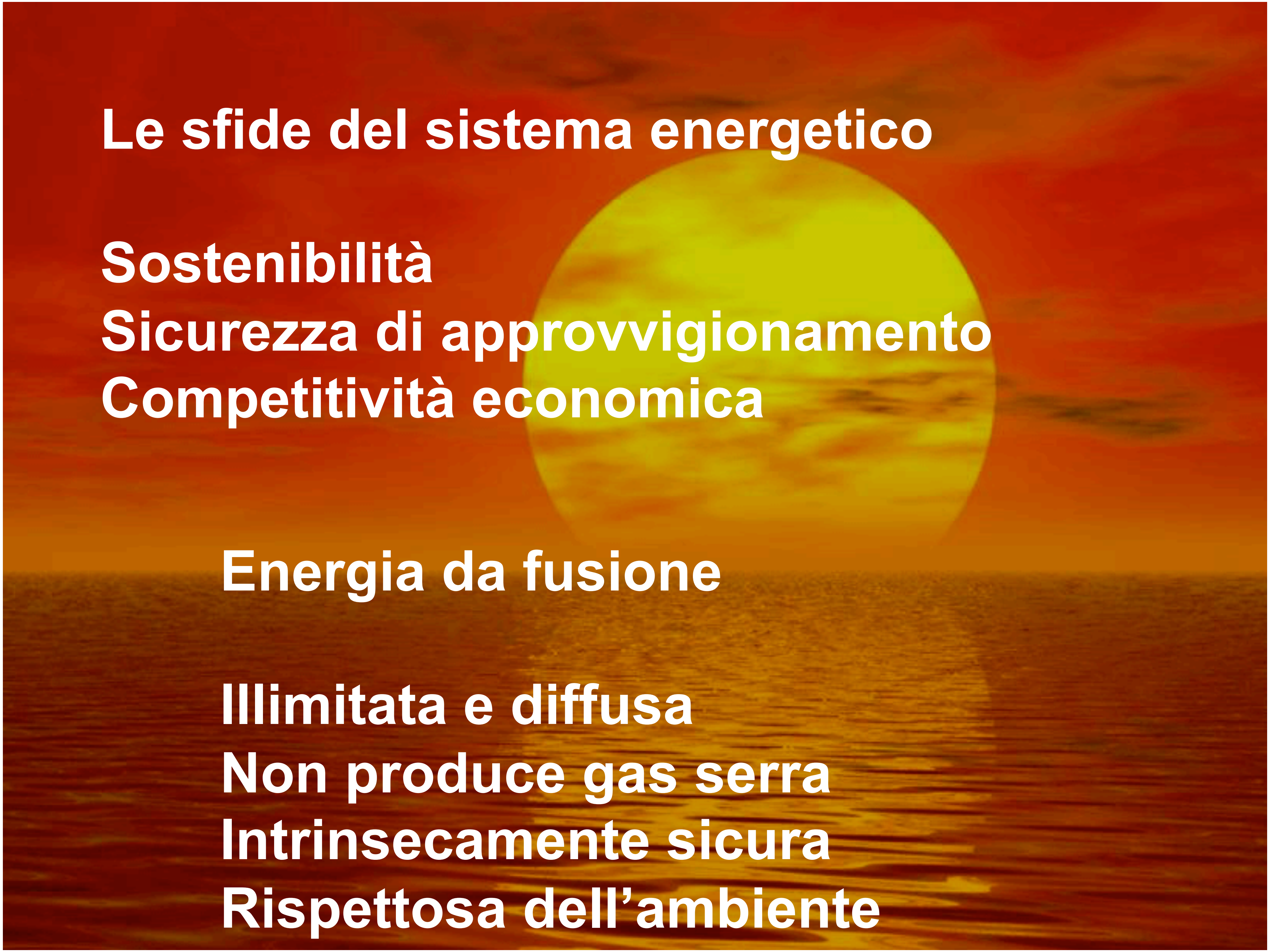
Il progetto DTT come costruire componenti che possano sopravvivere sulla superficie del Sole

Pisa, 13 maggio 2024

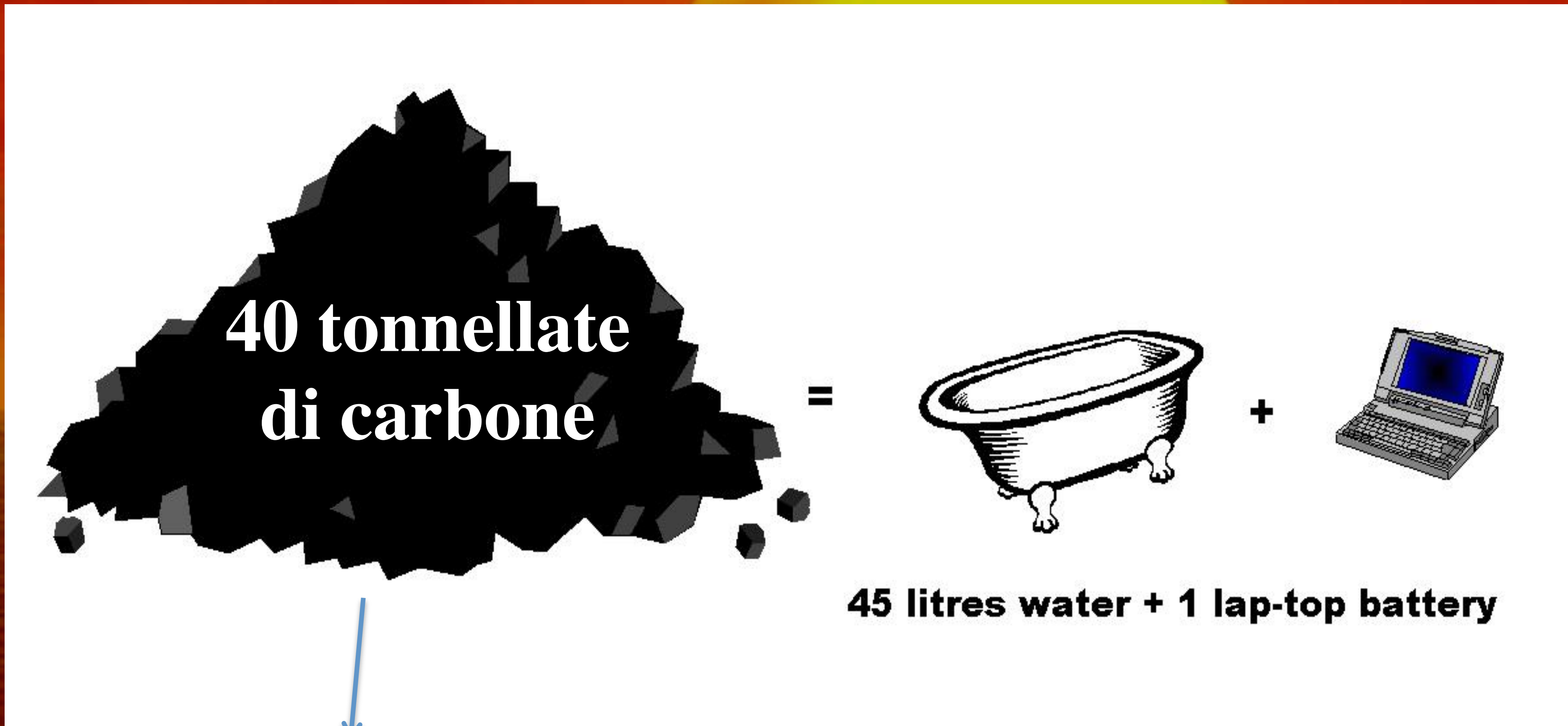
Francesco Romanelli
Università di Roma "Tor Vergata"
Presidente DTT scarl
francesco.romanelli@uniroma2.it

Outline

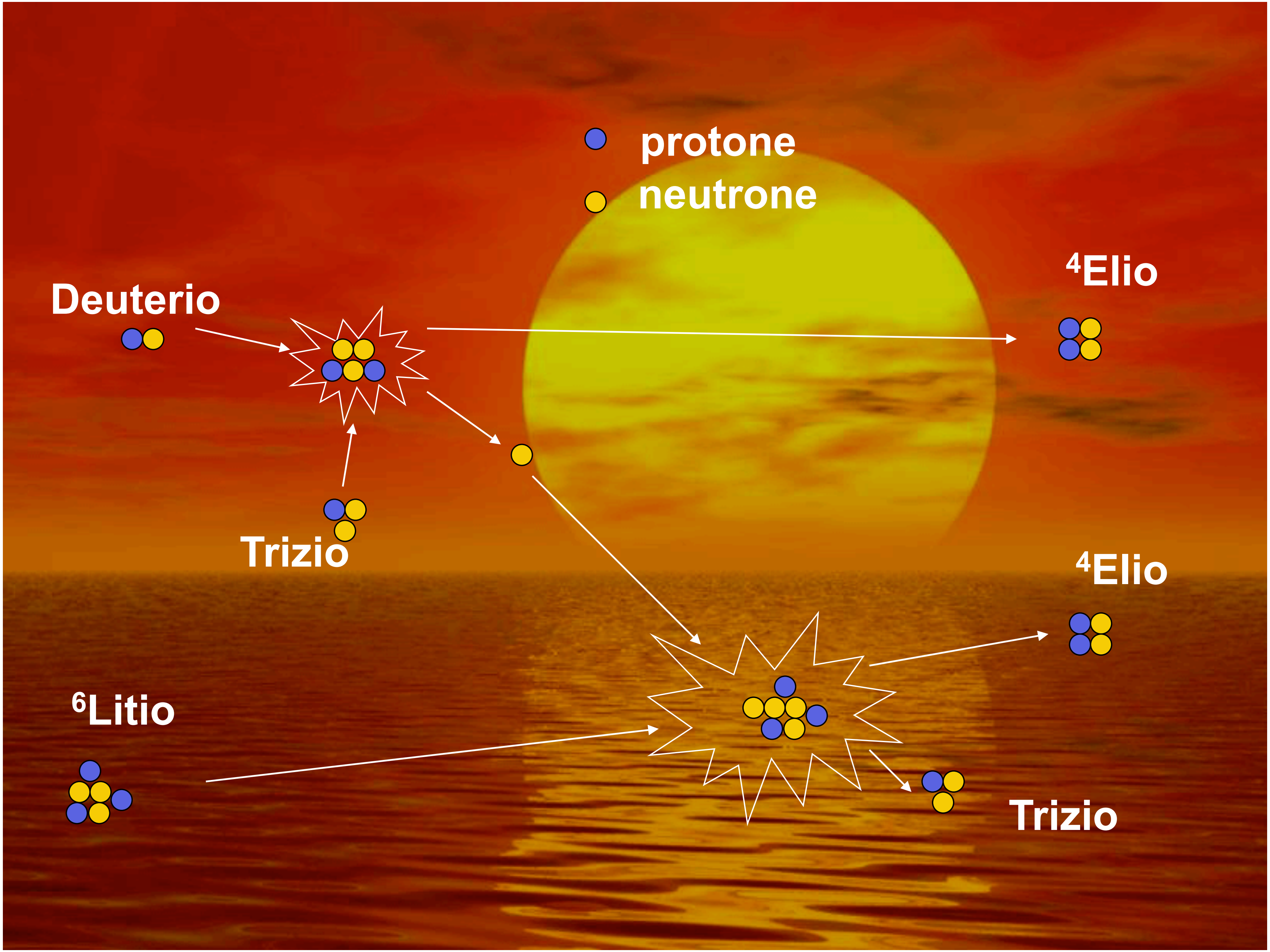
1. Come confinare gas più caldi del Sole.
2. La Roadmap all’elettricità da fusione - ITER
3. Il progetto DTT


Le sfide del sistema energetico
Sostenibilità
Sicurezza di approvvigionamento
Competitività economica
Energia da fusione
Illimitata e diffusa
Non produce gas serra
Intrinsecamente sicura
Rispettosa dell’ambiente

Consumo di elettricità per 30 anni da parte di un cittadino europeo.



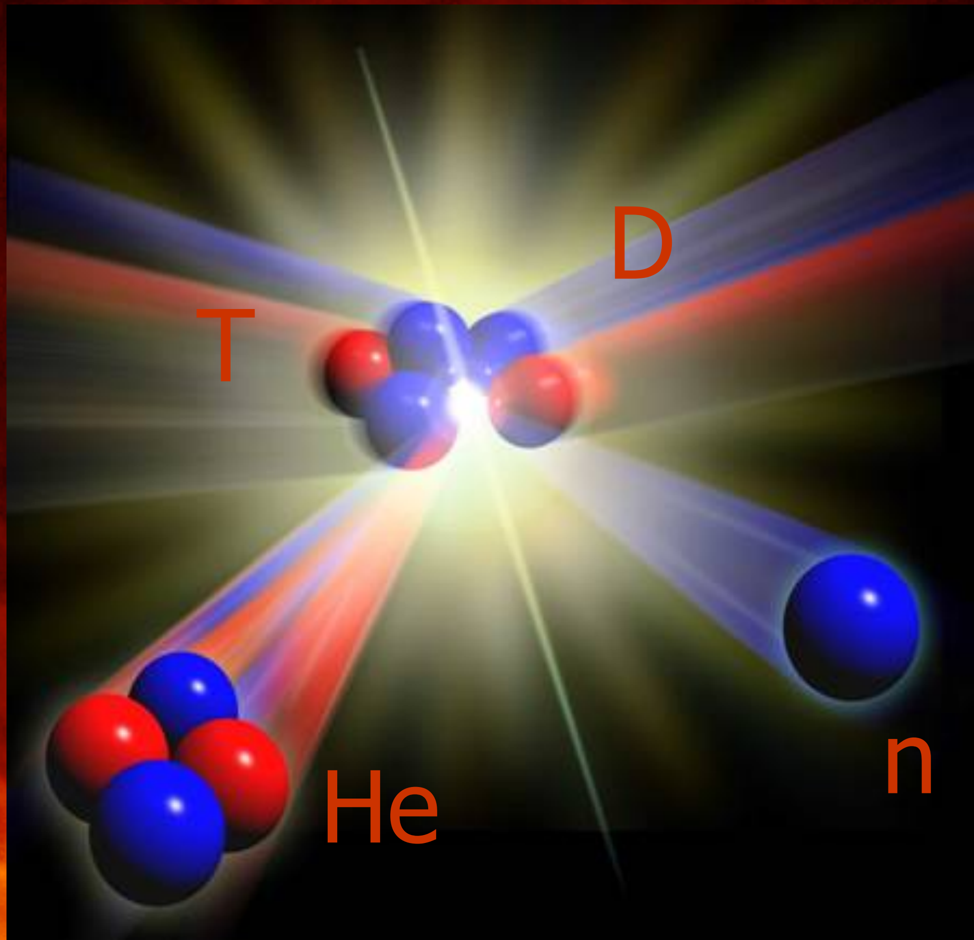
150 tonnellate di CO_2!



protone
neutrone
Deuterio
⁴Elio
Trizio
⁴Elio
⁶Litio
Trizio

Come confinare gas più caldi del Sole

magnetic field lines



I nuclei reagenti sono carichi

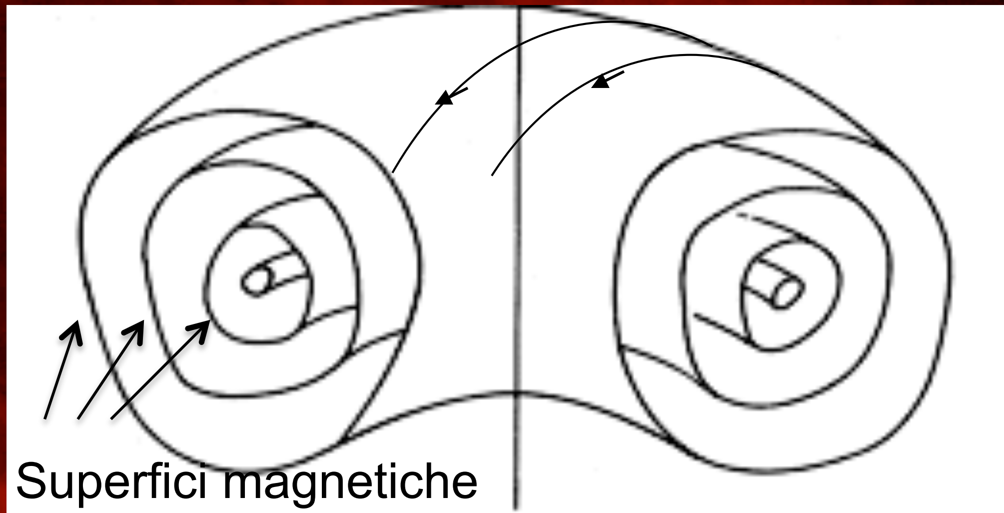
➔ Si respingono!

