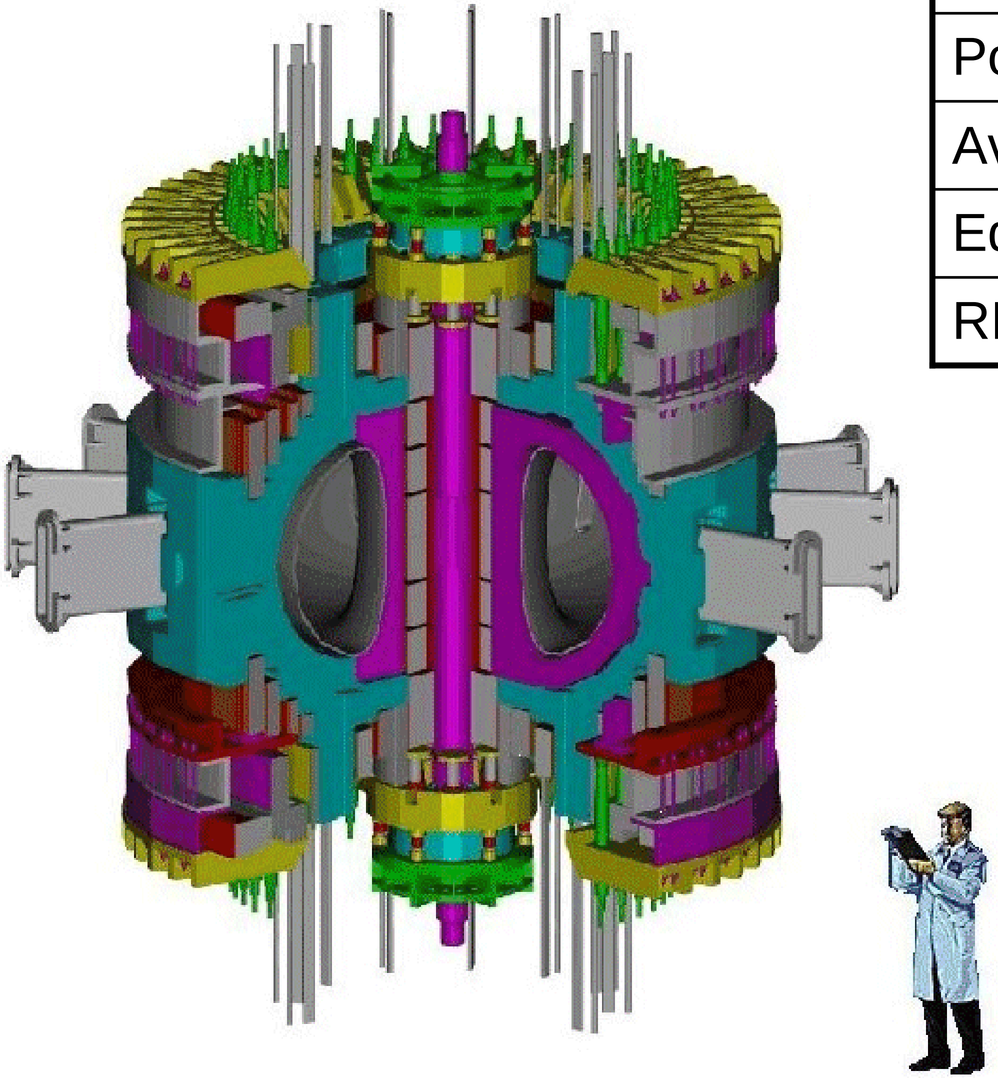
a larger plasma volume, a factor 1,3 in the case presented
an increase of the plasma current by 1,2
an increase of the plasma pressure by 1,1
a higher fusion power by a factor 1,5

H mode plasma have been possible on JET with the X point pushed into the wall.

- **Better technical solution**

a simpler technical solution with a larger wetted area
an easier possibility to sweep and move the contact area

IGNITOR PARAMETERS



Plasma Current I_P	11 MA
Toroidal Field B_T	13 T
Poloidal Current I_θ	8 MA
Average Pol. Field $\langle B_p \rangle$	3.5 T
Edge Safety factor q_ψ	3.5
RF Heating P_{icrh}	<18 MW