➔ Riscaldare il gas a 200Milioni °C

La materia e' nello stato di *plasma*

Come confinare gas più caldi del Sole

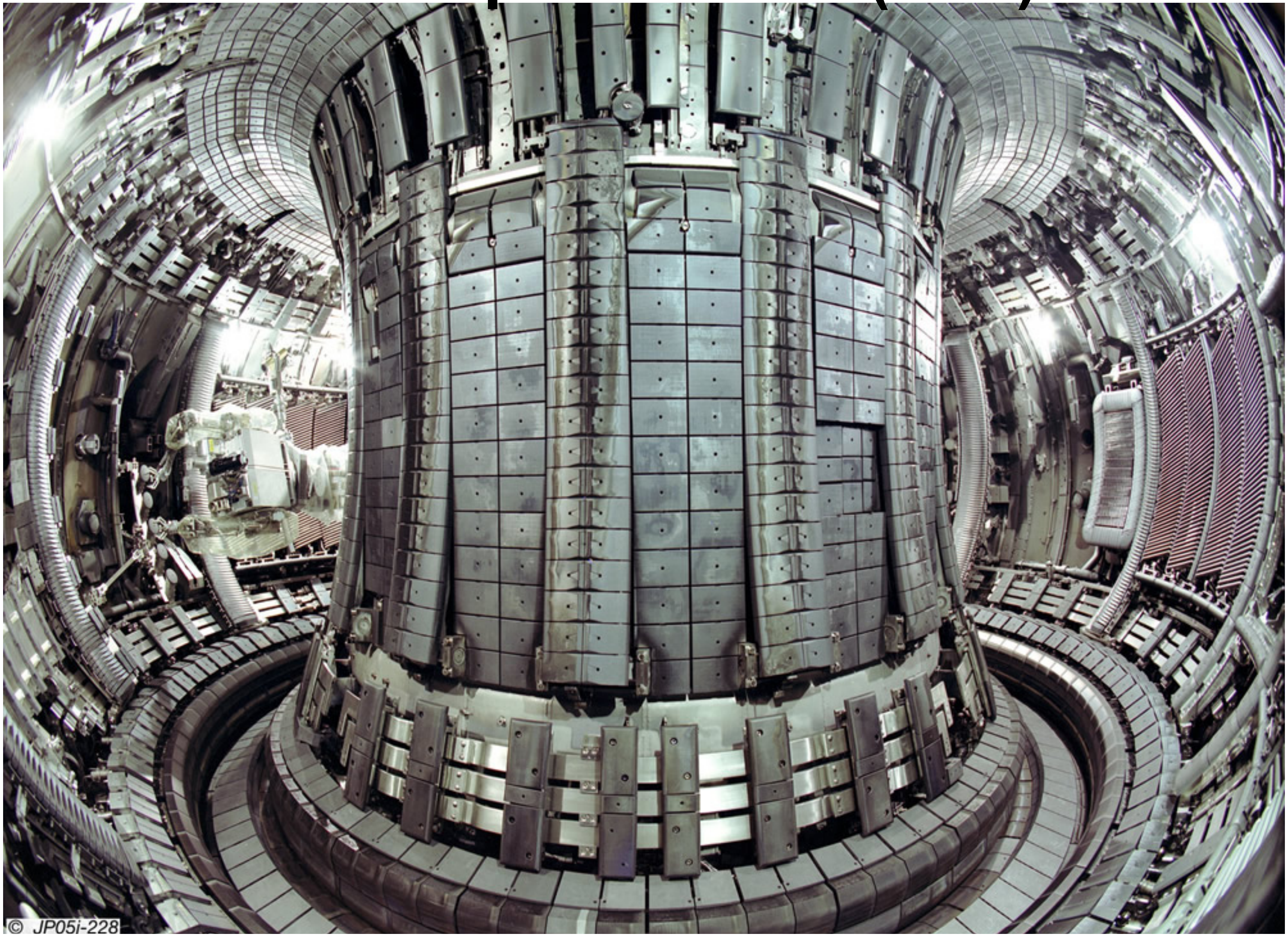
Confinamento magnetico



magnetic field lines

- **Campi magnetici intensi**(100000 x il campo Magnetico terrestre) prodotti da bobine esterne e dal plasma
- **Geometria a forma di anello (toro)**

The Joint European Torus (JET)



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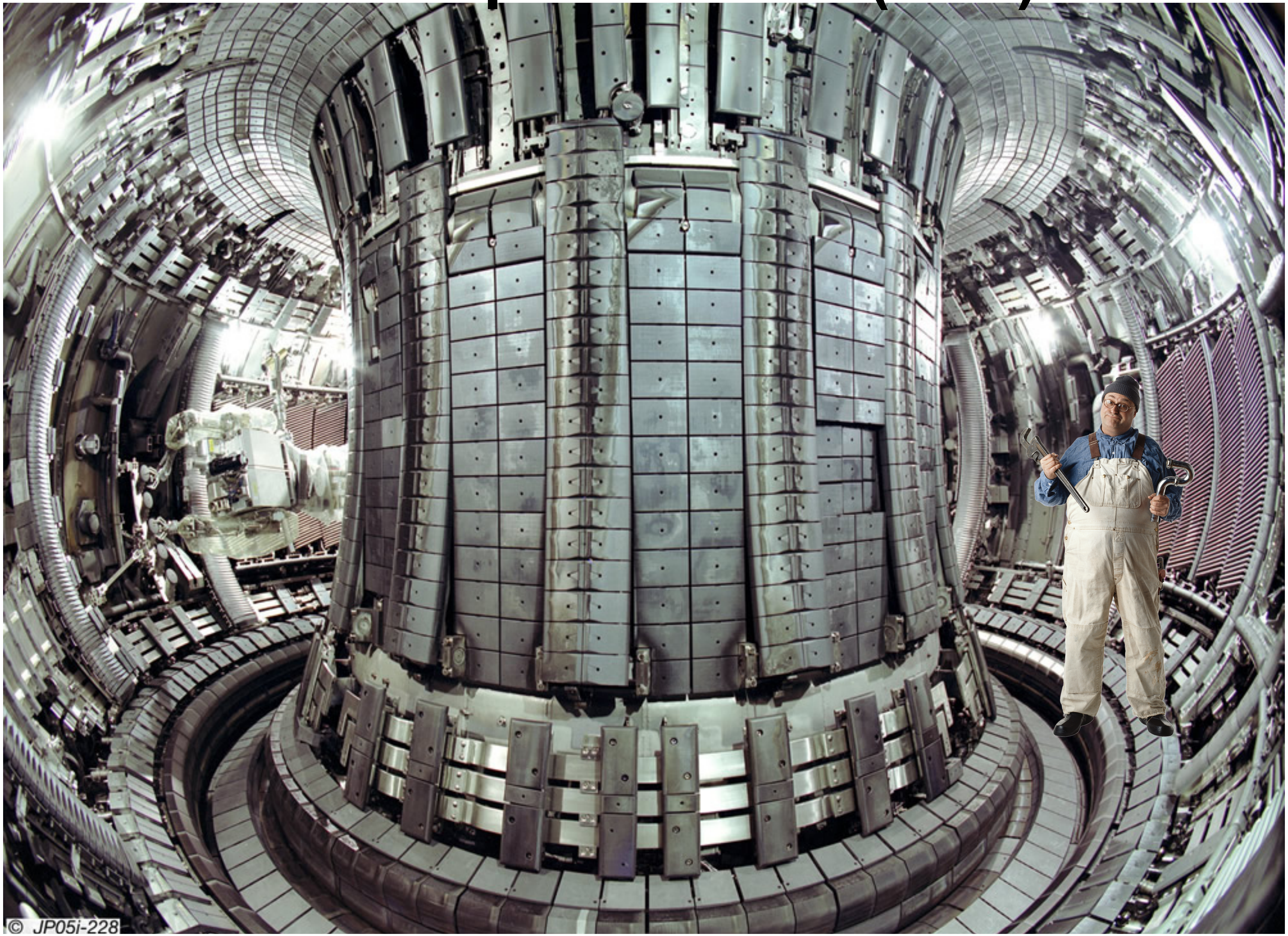

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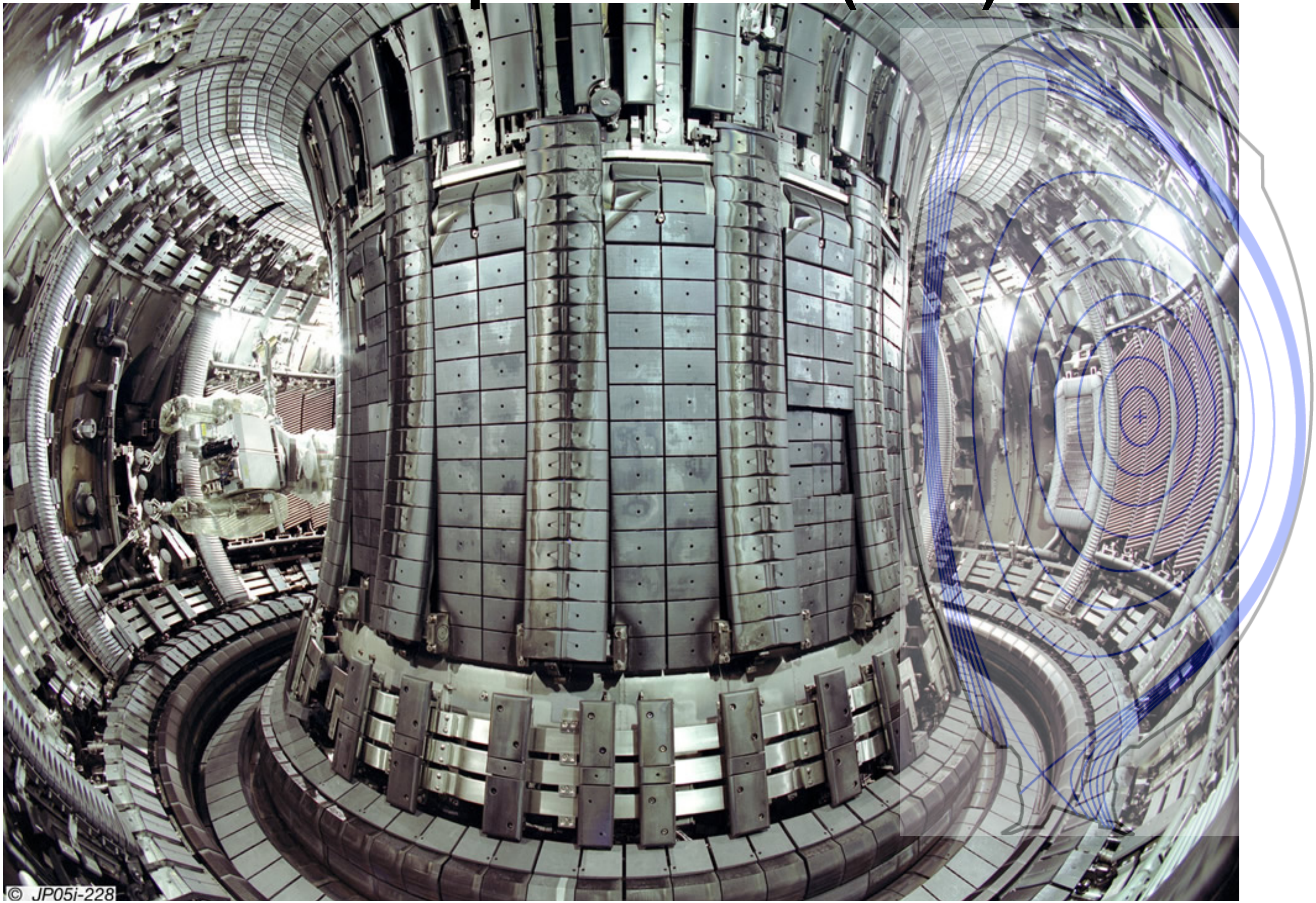

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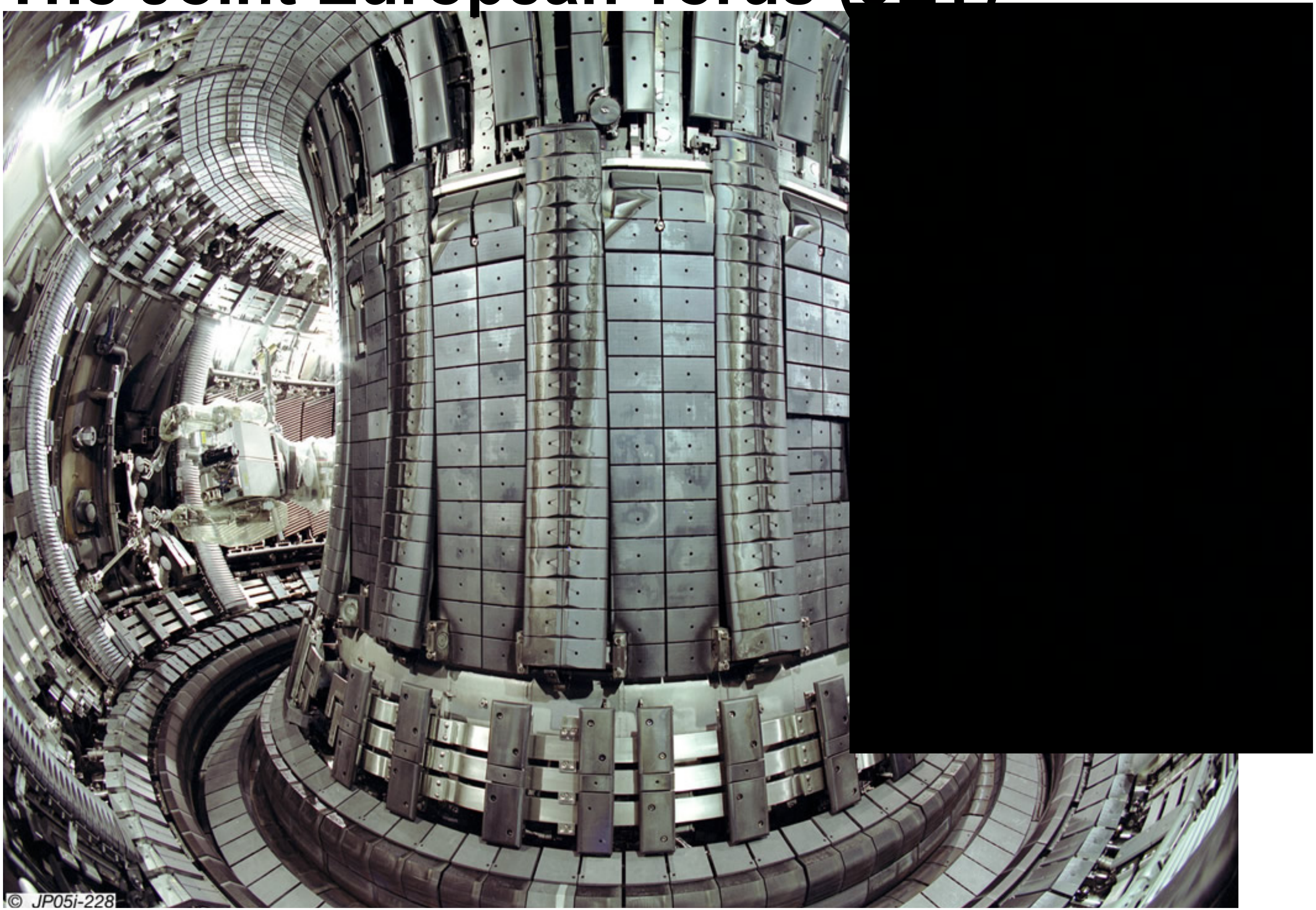

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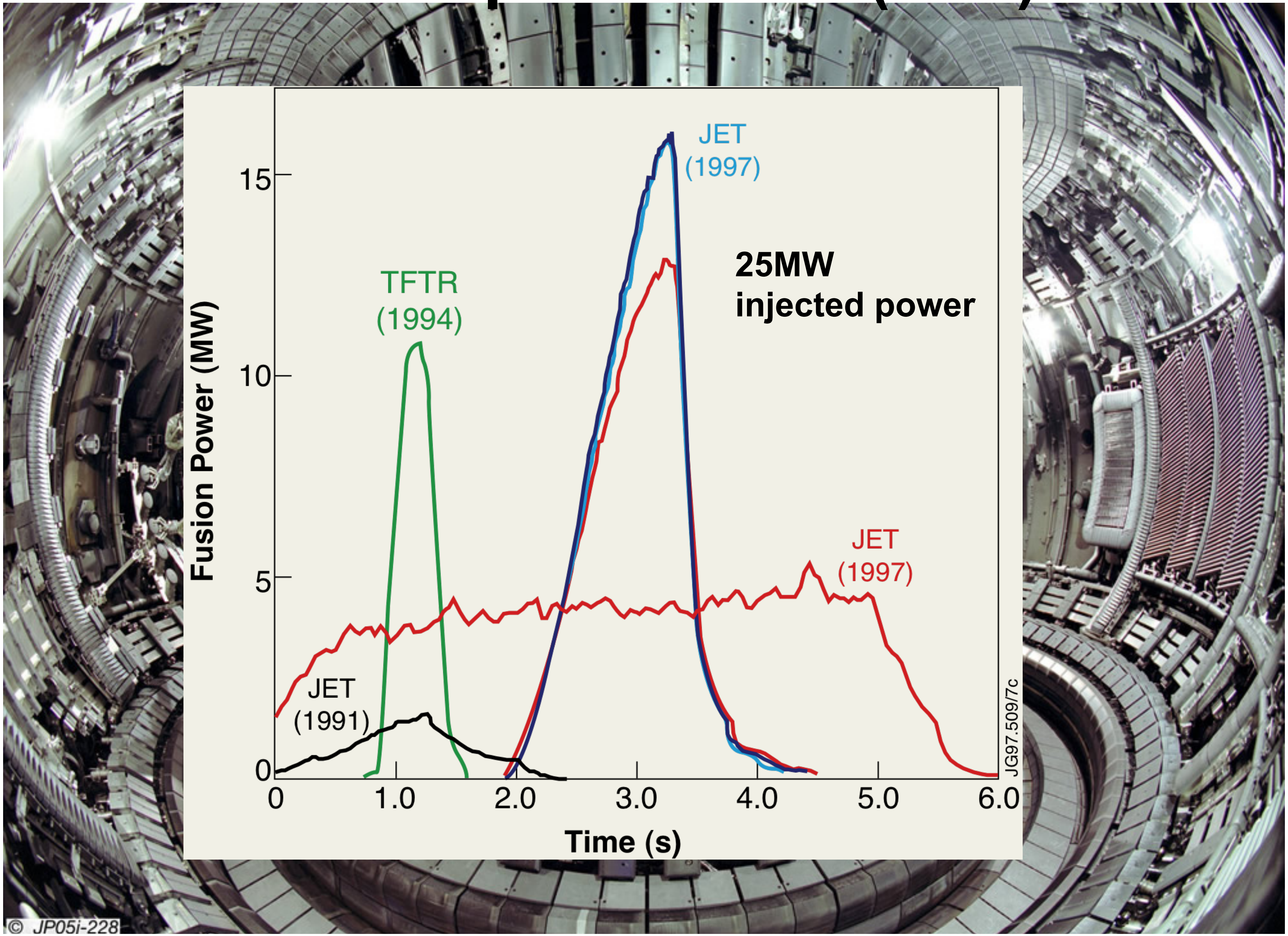