R	1.32 m
a	0.47 m
b	0.86 m
κ	1.83
δ	0.4
V	10 m^3
S	36 m^2
Pulse length	4+4 s

The Ignition Strategy

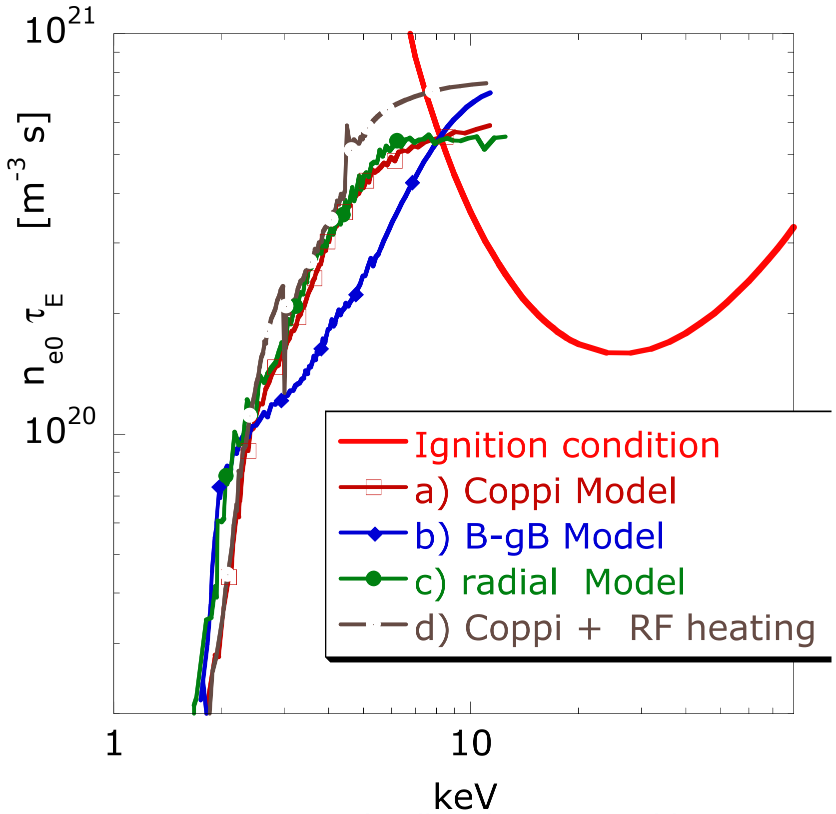
$n\,\tau_T$: high density, moderate τ_E, low temperature

$n/n_{limit} < 0.5$, low $\beta \Rightarrow$ far from empirical operational limits

$\tau_{\alpha,sd} << \tau_E$, $\tau_{burn} >> \tau_E$

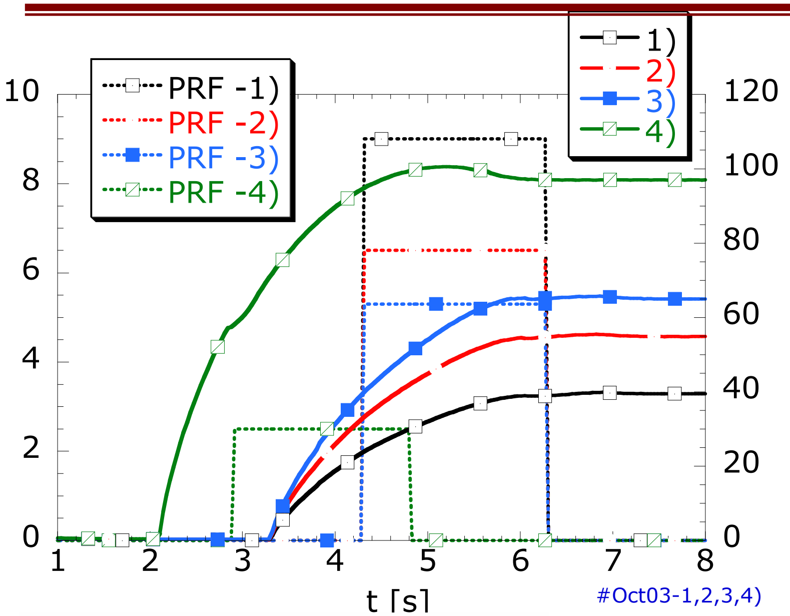
Typical Parameters at Ignition

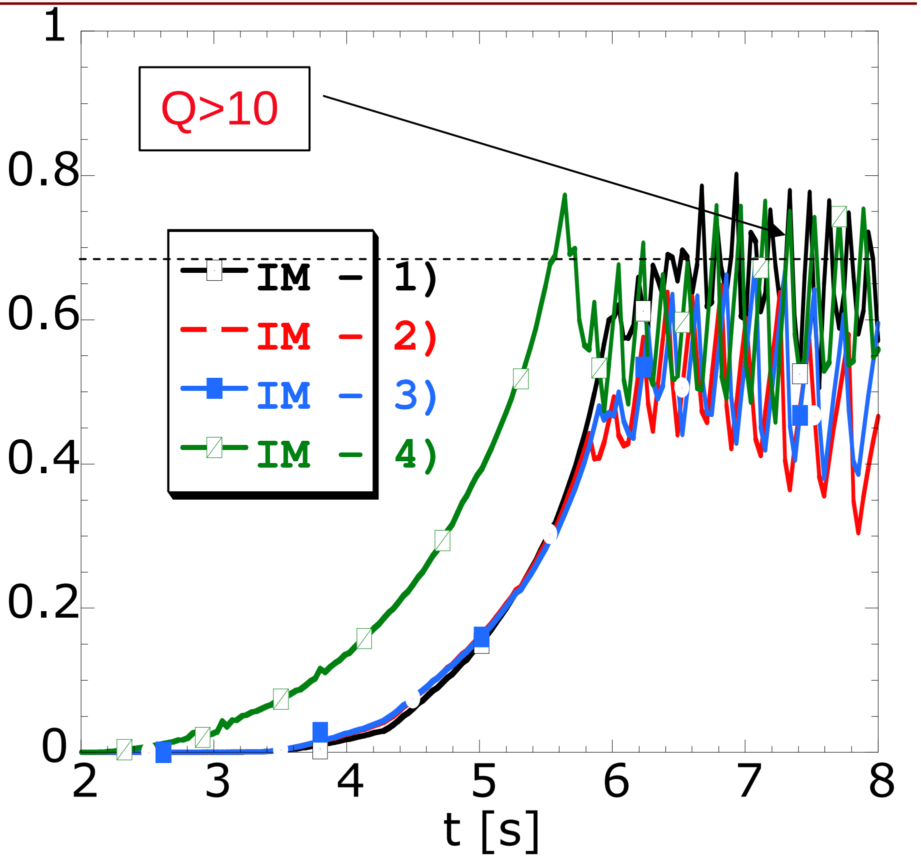
T_{e0} , T_{i0}	11.5, 10.5 keV
n_{e0}	10^{21} m^{-3}
$n_{\alpha 0}$	1.2×10^{18} m^{-3}
P_α	19.2 MW
β_{pol}, β	0.2, 1.2%
τ_E	0.62 s
τ_{sd}	0.05 s
Z_{eff}	1.2

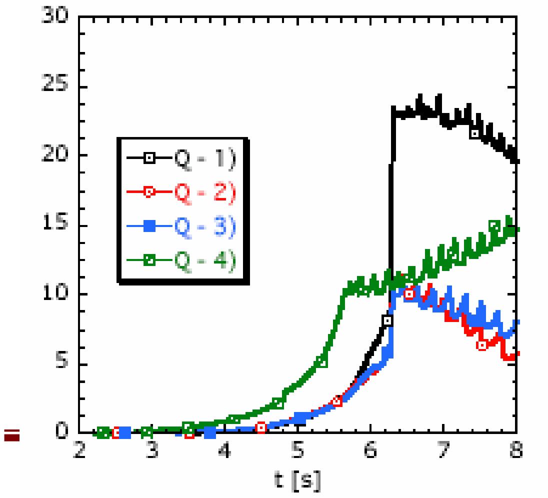


A. Airoldi and G. Cenacchi, 2001

Ignition control by means of Tritium and RF







With proper timing, the RF power compensates for the unbalanced fuel ratio. As a result, only small differences in the ignition margin are observed.

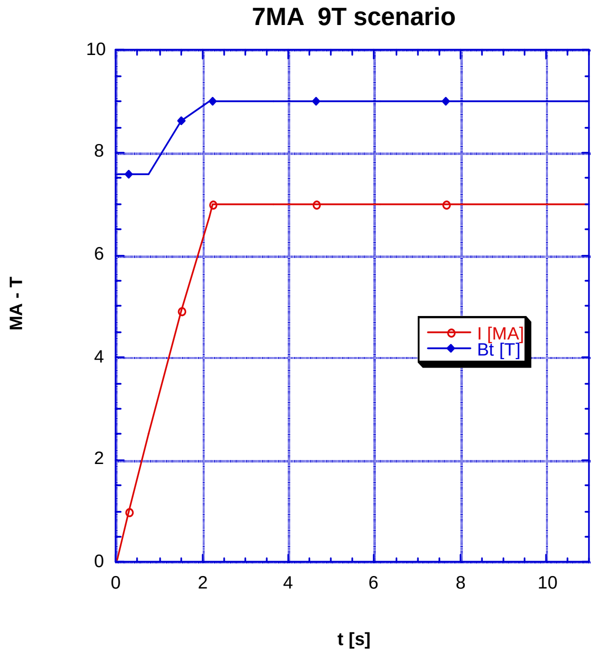
Scenarios with reduced parameters

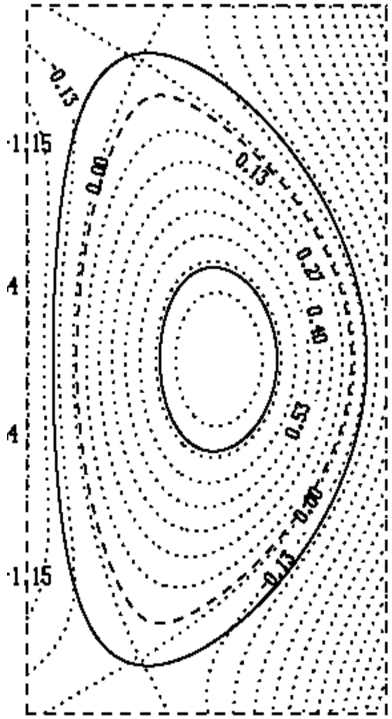
Magnetic field up to 9T

Plasma current up to

i) 7 MA (“limiter” configuration)