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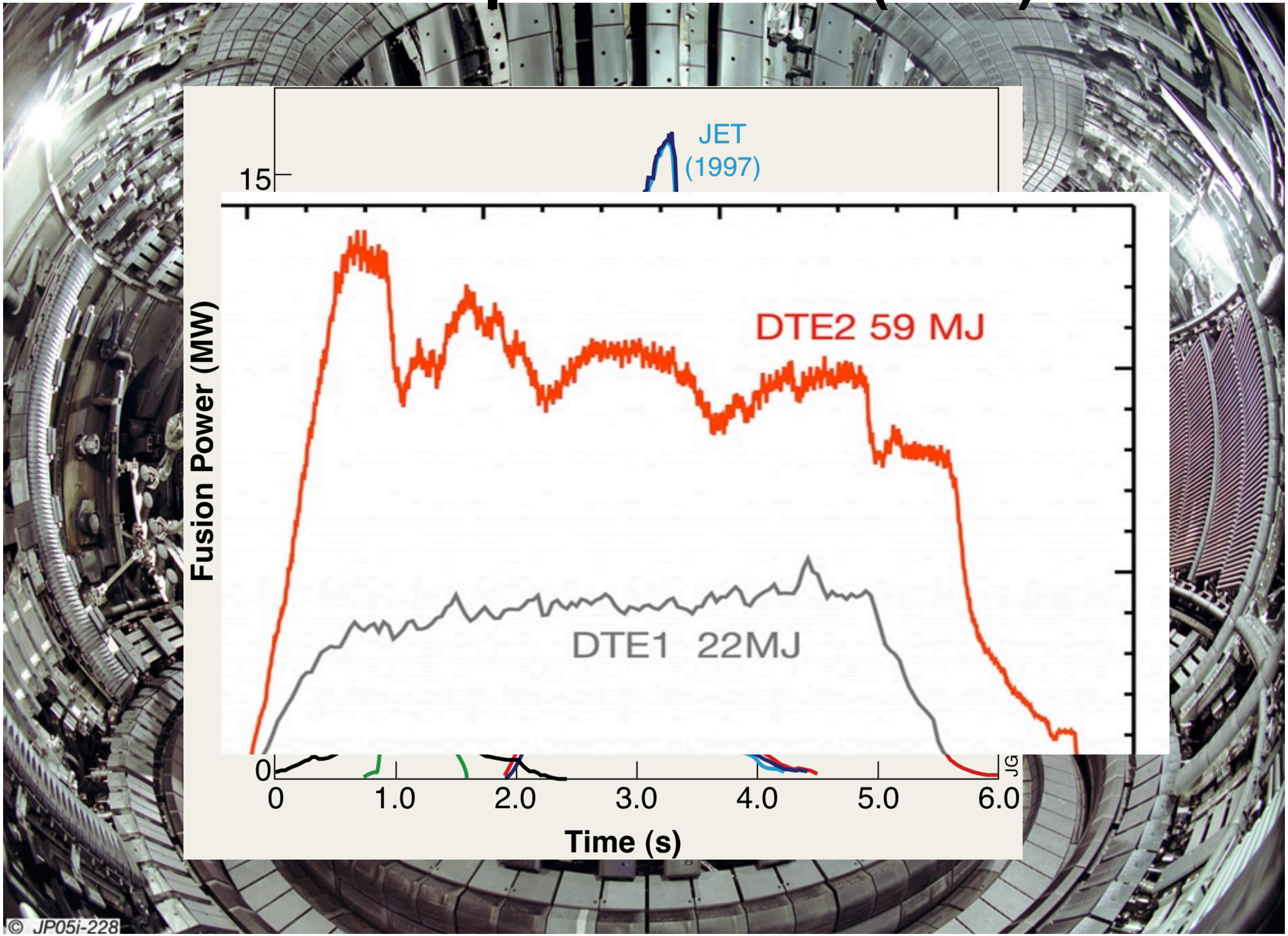
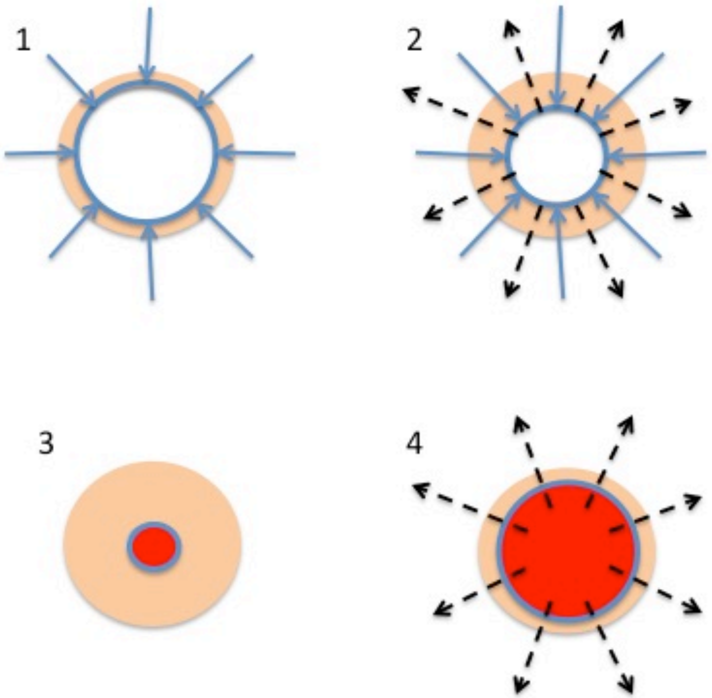
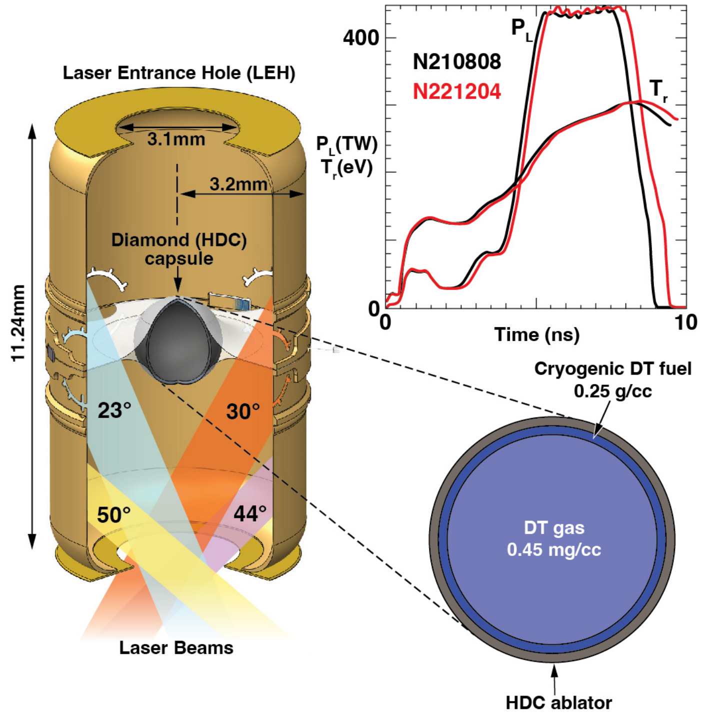
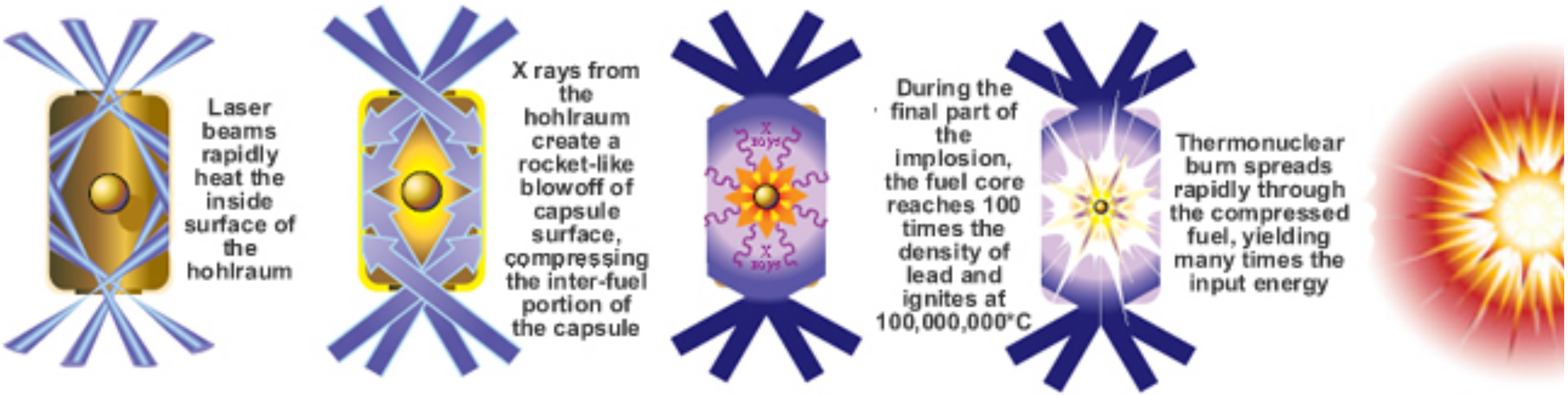


NIF ha ottenuto 3MJ di energia da fusione a fronte di 2 MJ iniettati

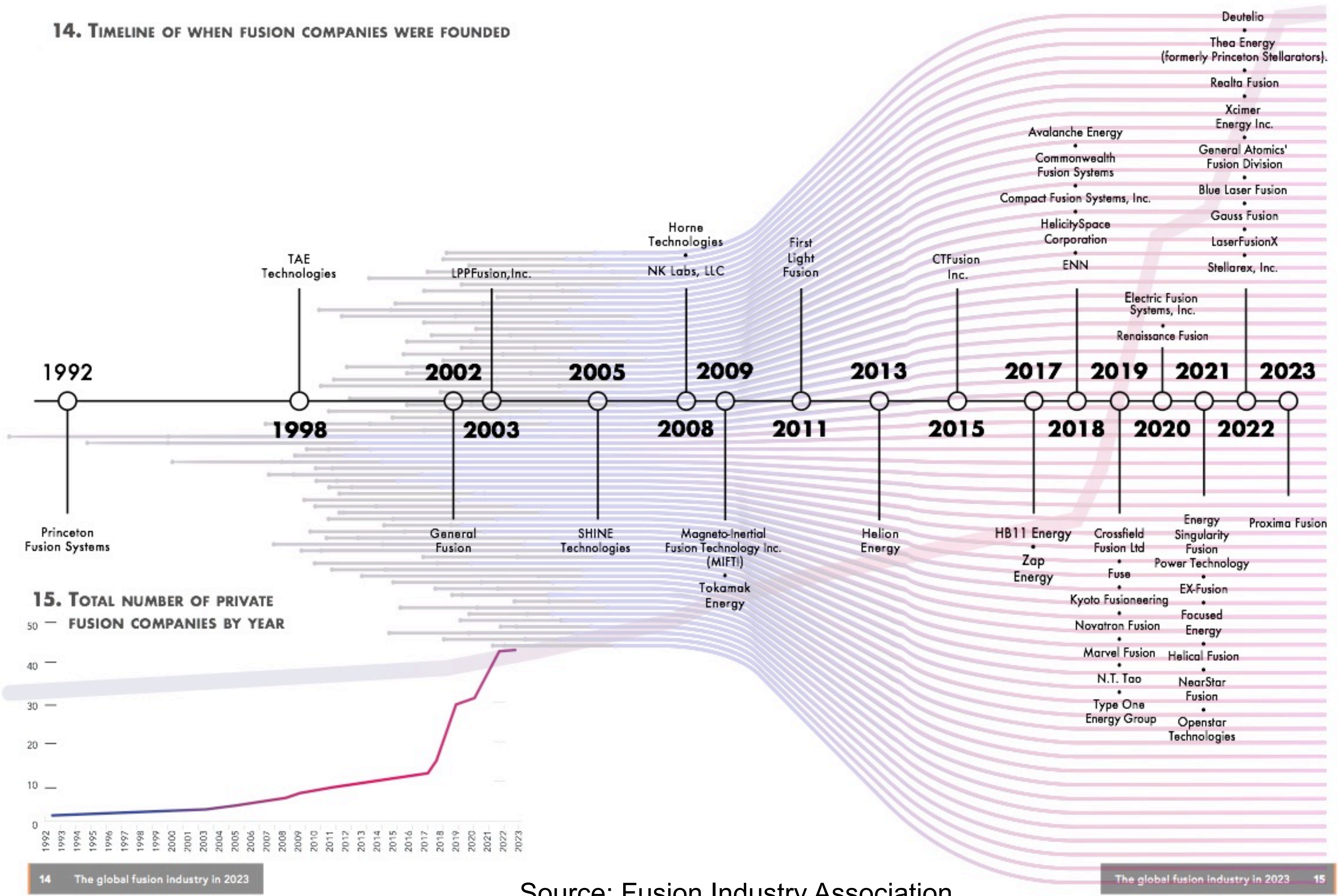






14. Timeline of when fusion companies were founded

15. Total number of private fusion companies by year



Source: Fusion Industry Association

1. Guadagno di energia

2. Estrazione del calore

3. Materiali resistenti ai neutroni

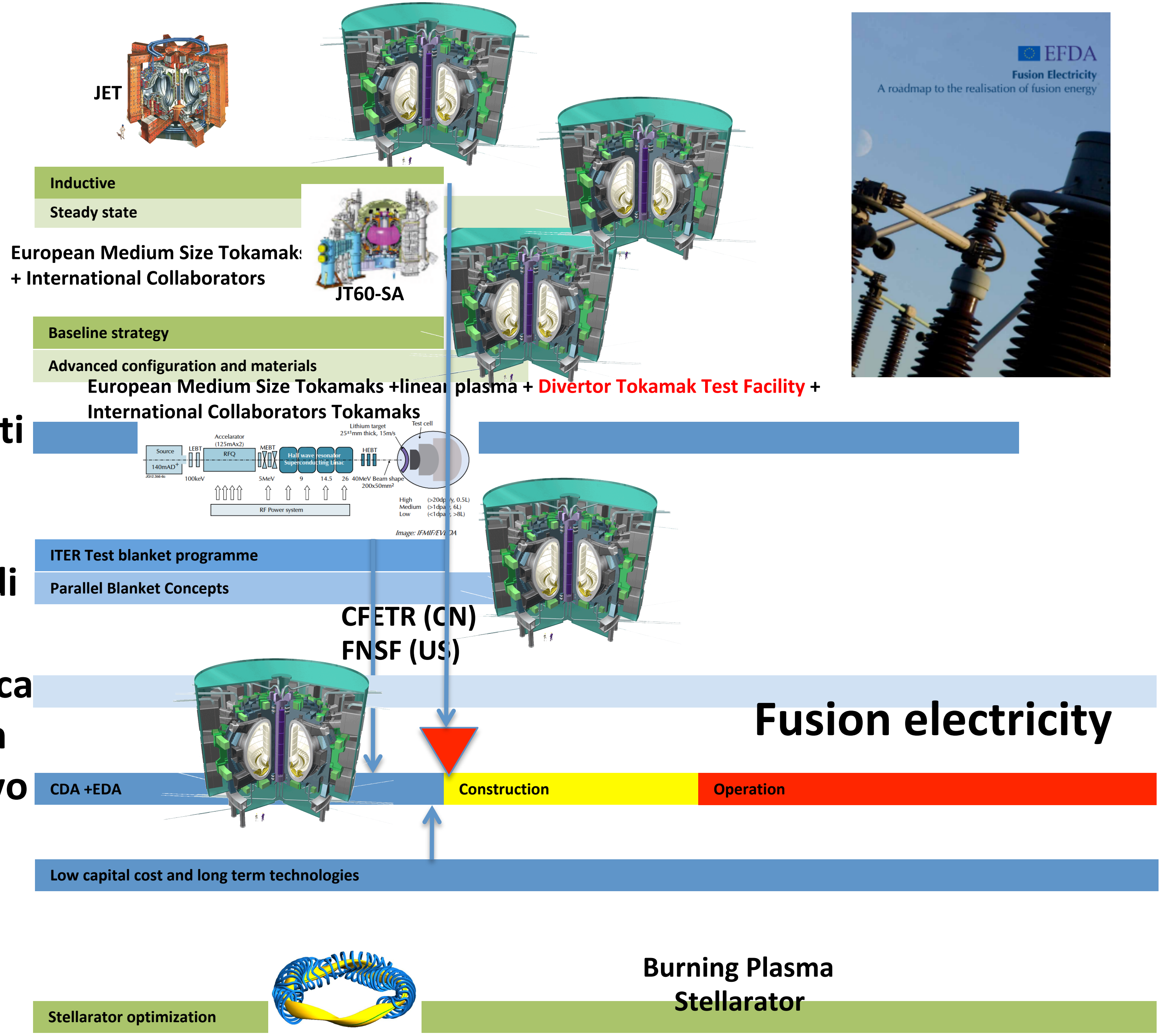
4. Autoproduzione di Trizio

5. Sicurezza intrinseca

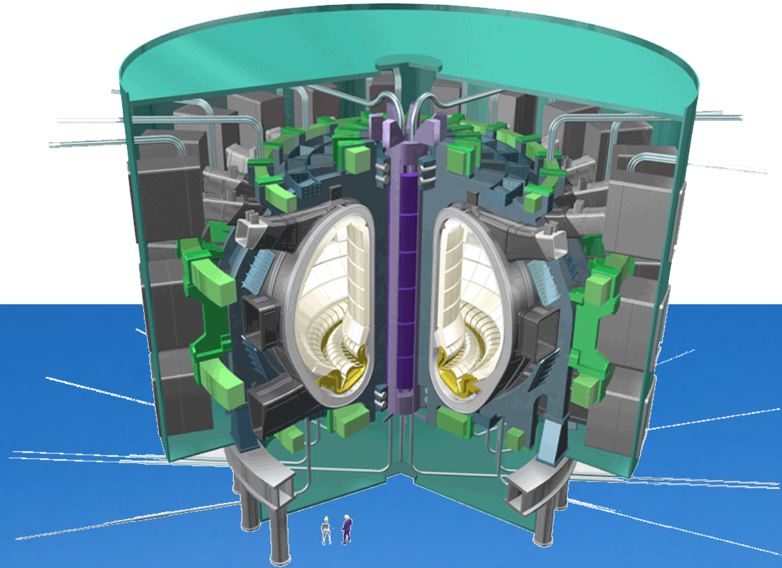
6. Integrazione in un reattore dimostrativo

7. Basso costo

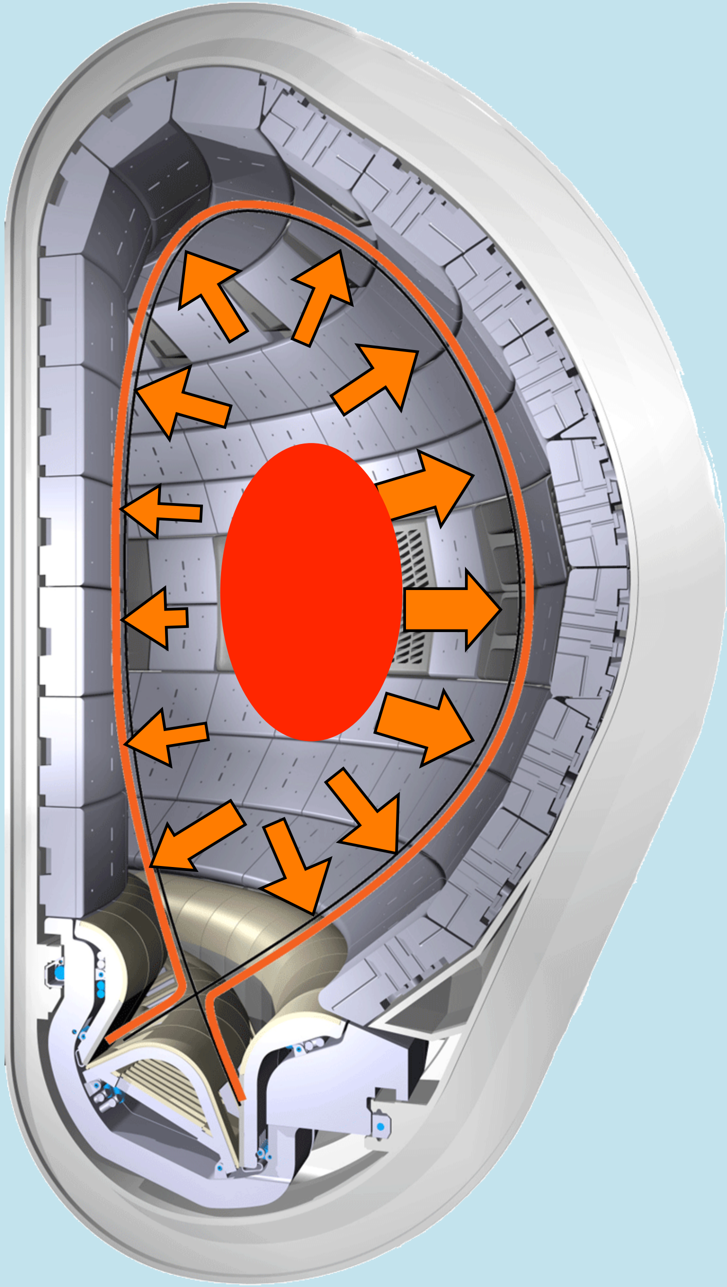
8. Stellarator

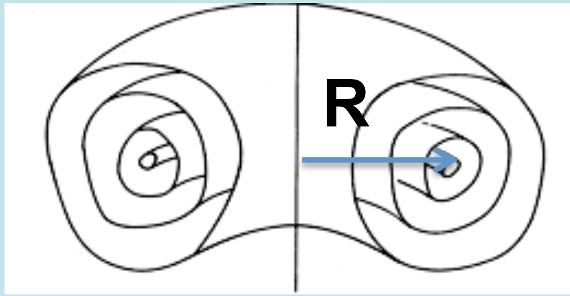


ITER



Obiettivo 1: Produrre più energia di quanto se ne consumi

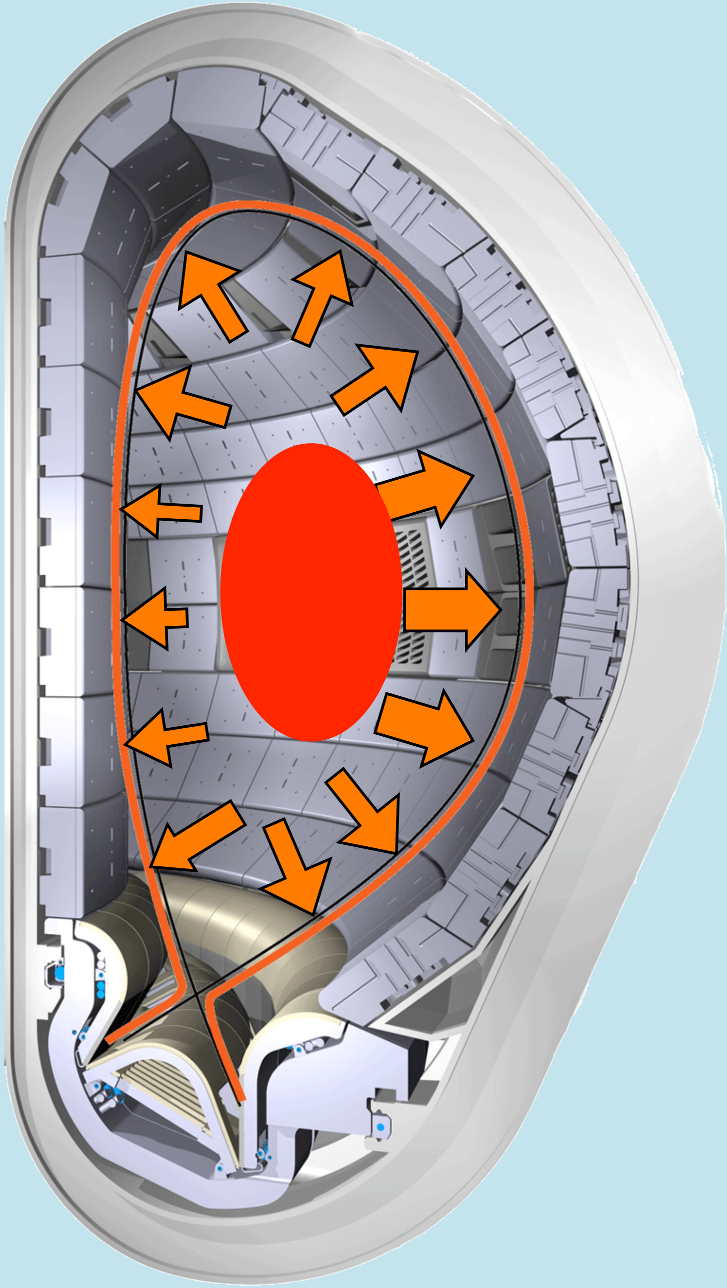


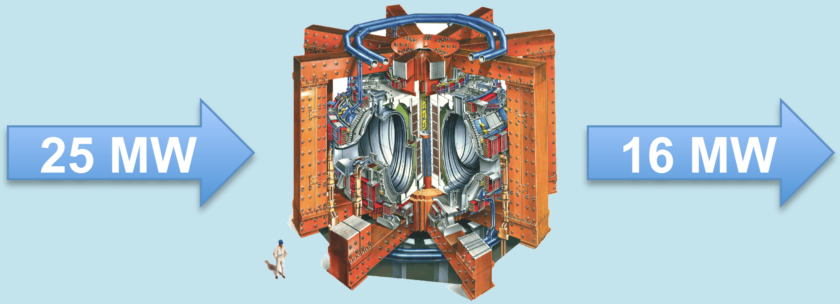


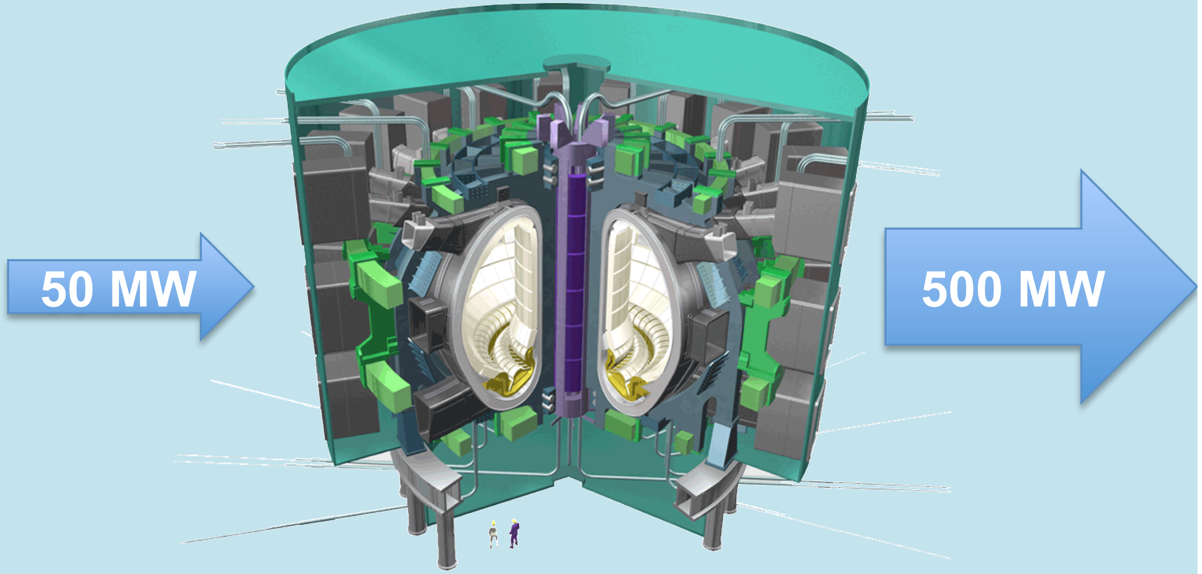
- **Per un dato campo magnetico:**
- Le perdite aumentano al più proporzionalmente a R
- La potenza di fusione aumenta come il volume ($\approx R^3$)

OCCORRE COSTRURE MACCHINE DI GRANDI DIMENSIONI

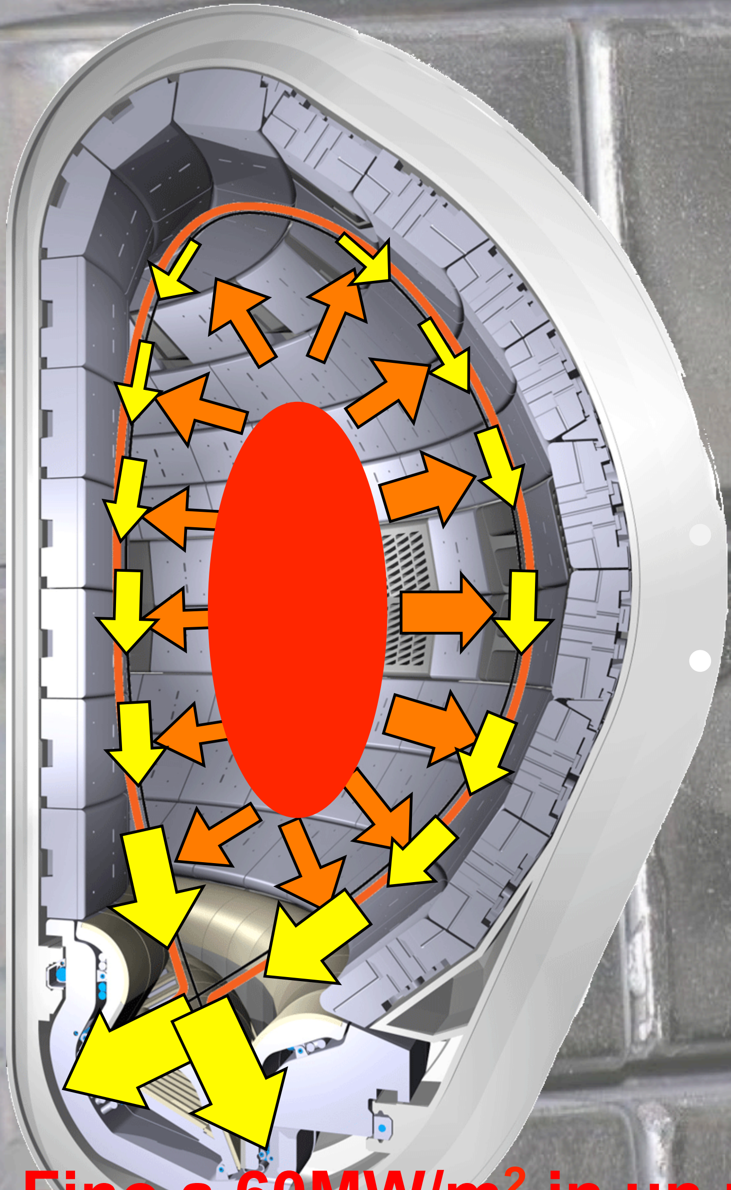
Obiettivo 1: Produrre più energia di quanto se ne consumi

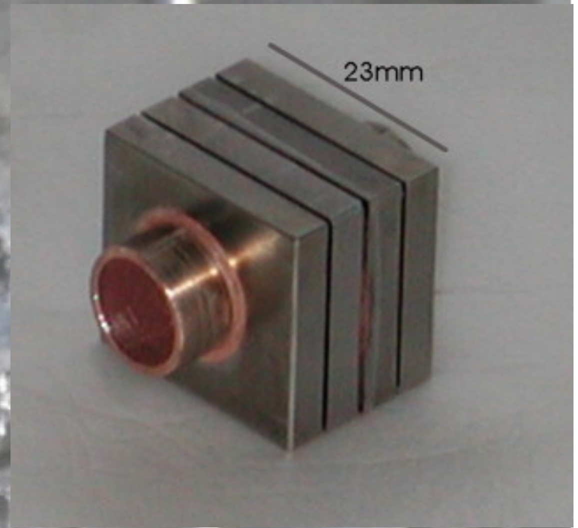






Obiettivo 2: Estrazione del calore

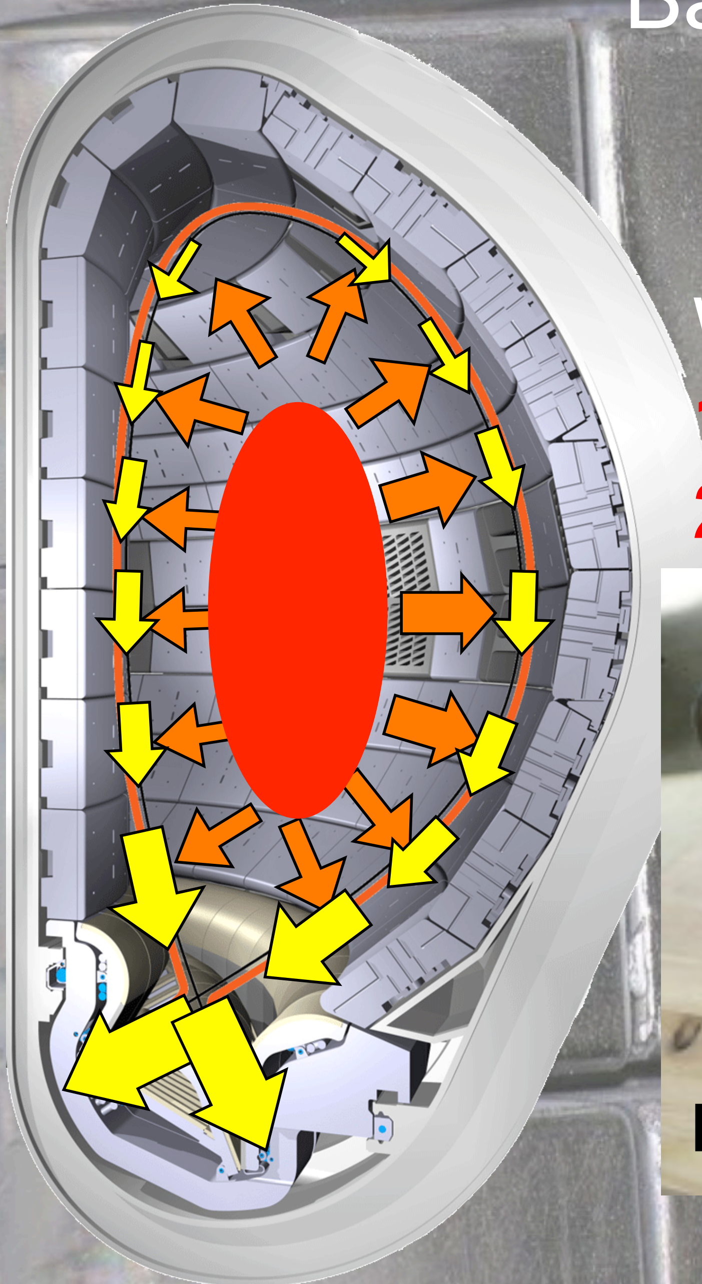




- Erosione
- Danneggiamento dei materiali esposti

Fino a 60MW/m^2 in un reattore
~ flusso di calore sulla superficie del Sole!

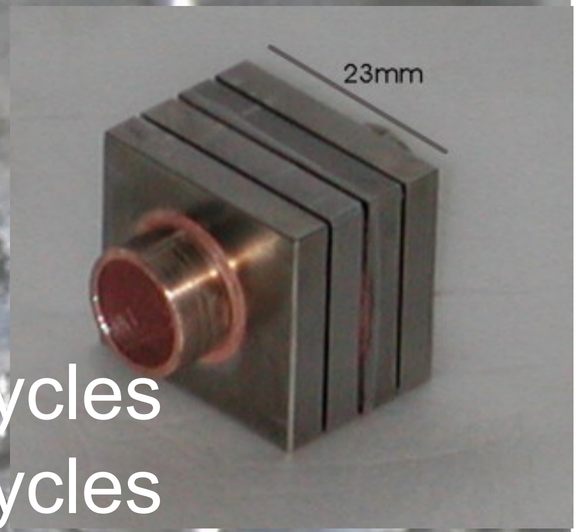
Obiettivo 2: Estrazione del calore
Baseline strategy



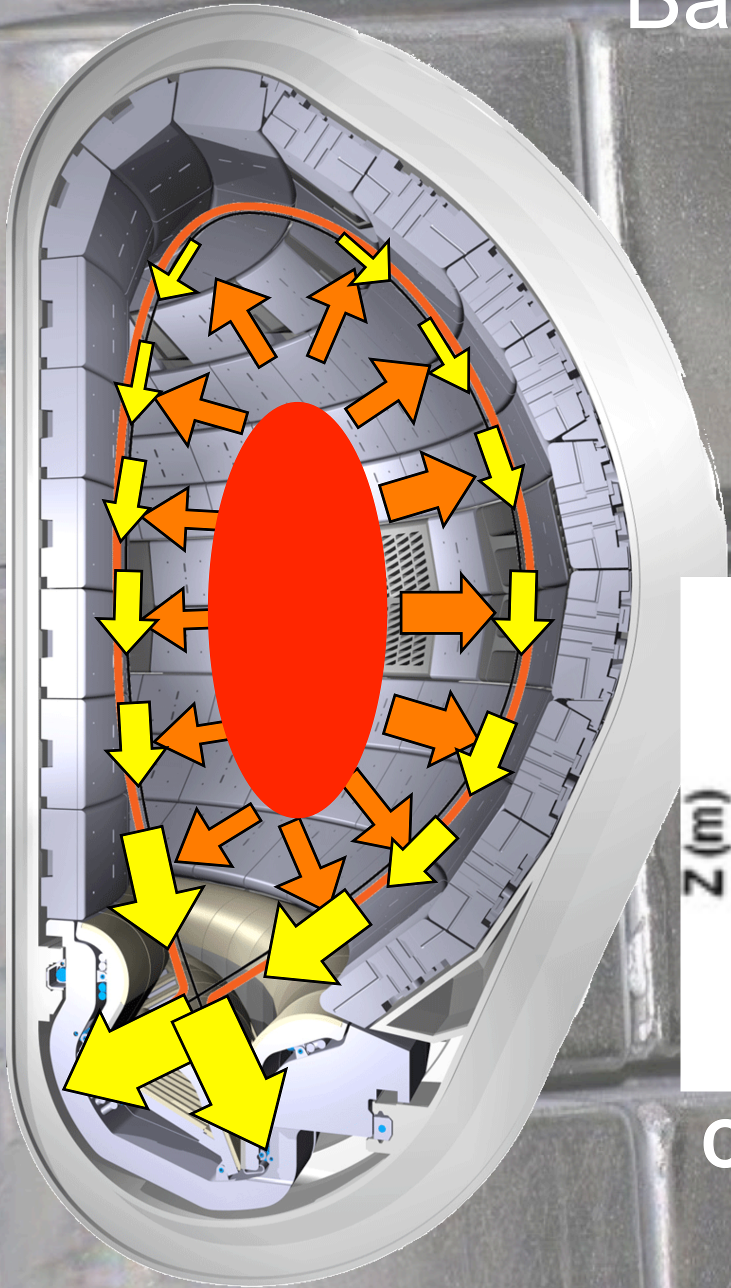
W monoblock:

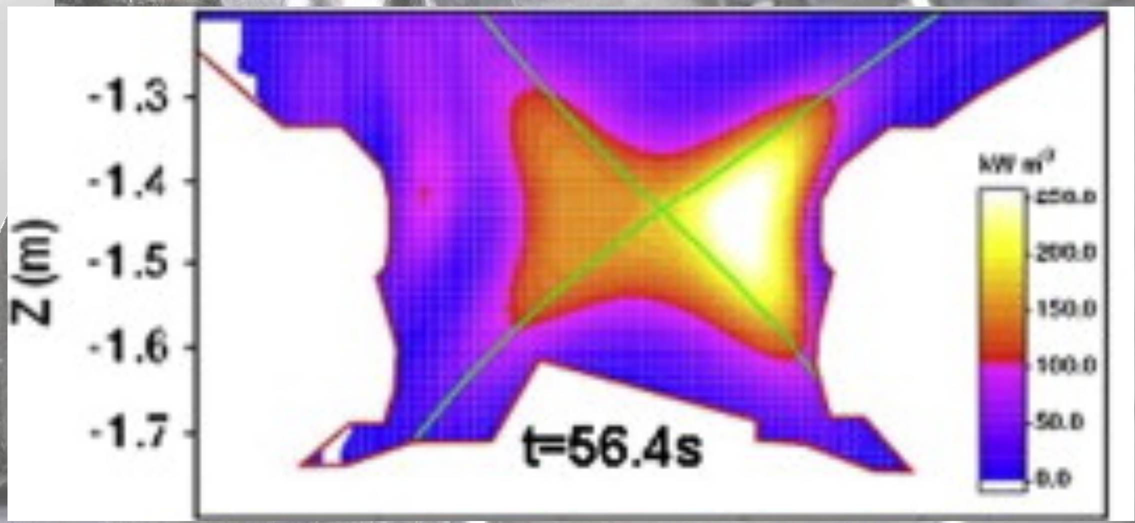
10 MW/m² x 5000 cycles

20 MW/m² x 1000 cycles



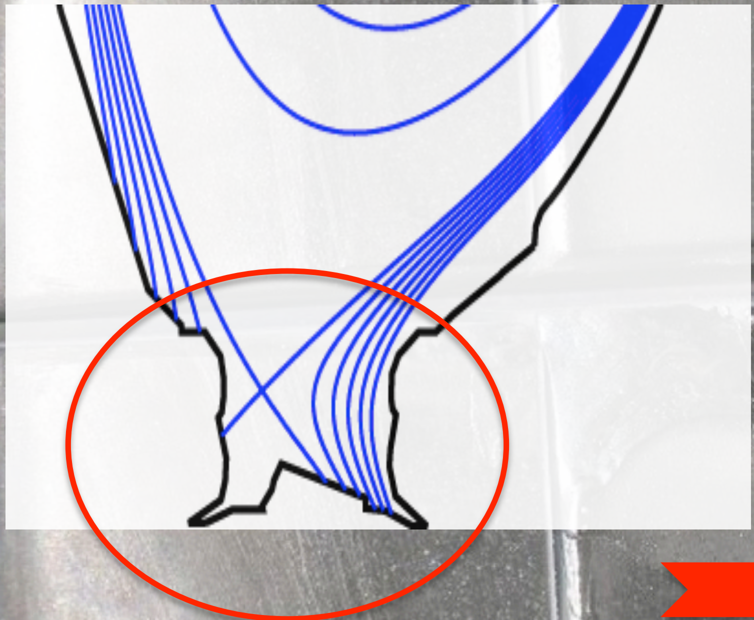
Obiettivo 2: Estrazione del calore
Baseline strategy

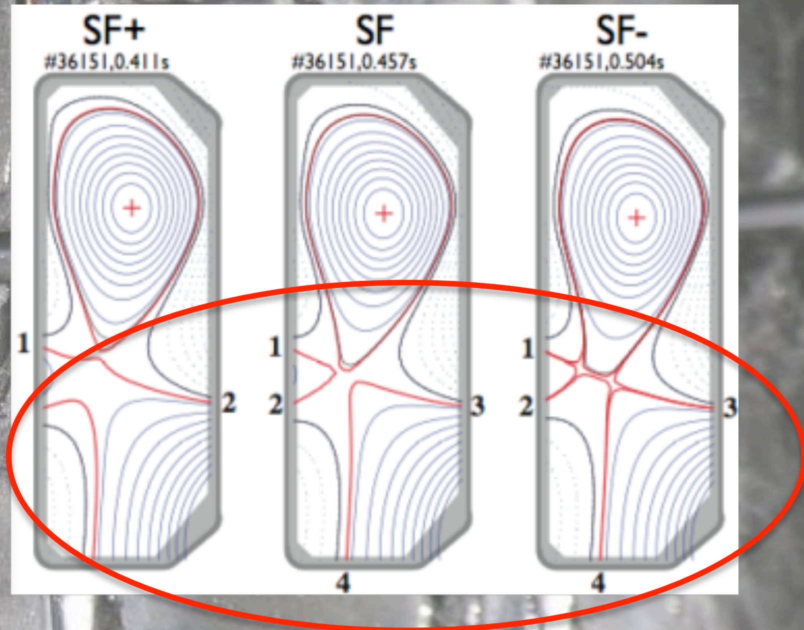




Condizioni di divertore staccato

Obiettivo 2: Estrazione del calore
Alternative strategies





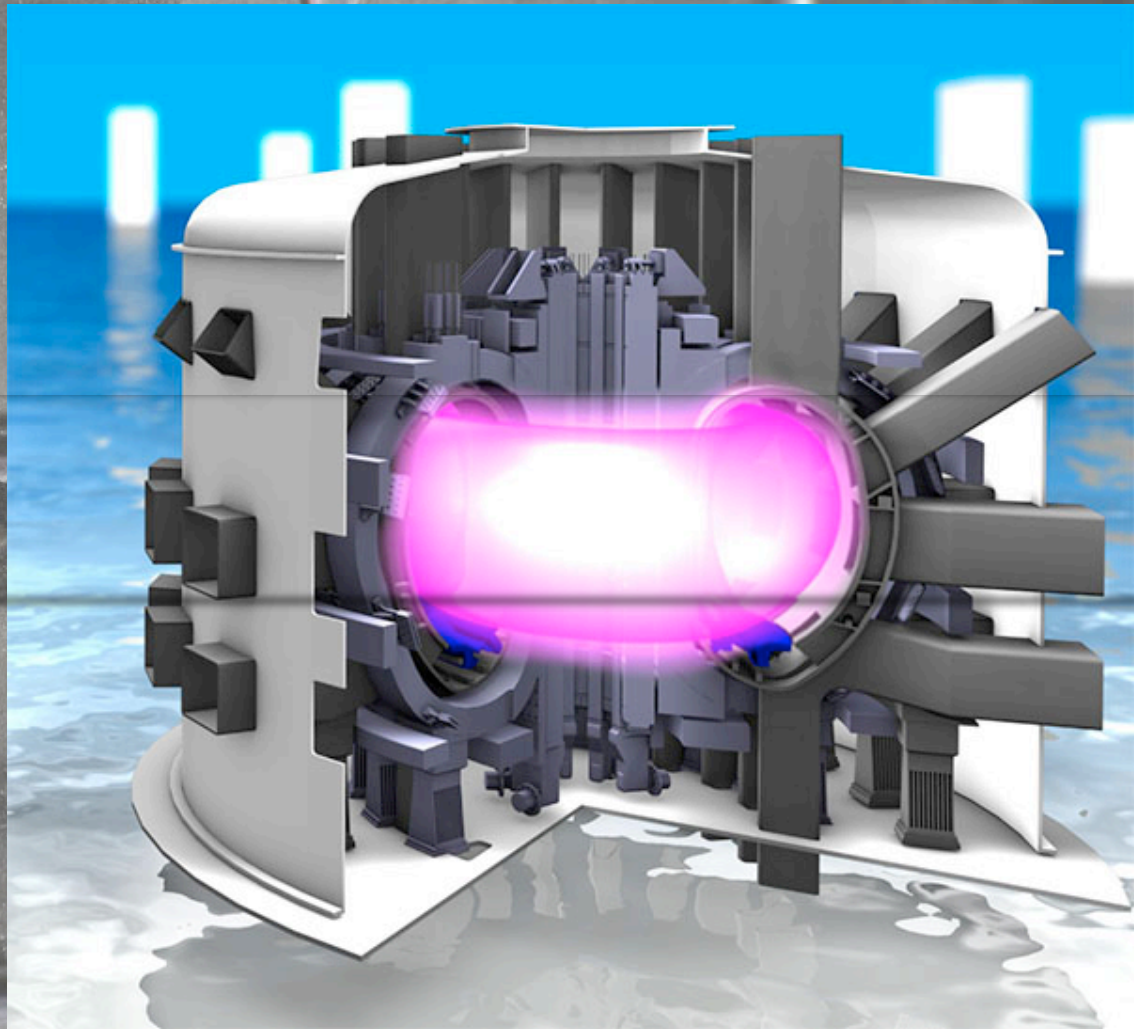
TCV – CRPP-EPFL

Principale strategia alternativa:
Aumentare l'area del divertore esposta al plasma

Obiettivo 2: Estrazione del calore
Alternative strategies

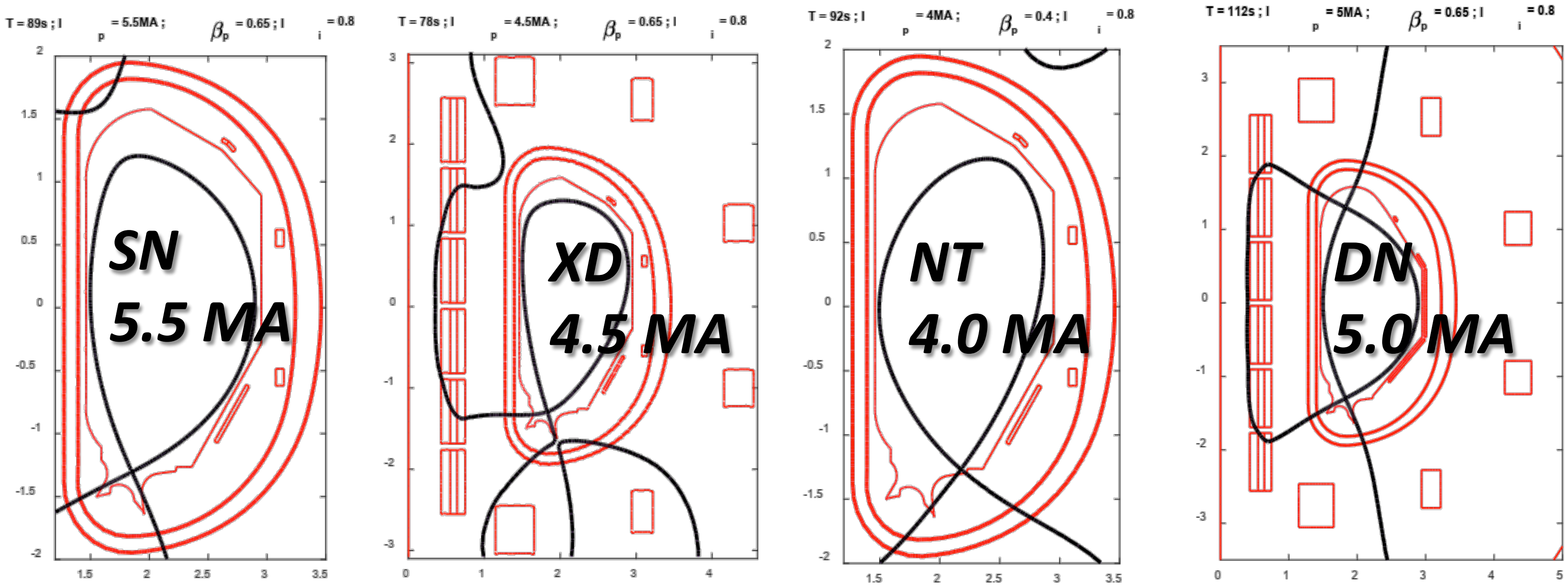
Divertor Tokamak Test facility (DTT) proposta nella roadmap europea.

In costruzione aENEA Frascati da parte di un consorzio tra gli enti di ricerca le università e la maggiore industria energetica.



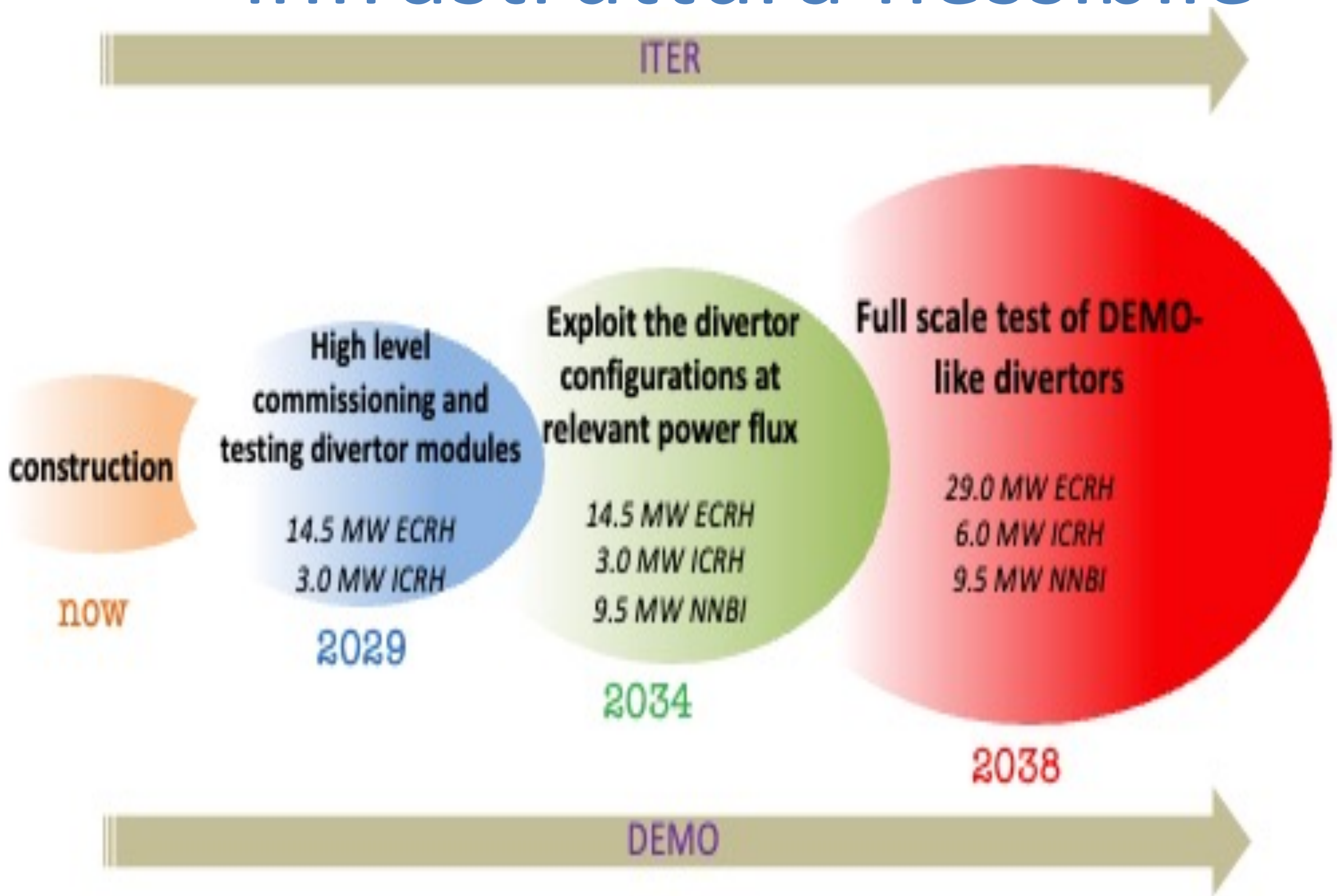
DTT è stata progettata come infrastruttura flessibile

Obiettivo: Test di soluzioni innovative per l'estrazione del calore.



DTT è un elemento essenziale della Roadmap Europea all'elettricità da fusione.

DTT è stata progettata come infrastruttura flessibile



Timeline coherent with EU objectives

DTT nel programma Europeo

ITER

JT-60SA (Giappone)

DTT

JET (chiuso)