⇒ Long pulse





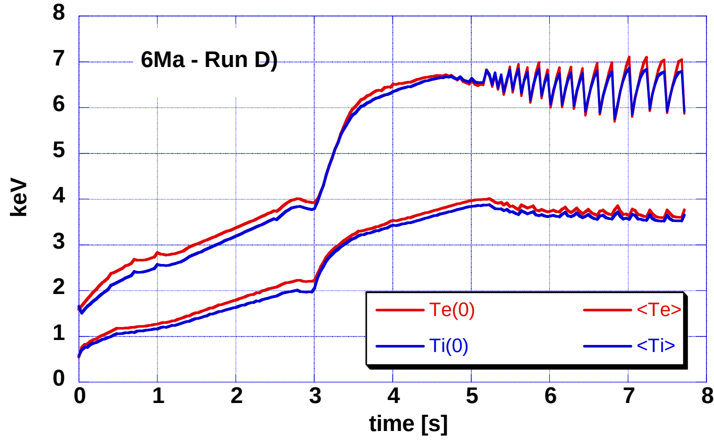
or

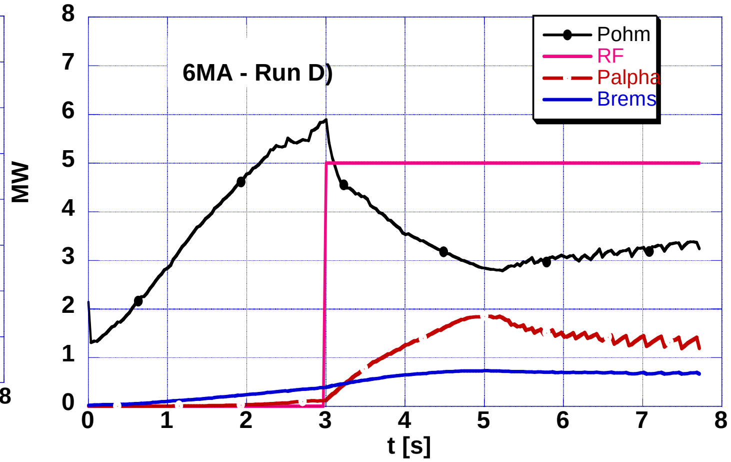
ii) 6 MA (double X-point)

Pulse length consistent with mechanical and thermal requirements of the magnets, and available magnetic flux

Double X-Points Scenario

(6 MA, no transport barrier)

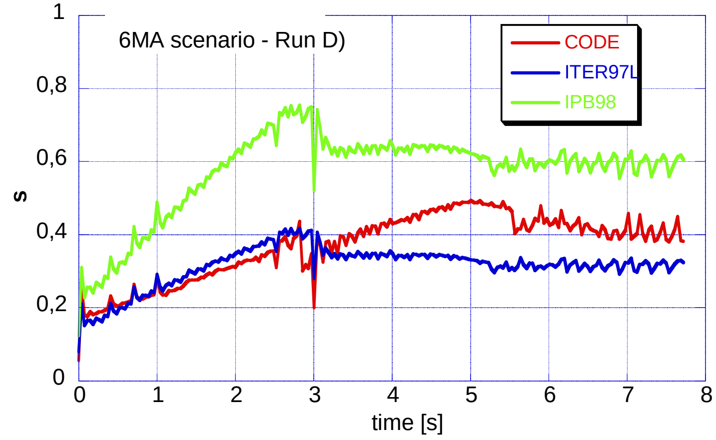


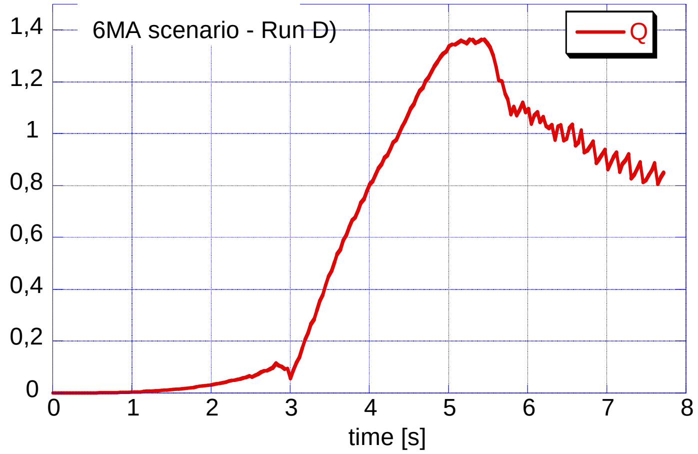


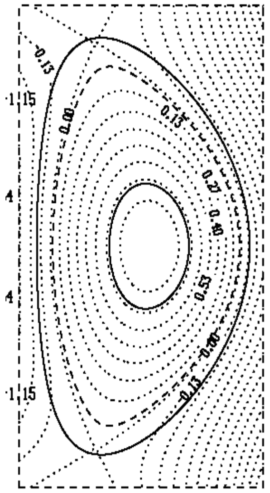
Equilibrium configuration with X-points inside the first wall