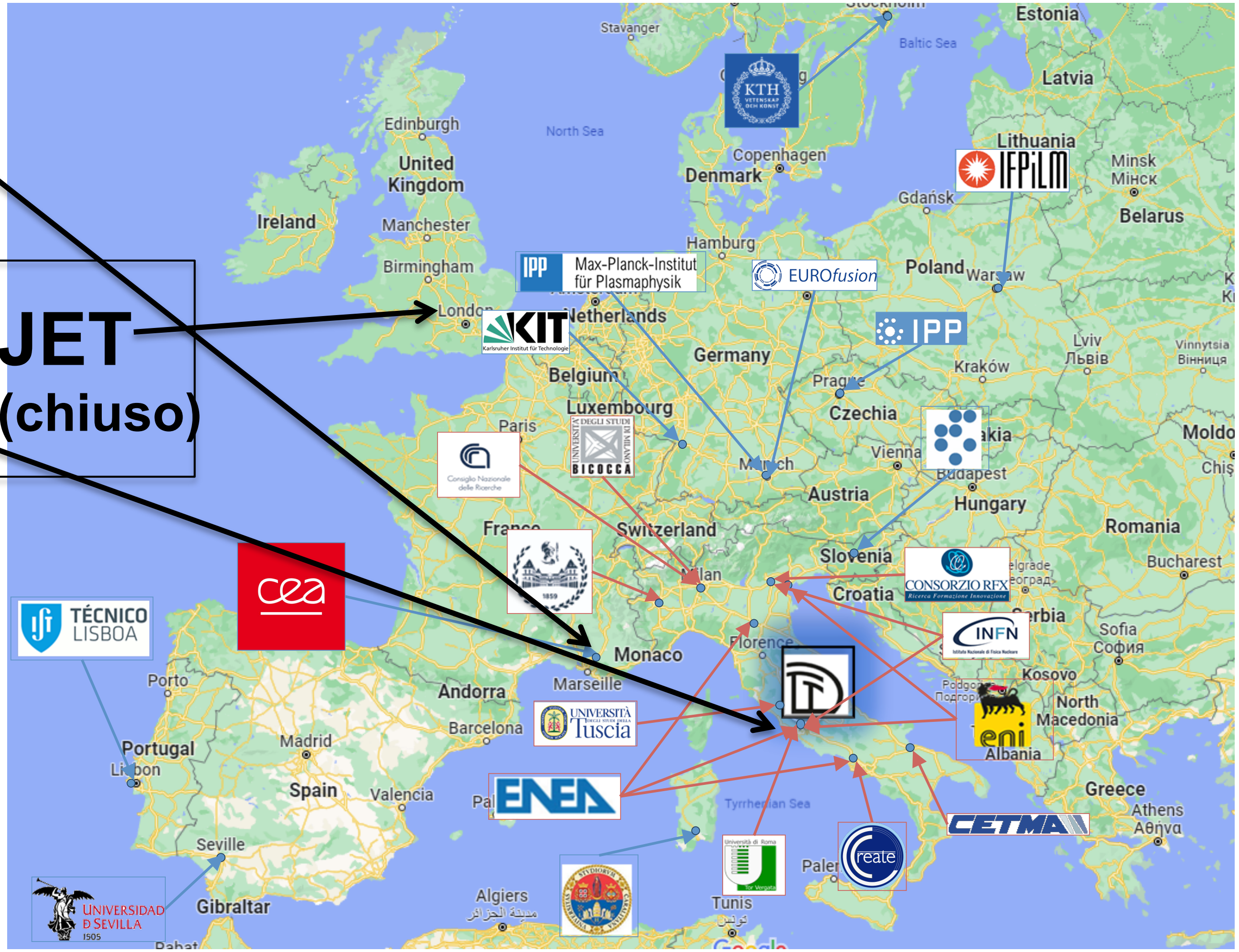
ASDEX -U

WEST

MAST-U

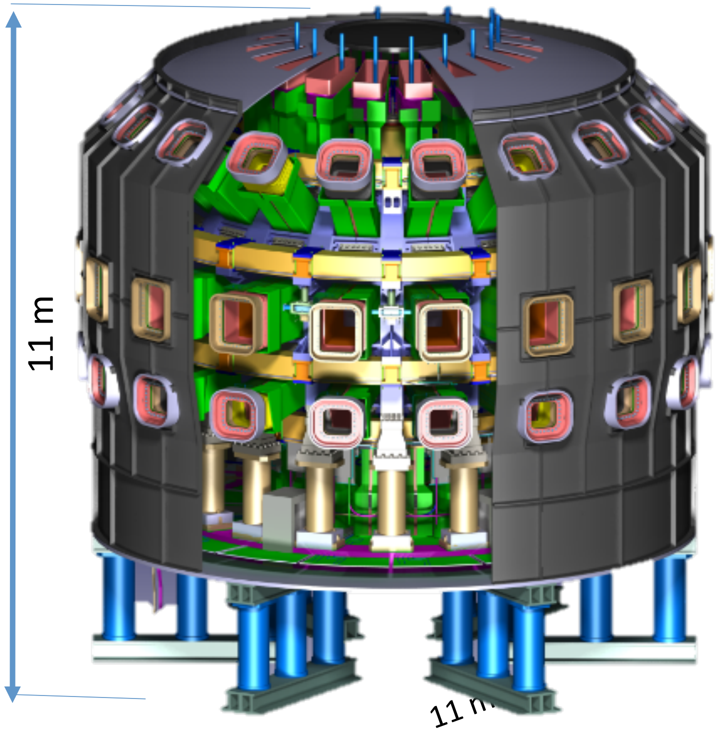
TCV

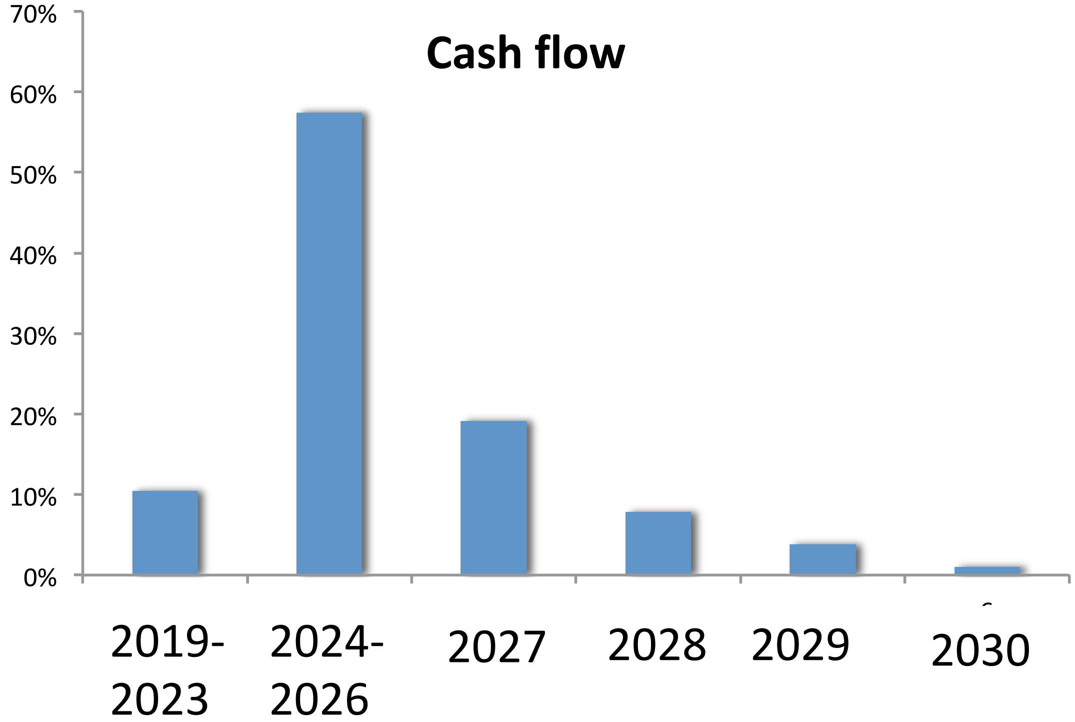
COMPASS



60M€ di fondi EURATOM per DTT

DTT è una sfida e un'opportunità per il sistema Italia



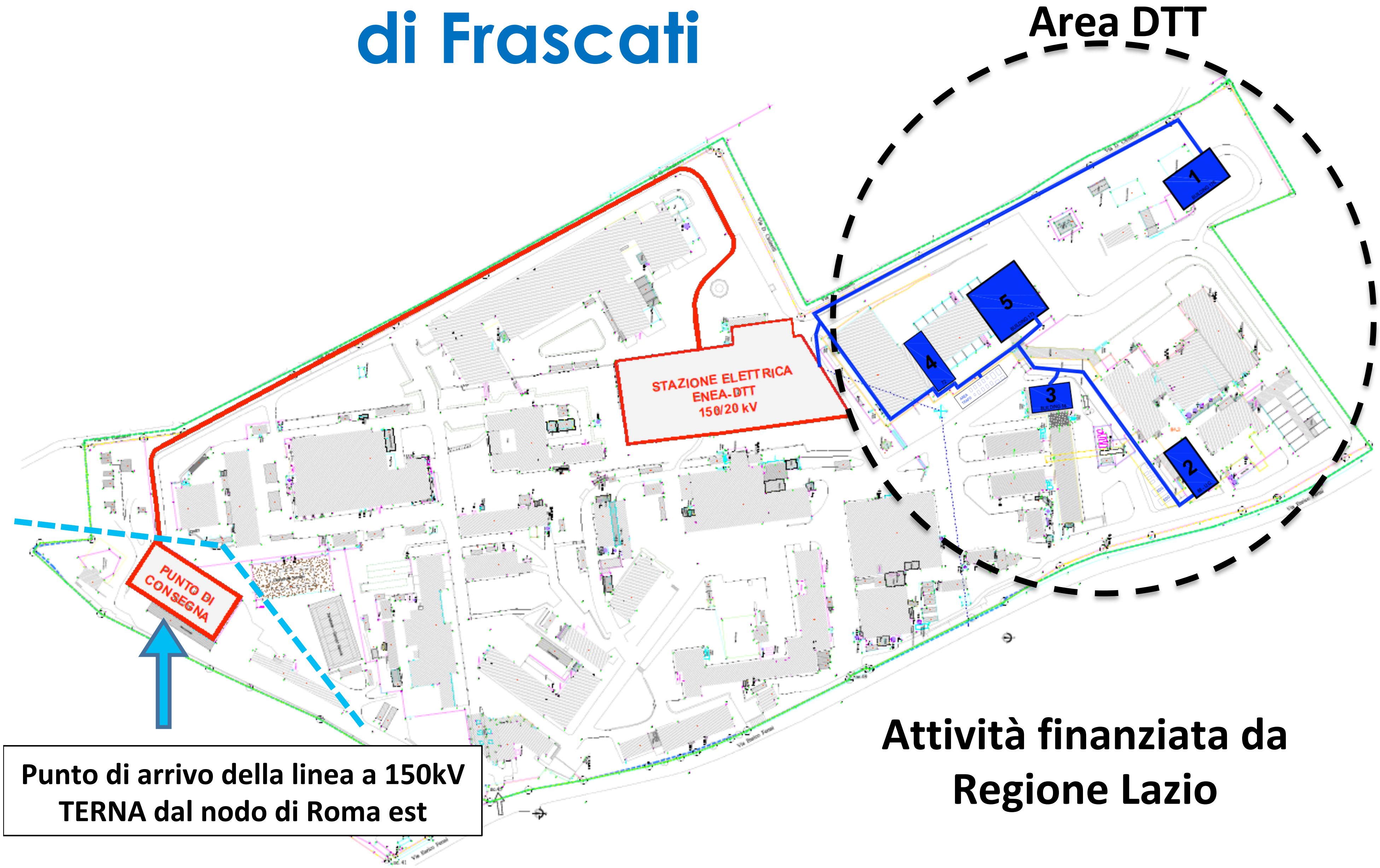


Costi di investimento assicurati da ENEA 650Meuro

Costi di progettazione e qualifica (pro rata soci) 130Meuro

ENEA Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile · CETMA · Consiglio Nazionale delle Ricerche · Create · Consorzio RFX Ricerca Formazione Innovazione · eni · INFN Istituto Nazionale di Fisica Nucleare · Politecnico di Torino · Università degli Studi di Milano Bicocca · Università di Roma Tor Vergata · Università degli Studi della Tuscia

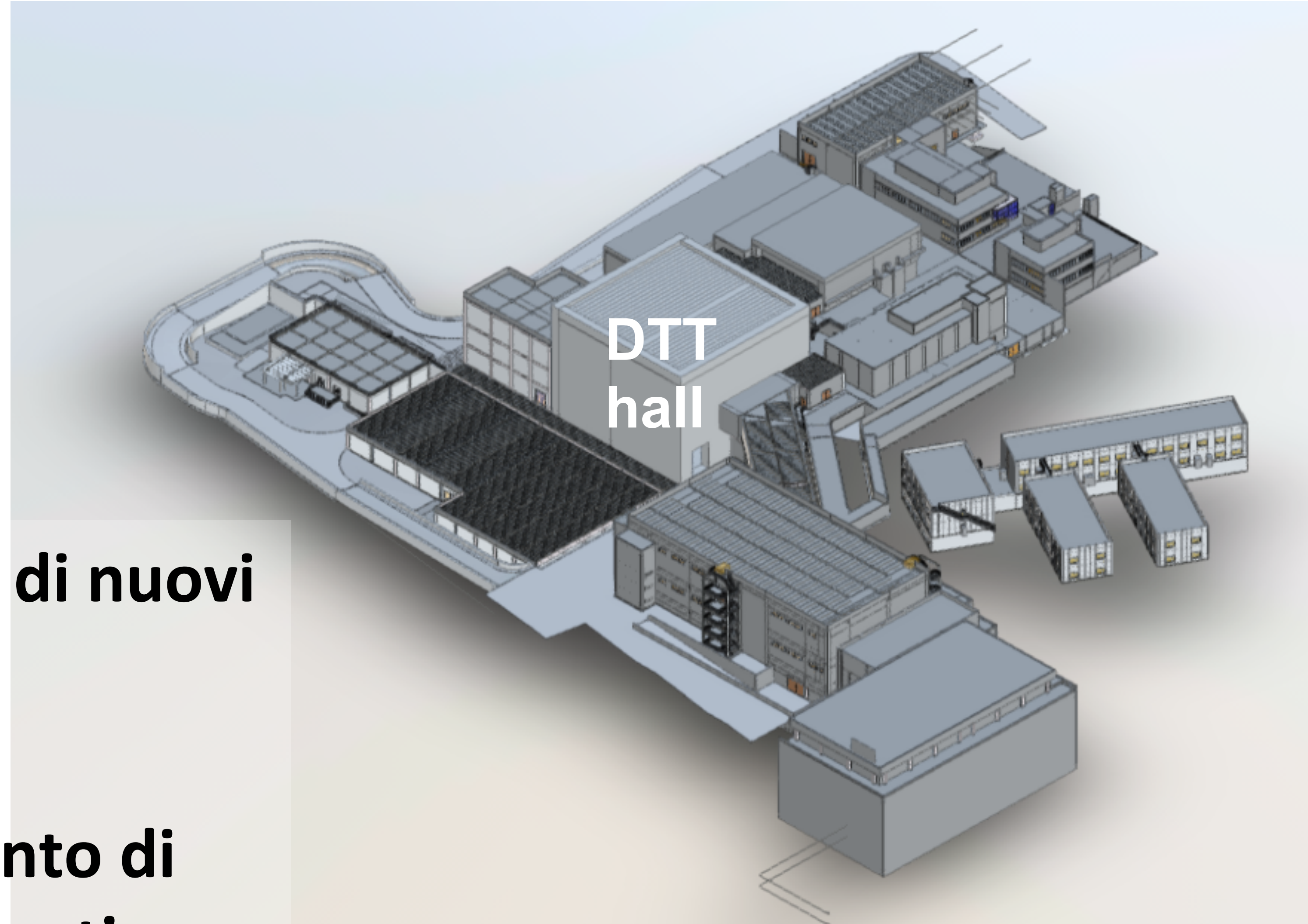
Area DTT nel Centro ENEA di Frascati



Punto di arrivo della linea a 150kV TERNA dal nodo di Roma est

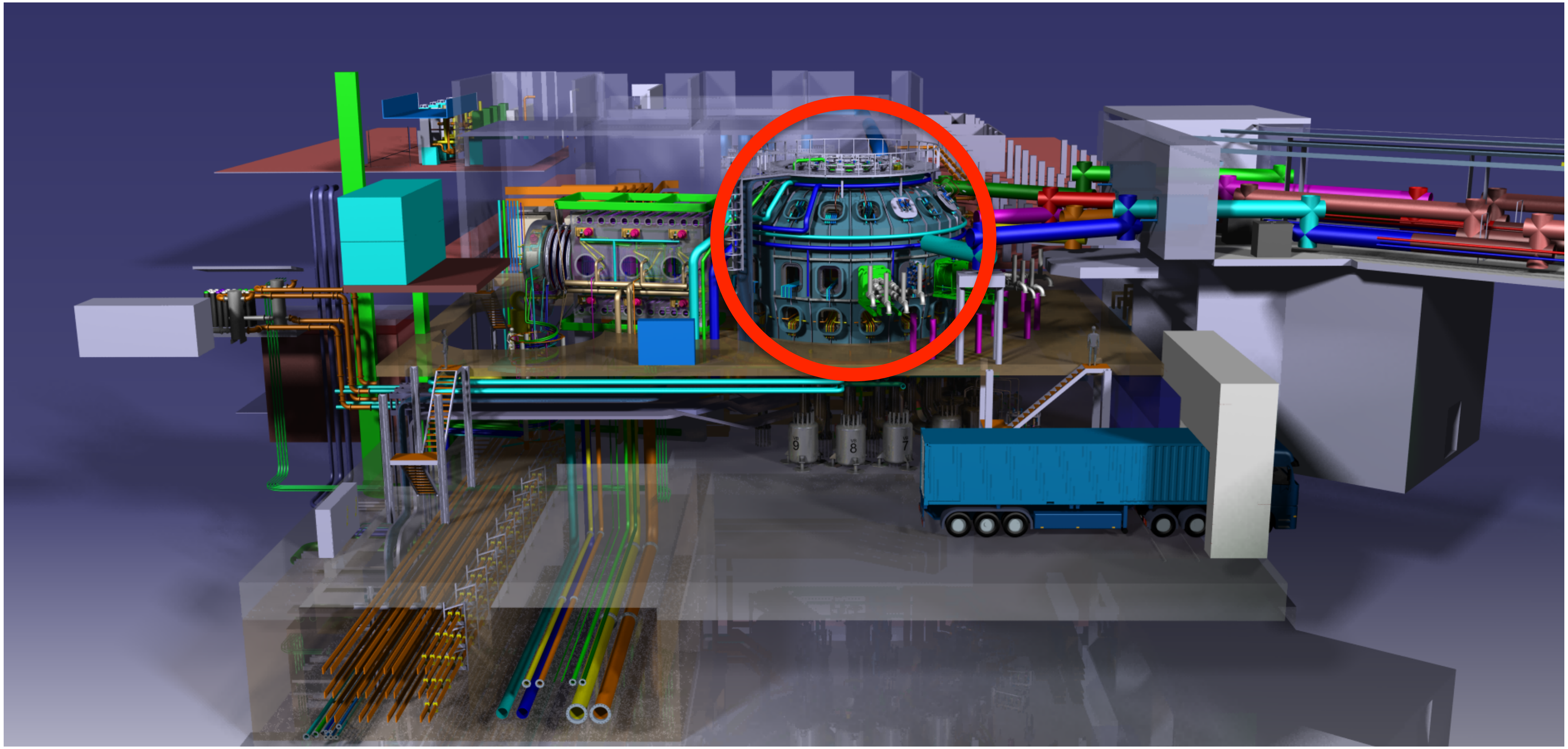
Attività finanziata da Regione Lazio

Layout edifici DTT



- ✓150.000mc di nuovi edifici
- ✓10.000mq riadattamento di edifici esistenti

DTT è un progetto complesso e tecnologicamente avanzato



Costruzione del magnete toroidale

55 ton di filo di Nb_3Sn

Completed

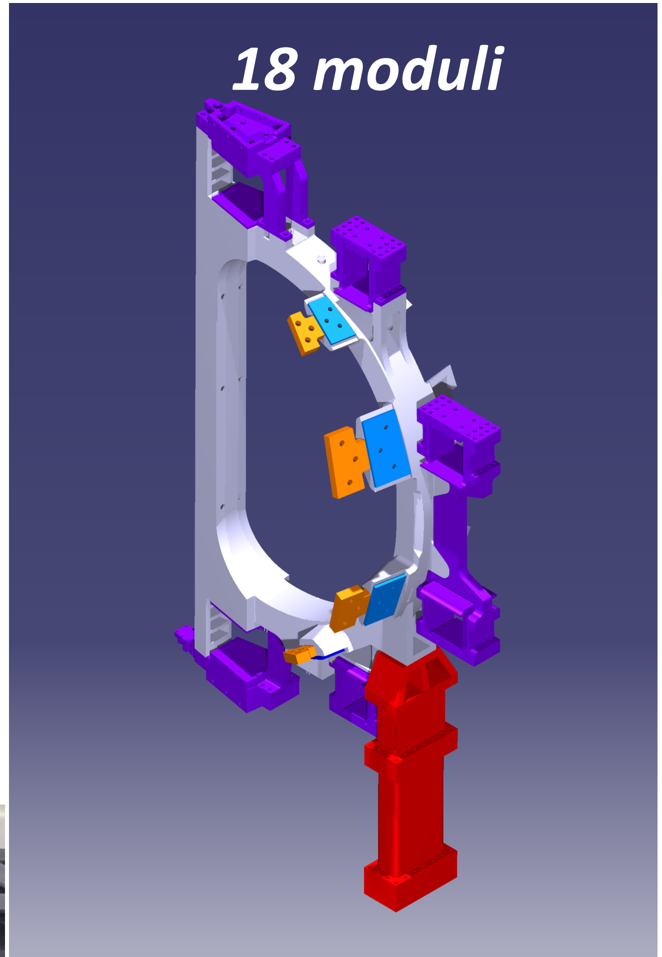
31 ton di filo di rame cromato

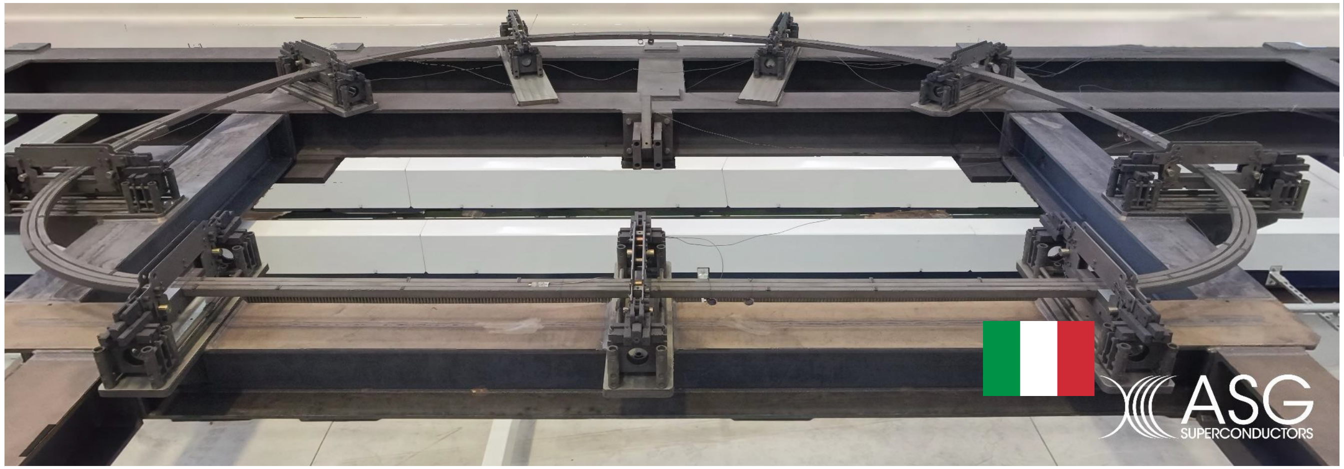
Completed

CICC

icas

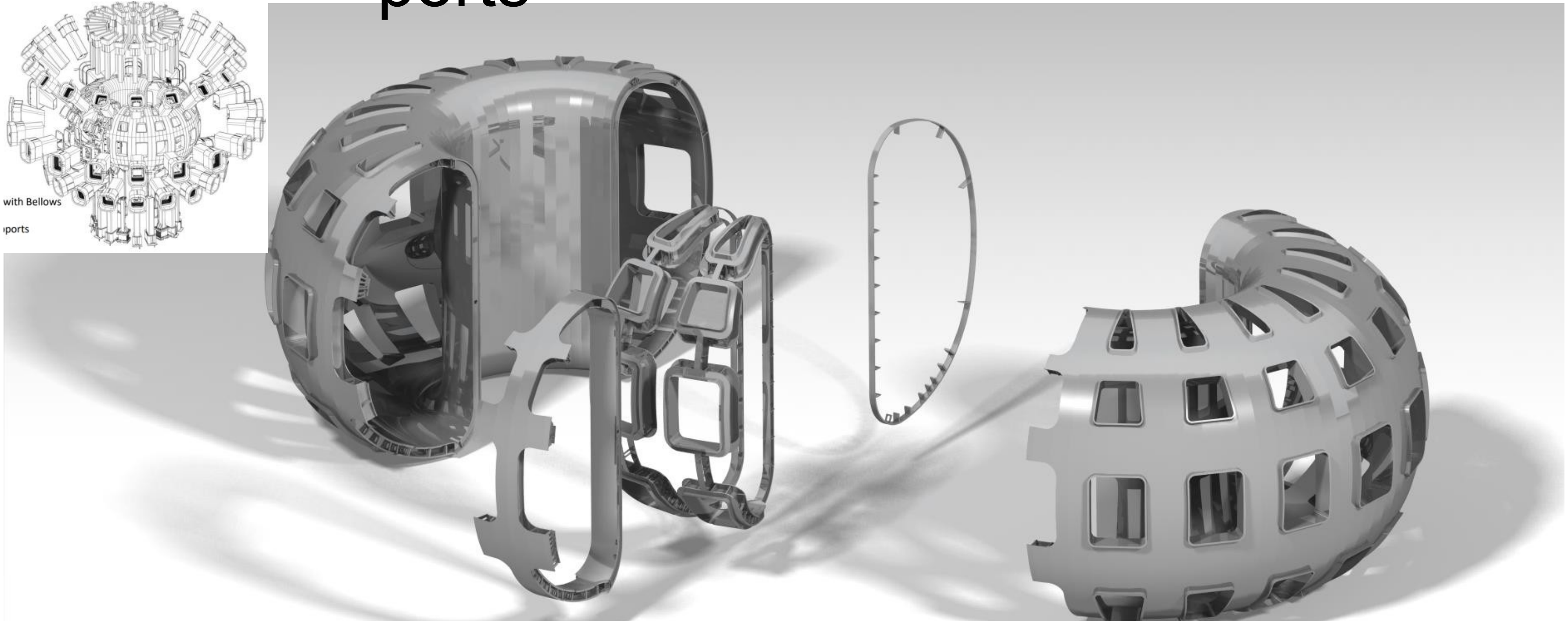
20,4 km di conduttore (un terzo già fabbricato)





Avvolgimento delle bobine (in avvio)

Vacuum vessel and ports



June the 28th

- Call for tender launched on June the 28th
- Deadline with no offer 16/10/2023
- New call to be launched soon

- JT-60SA like double wall 316 LN
- M=37 ton (main vessel only, 175 ton all)
- H = 3,9 m (main vessel only)
- D = 2,5 m (inner) – 6.8 m (outer)
- Water in the interspace (borated later) as neutron moderator

Qualifica dei campioni del divertore completata con successo.

I campioni sviluppati in ENEA sono stati provati con successo per 1000 cicli a 20MW/m²

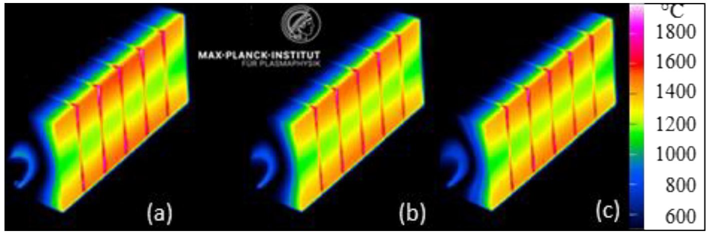
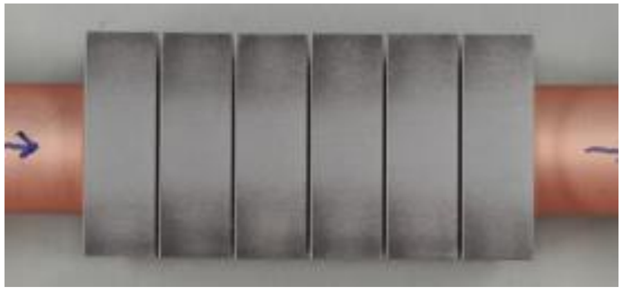
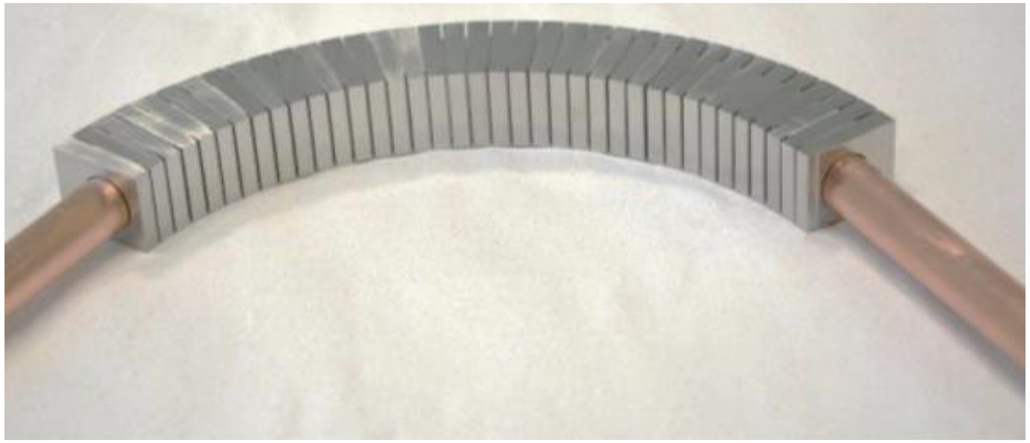
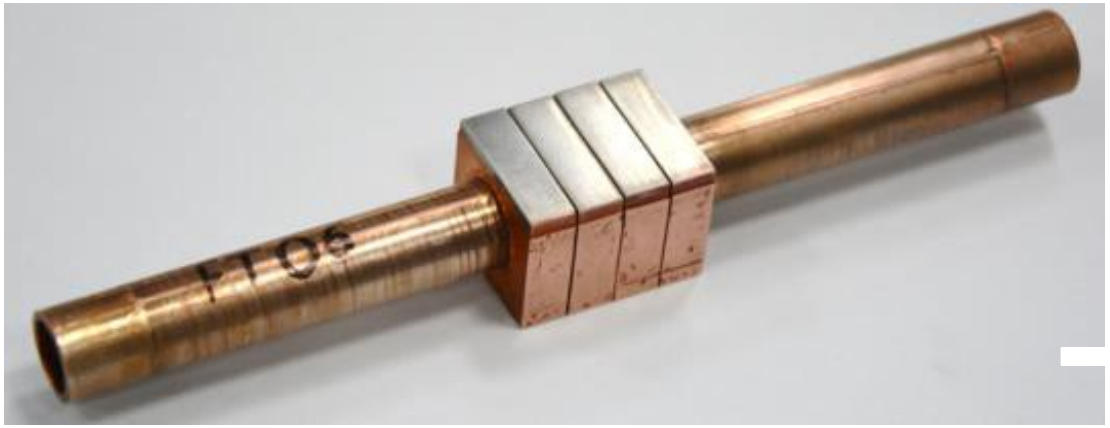


Foto agli infrarossi del campione esposto a 20MW/m²



Campione dopo 1000 cicli



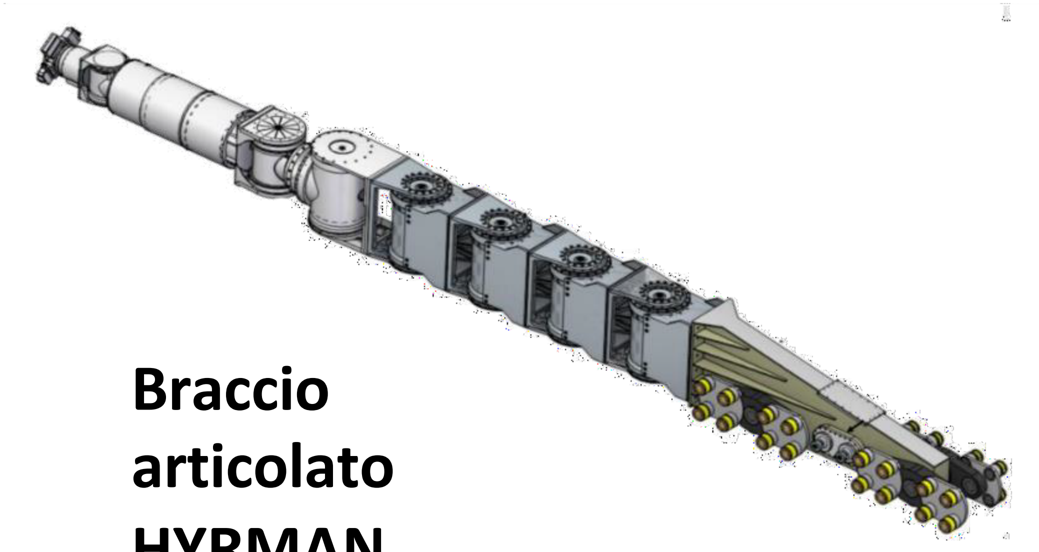


In avvio la produzione di serie in ENEA

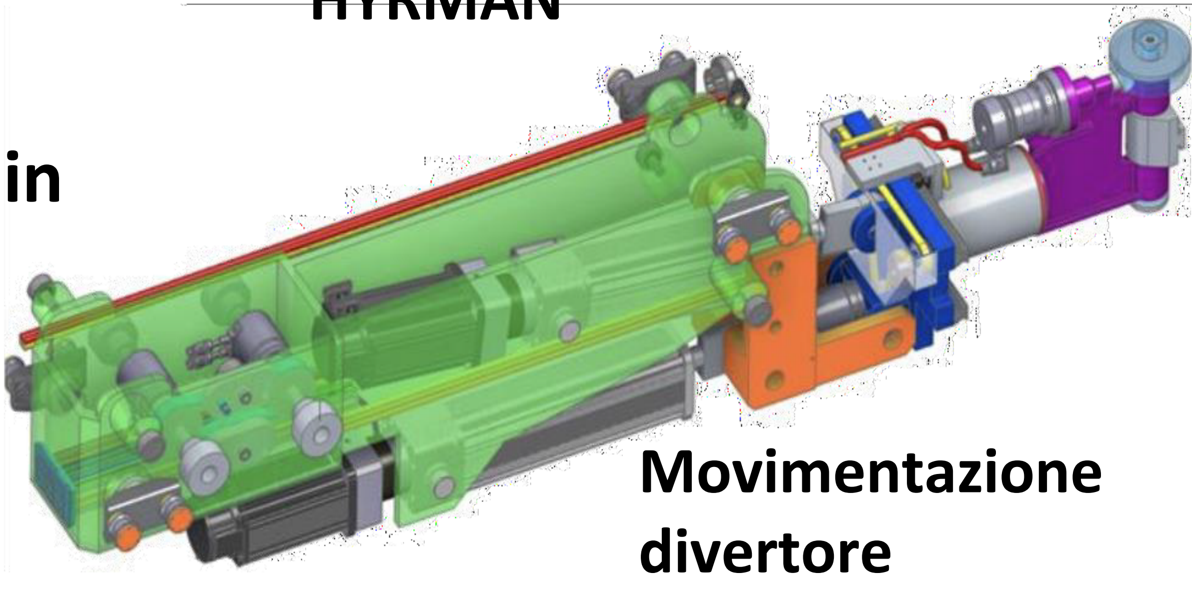
Sistema di manipolazione remota (DTTU)

Il sistema di manipolazione remota è essenziale per smontare e rimontare le componenti interne al reattore.

Una facility di prova è in costruzione in collaborazione con l'Università Federico II



Braccio articolato HYRMAN



Movimentazione divertore

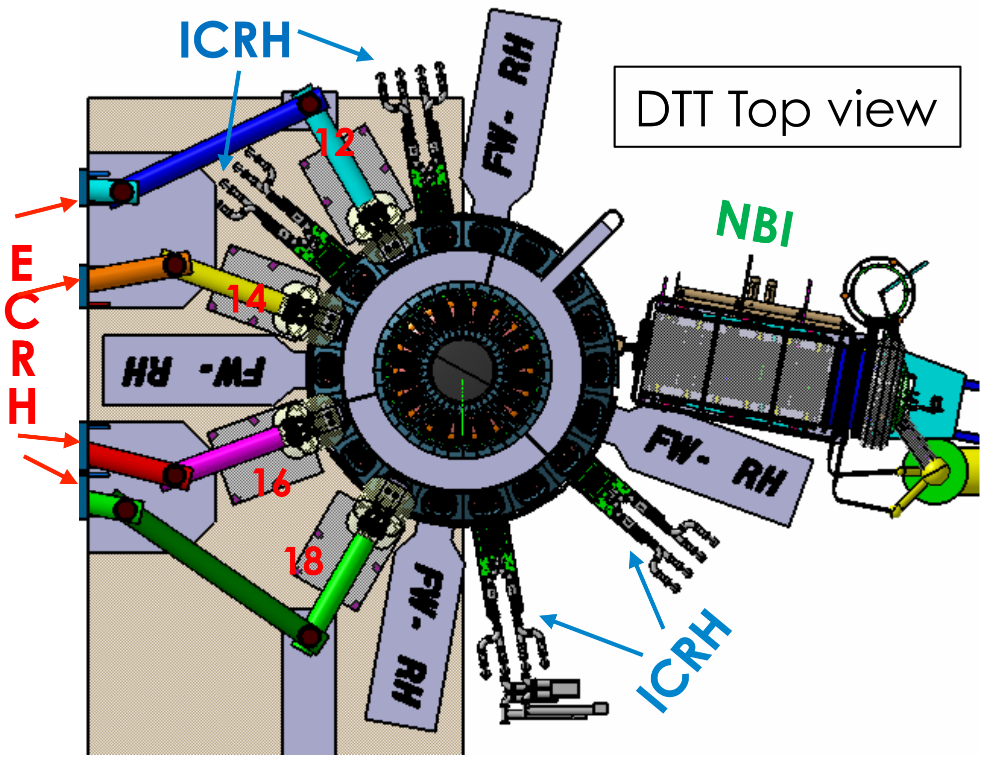
Additional Heating Systems

Up to **45 MW** of additional heating power to DTT by installation of :

ECRH
- 16 MW first phase
- 32 MW third phase
- Gy. Joint proc. with F4E

ICRH
- 4 MW first phase
- 8 MW third phase
- Solid state transmitter

NBI
- 10 MW 500 keV
- Foreseen in the second phase



ECH System: pre-series Gyrotron manufacturing

ECH Progress

Pre-series Gyrotron (1 MW, 170 GHz, 100 s) manufactured and assembled under DTT-THALES specific contract n.1.

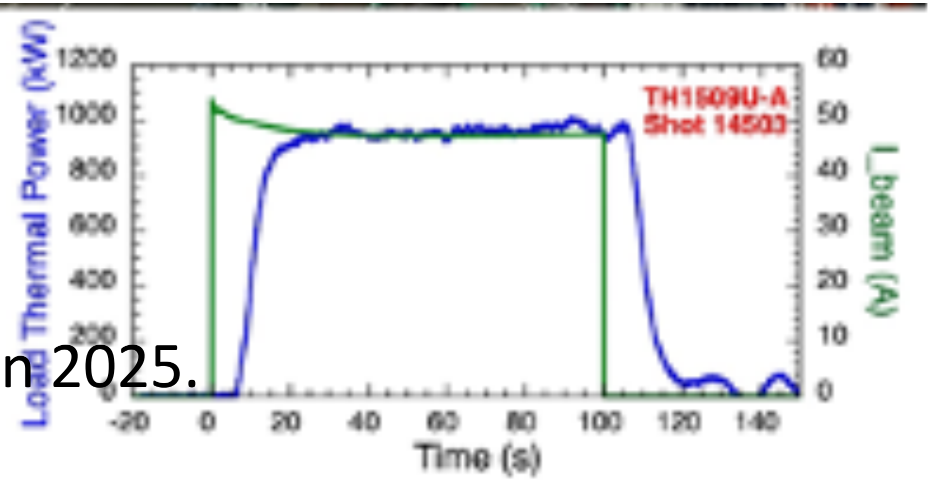
Commissioning performed at the FALCON facility (SPC-EPFL, Lausanne), and DTT requirements demonstrated

A **maximum power level** of 1.03 MW at the gyrotron output window obtained corresponding to **990 kW** at the output of the Matching Optics Unit.

Efficiency exceeding the 40 % demonstrated **during 100 s pulses**.

The specific contract n.2 for **the procurement of the additional 15 gyrotrons signed in December 2023**.