Rx=1.17m

Zx=0.84m







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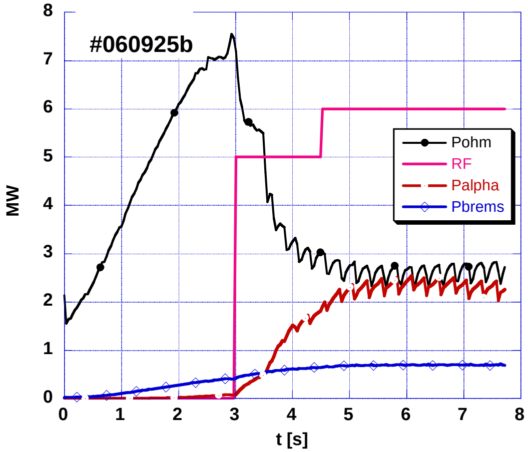
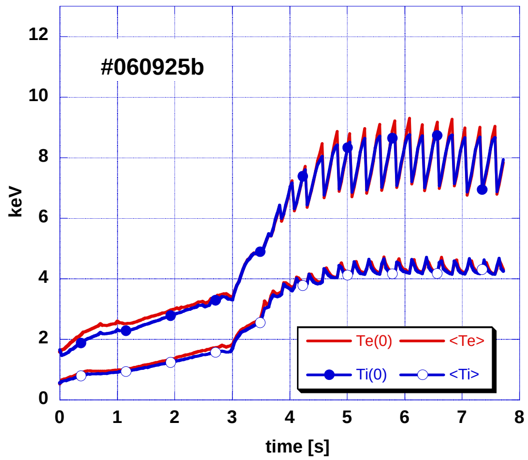
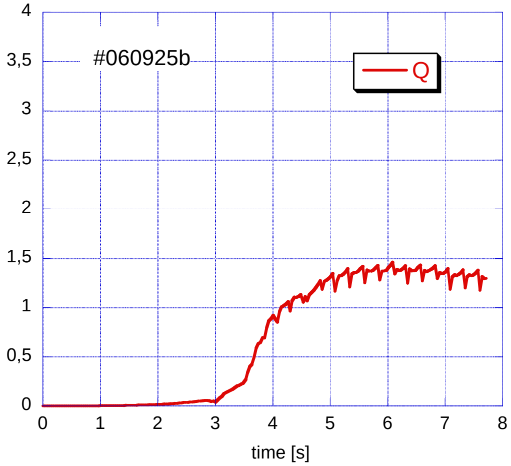
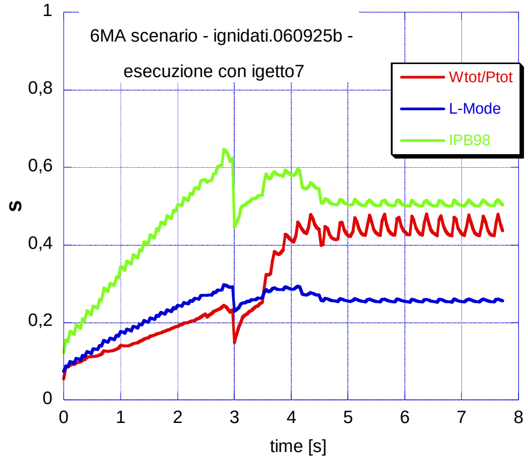
Double X-Points Scenario

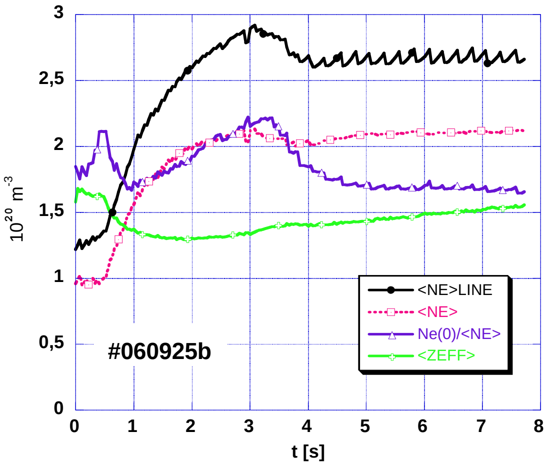
(6 MA, H-mode)

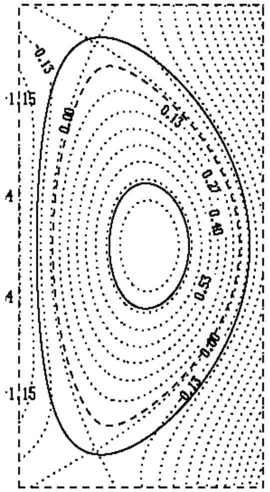












A. Airoldi, G. Cenacchi

The Compact, Multiple Barrel High Speed Pellet Injector

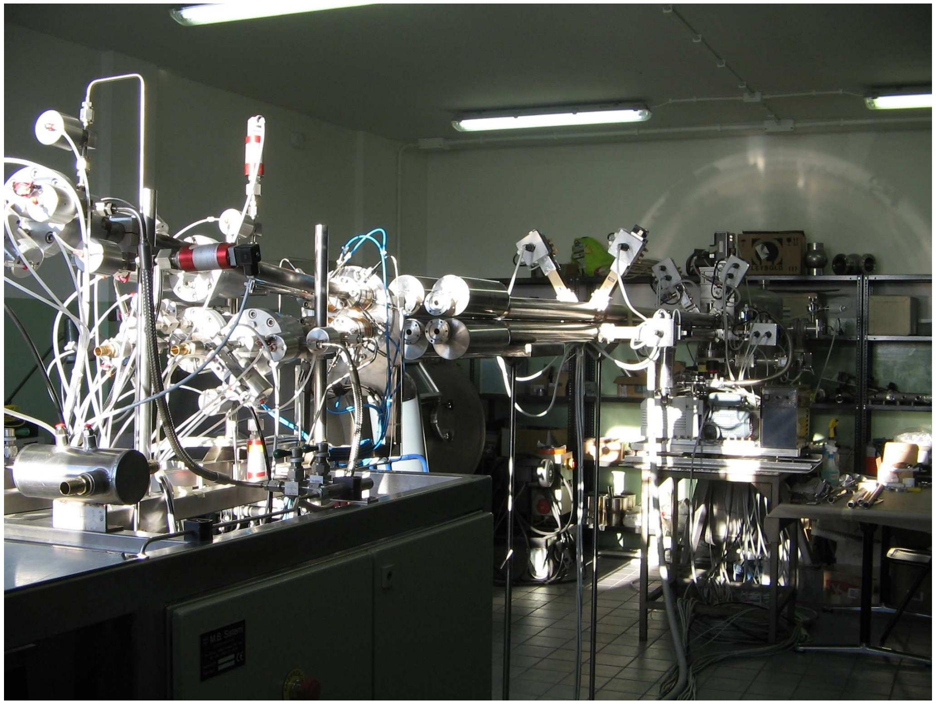
Both high and low magnetic field experiments have shown that low thermal diffusivities can be produced in the central part of the plasma column as a result of peaked density profiles, such as those resulting from pellet injection.

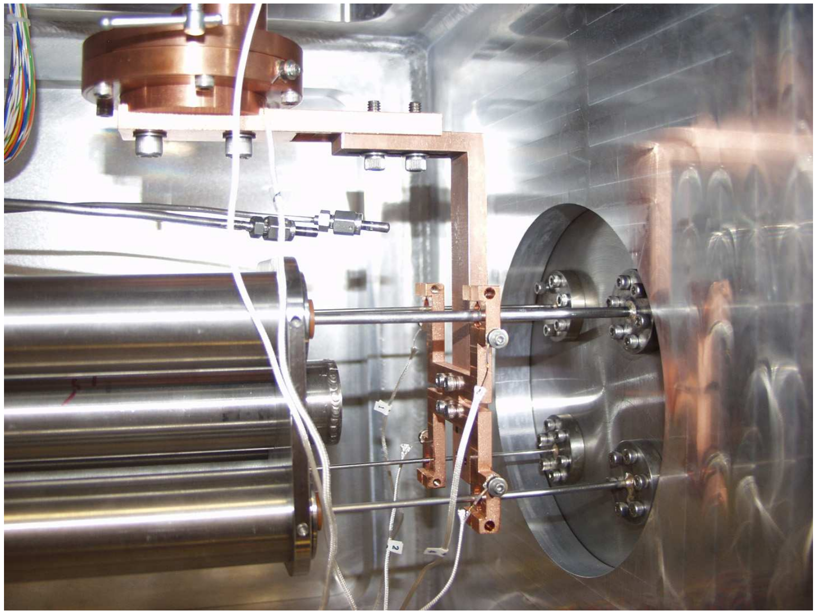
A new multiple barrel, 4 km/s pellet injector for the Ignitor experiment is being developed jointly by ENEA and ORNL.

In Ignitor good pellet penetration from the low field side can be expected in burning plasma condition

The propelling sub-system is undergoing final testing in Italy before shipping to ORNL for complete integration with the cryogenic system.

Testing with real pellets has begun at ORNL.

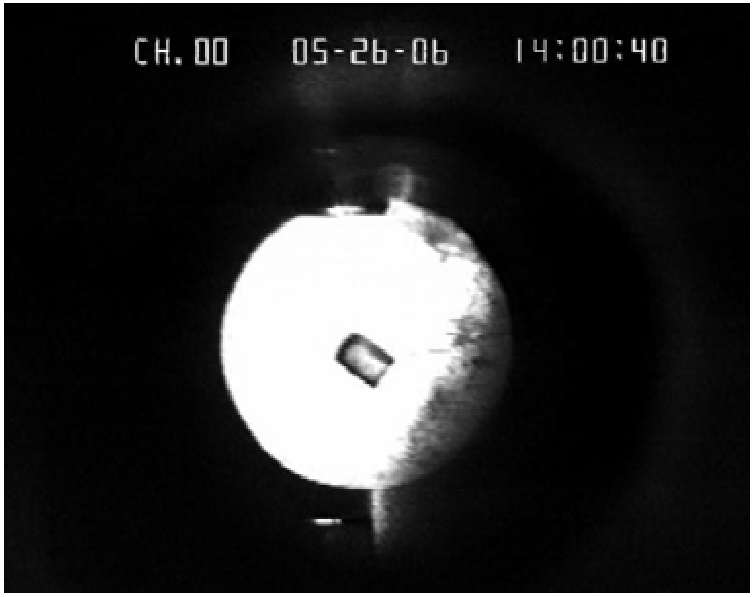




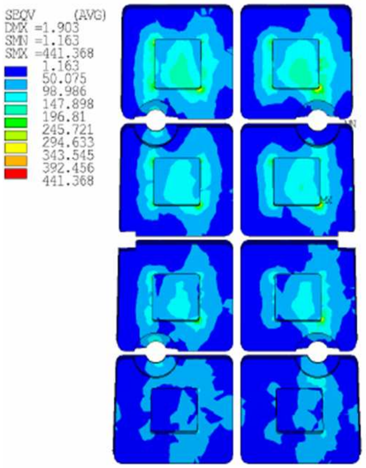
ENEA Propelling sub-system
built at Criotec Impianti.

The pellet injector cavity built at O.R.N.L (top right)

In-flight picture of a 3 mm D2 pellet, traveling at about 1.2 km/s (right)

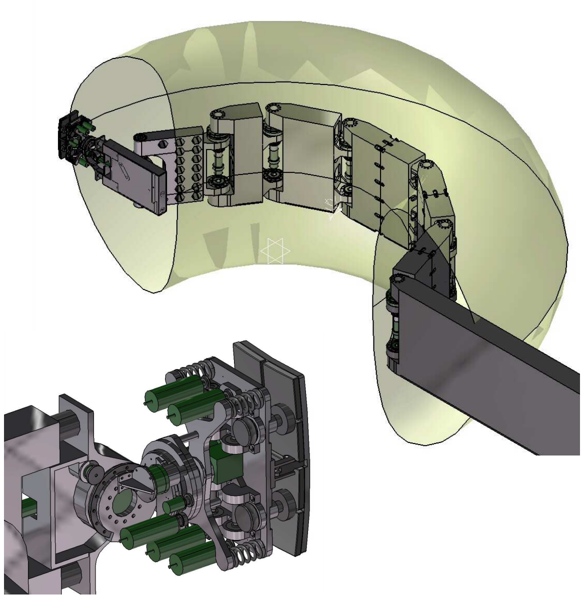


Design Progress



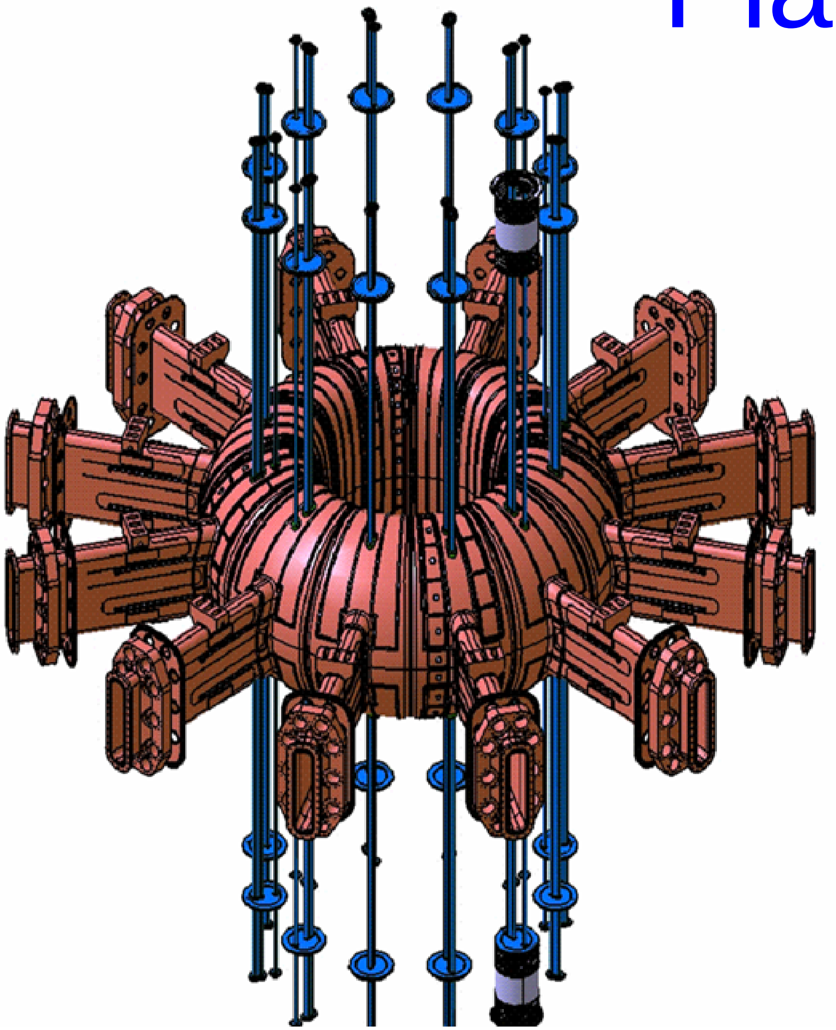
Maximum VM stress (MPa) on tile carries during a VDE disruption

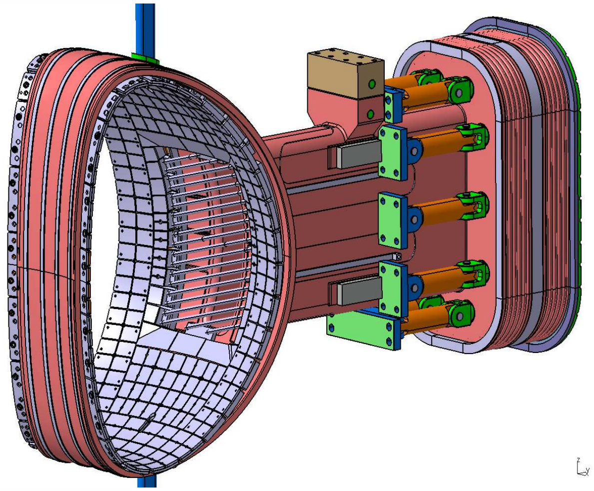
- Non-linear structural analyses of the machine Load Assembly have been performed taking into account the effect of friction coefficients between the significant components.
- Updated plasma disruption conditions for VDE’s that result in higher out-of-plane loads have been considered.
- The relevant 3D virtual mockup has allowed for the Remote Handling (RH) analysis of the boom kinematics to cover all positions inside of the Plasma Chamber



Fully extended boom inside the plasma chamber and end effector for tile carrier

Plasma Chamber





One sector of the plasma chamber including the ICRH Faraday shield and first wall.

Inconel 625

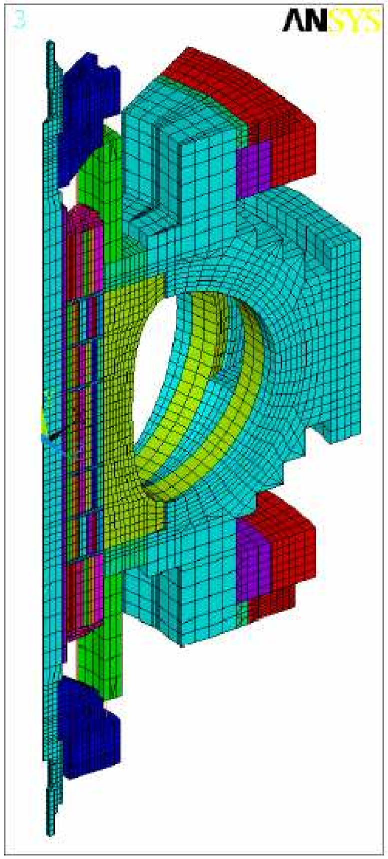
12 D-shaped sectors

Variable thickness

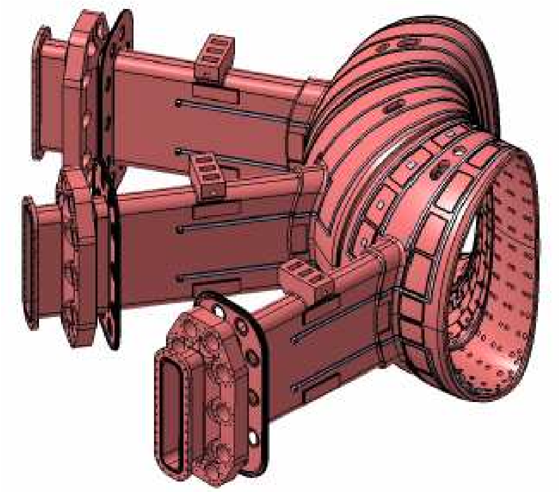
TZM (Mo) First Wall tiles

New concept of TFC turns cooling

The Toroidal Field Coil is cooled down to 30 K by gaseous helium. OFHC Copper has been selected for these plates, allowing for an Electron Beam (EB) welding solution of the cooling channels.

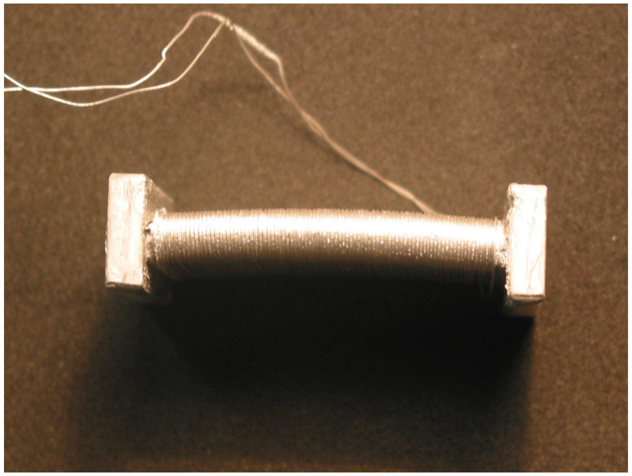


The Finite Element ANSYS model of the Load Assembly takes into account friction at the interfaces of significant components.



Plasma Chamber equipped with electromagnetic diagnostics.

Magnetic Diagnostics



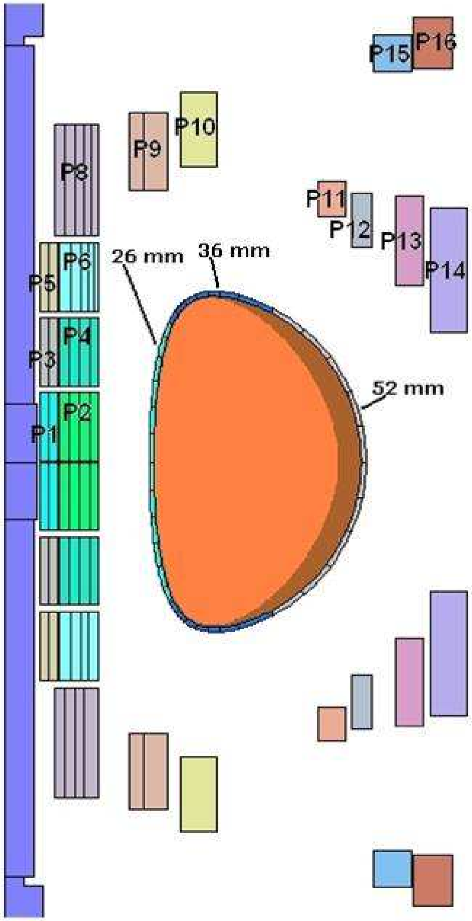
Sample of pick-up coil of insulated Ni wire on macor support

MgO impregnation techniques of pre-insulated Ni wire are being tested for prototypes coils to be used on existing experiments.

Plasma Position Control

The capability of the Poloidal Field Coil (PFC) system, as presently designed, to provide an effective vertical stabilization of the plasma has been investigated using the CREATE_L response model

An optimization of the vertical position control strategy has been carried out and the most effective coil combination has been selected to stabilize the plasma while fulfilling engineering constraints on the coils and minimizing the required power and voltage.



Possible failure of the electromagnetic diagnostics has been taken into account, evaluating the robustness of the plasma position reconstruction strategy and investigating the possibility to use additional means to monitor the position of the plasma column for example through the plasma X-ray emission or fast thermometric diagnostics.