First series gyrotron delivered to DTT in 2025.



ECH Progress

HVPS for gyrotron: Technical Specification completed tender in 2024. Collaboration with F4E on ITER PS tests and FALCON operation.

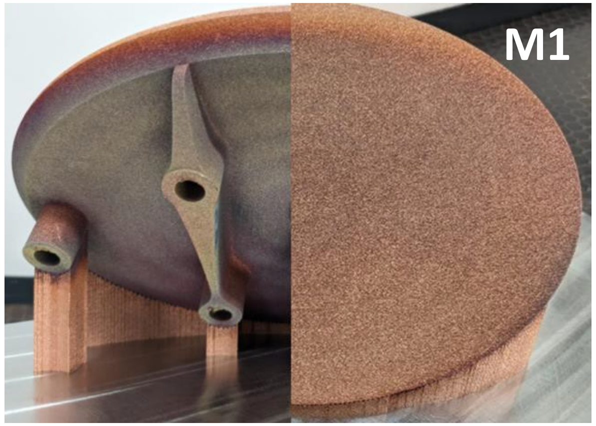
Transmission Line: Preliminary engineering activity (contract with Ansaldo) started to define: containment vessel, alignment solution and combiner/splitter mirrors unit.

Launcher: Engineering activity (L4 contract with ANN) to define mechanical plug-in structure and mirrors/drivers support has been started. Prototype M1 mirrors under preparation for test.

Control System and Diagnostics:

Test bed hardware procured under Next Generation EU funds

Support activity at FALCON to share solutions implemented by F4E and SPC.



ICH progress

SOLID-STATE TRANSMITTERS

Call for tender under Next Generation EU funds - 4 bidders: offers under assessment. Start of contract activities likely in 2024.

1st transmitter presumably by summer 2025

TRANSMISSION LINE & MATCHING

•Call for tender under Next Generation EU fundof the 1st batch of RF components (test-bed + initial part of TL)

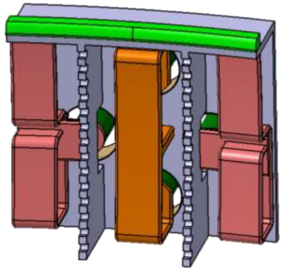
•Expression of interest to UKAEA for some RF components of JET

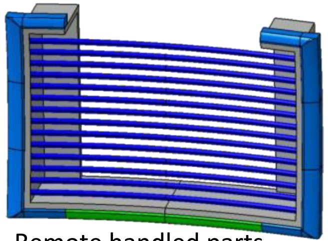
ANTENNA

•Conceptual design ongoing. A semi-plug design is the current favourite option

- straps, coax, backwall, septa, and top limiter preassembled and plugged;
- Faraday screen, part of limiter and box remotely handled.

Antenna plug-in

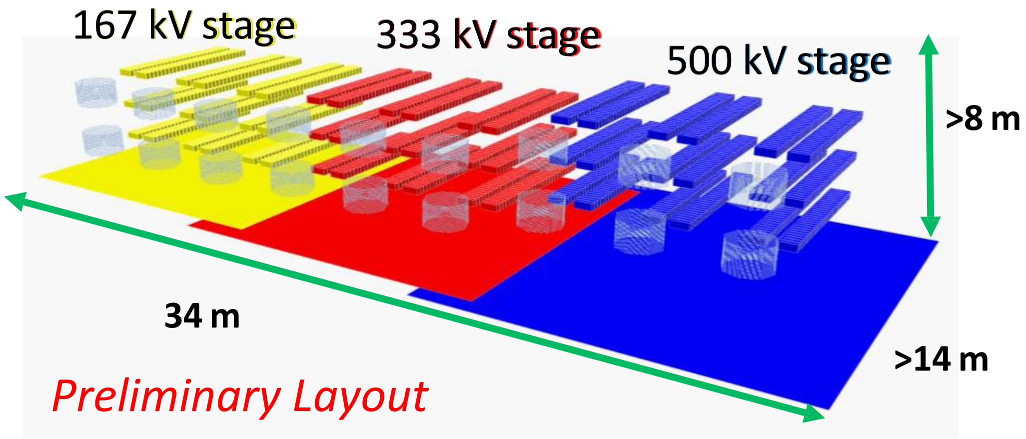




Remote handled parts

NBI Progress

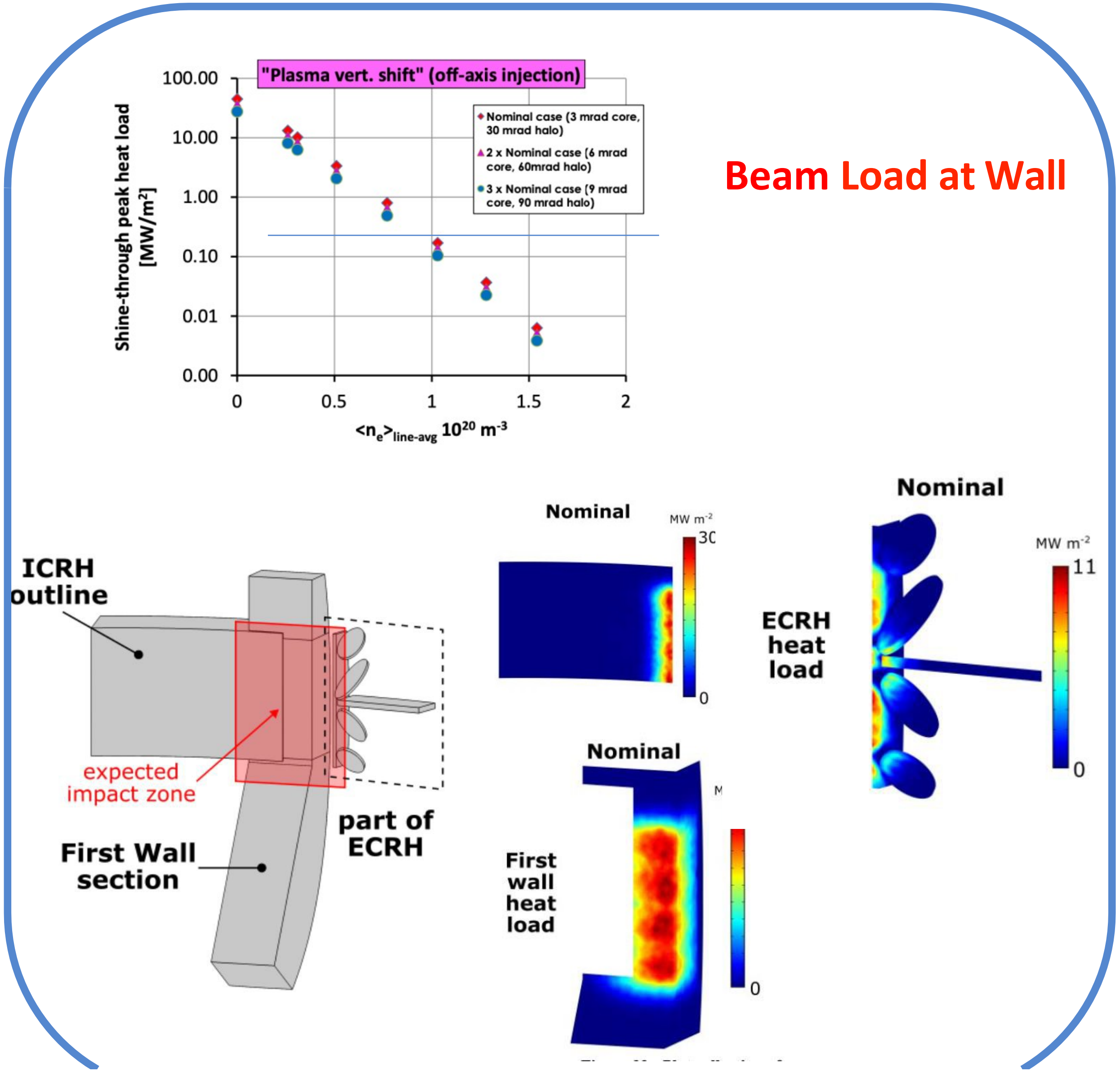
Power Supplies the realization of the High Voltage Test Bed is foreseen for the next year. Final report on MMC solution (alternative to MITICA PS) will be analyzed and considered to take a decision.

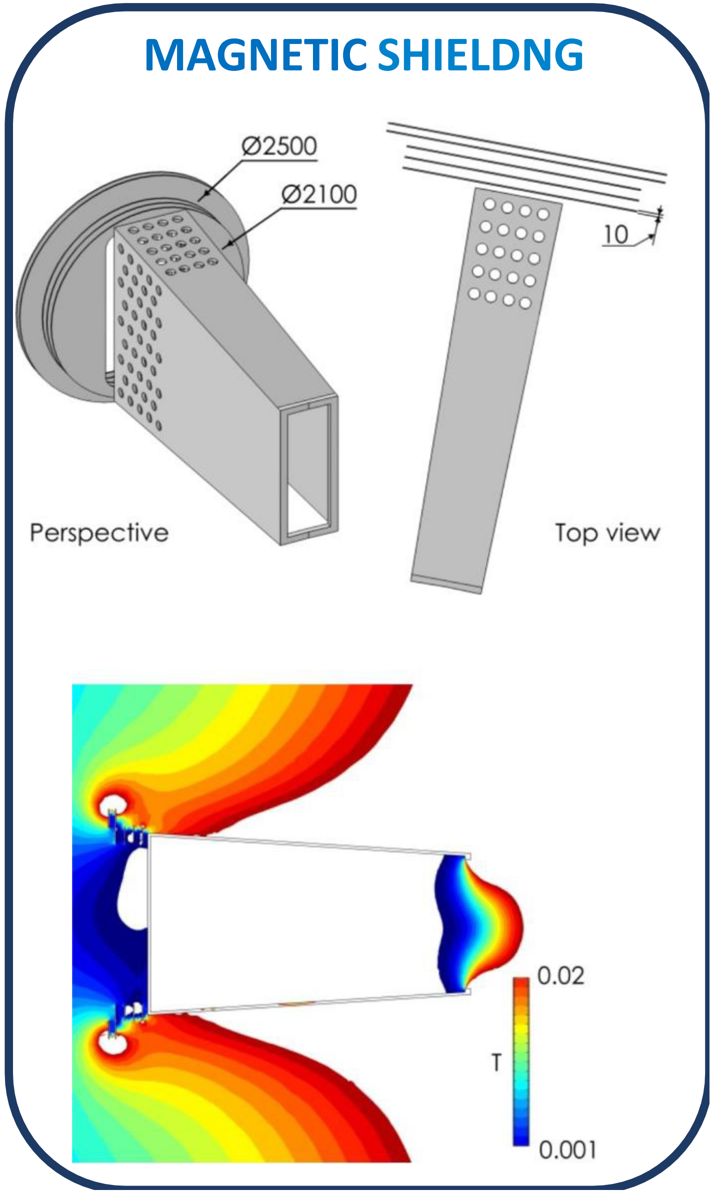


Preliminary Layout

Accelerator: Full size grid printed and machined to prepare welding (EBW) and qualification tests. In 2024 the engineering phase will be started.

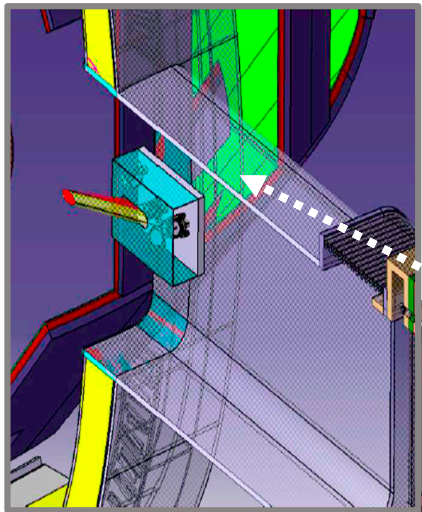
Injector: next objectives are the C-DRMs for the Beam Line Components, the Vacuum Vessel, the magnetic shielding of the injector and of the vacuum system.



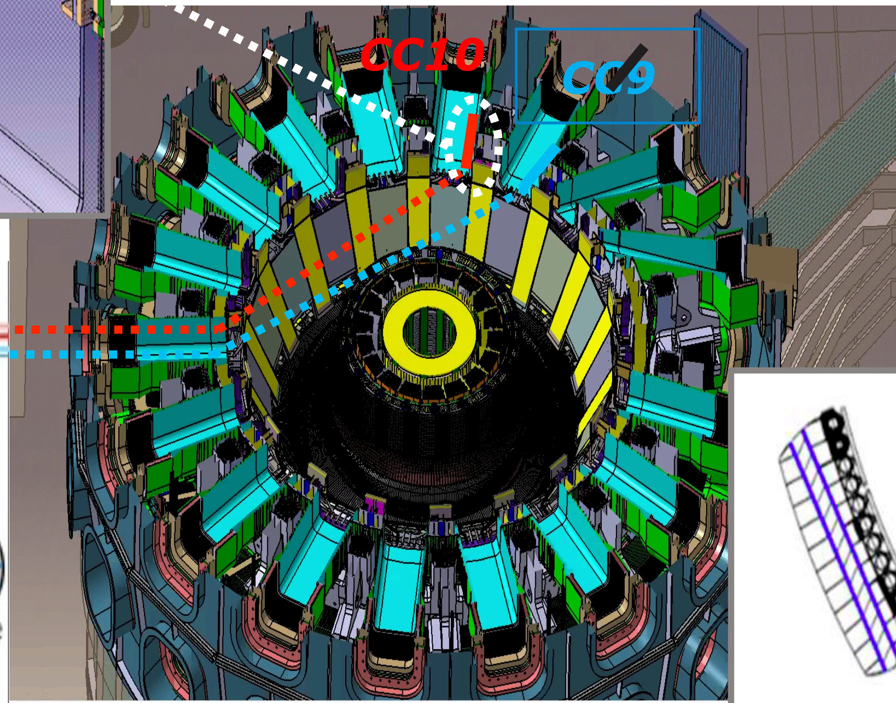


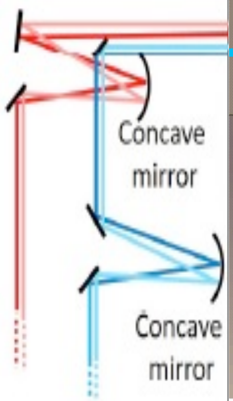
Density control: Tangential Dispersion Interferometer

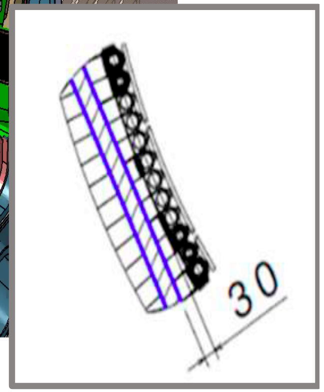
- Tangential dispersion interferometer ➔ 2-chords
- One chord ***from sector 15 to 10 (central),*** the other ***from sector 15 to 9***
- Corner Cubes (***CC9*** and ***CC10***) back-reflect the beams
- ***Laser Wavelength: 1,55 μm (ErYAG)***



- *Density control with Real time capabilities*







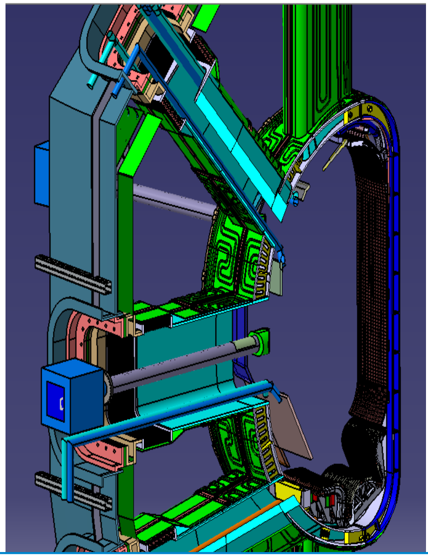
Critical Optical: Analysis of the required electronic components to align the systems in progress

Error on line integrated density	$\approx 10^{18}$ m^{-2}
Channels	2 chords, equatorial plane

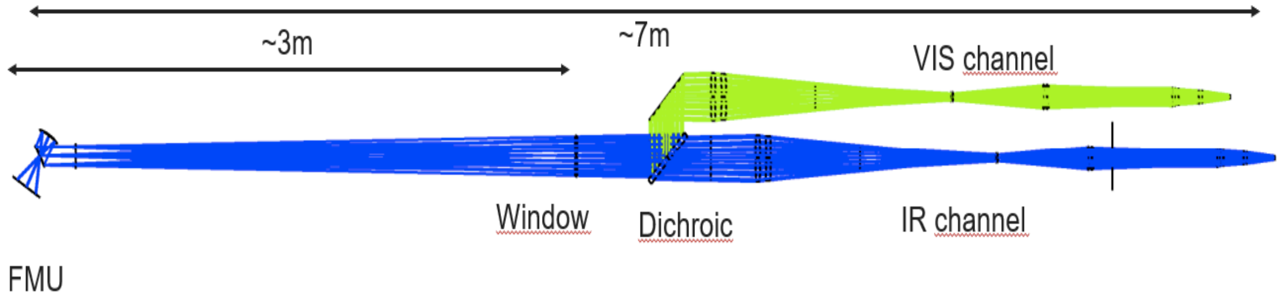
*Schematic Layout of Inner (**BLUE**) and Central (**RED**) Tangential Dispersion Interferometer chords, the inner chord passes 30mm far from the HFS-FW*

Visible and Infrared cameras

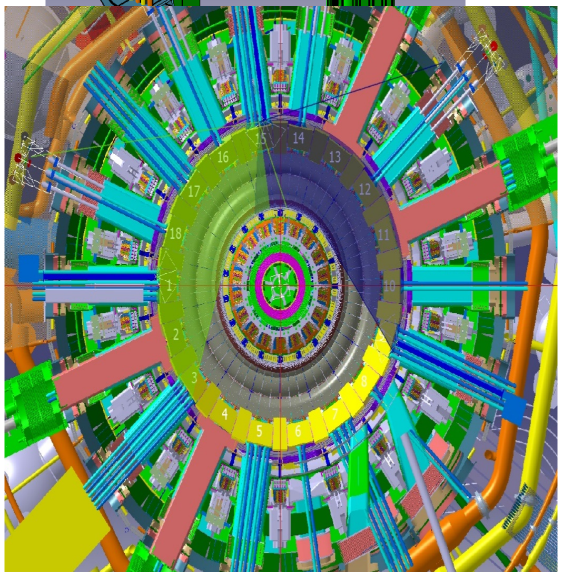
Equatorial port allocation with endoscope (left and right view) deemed as the best option ➔ 3 sectors 120° spaced ➔ ***Wide coverage of the chamber including the divertor region***



Optical path shared between IR and VIS cameras – periscope solution



- ❑ In Blue IR channel, in green VIS channel
- ❑ **In-vessel optics** ➔ only **2 mirrors** (one parabolic and one flat)
- ❑ the current volume allocation(width mostly) **prevents for having off-axis configurations which could allow avoiding blind spot**



Sector15: Right and left cameras views

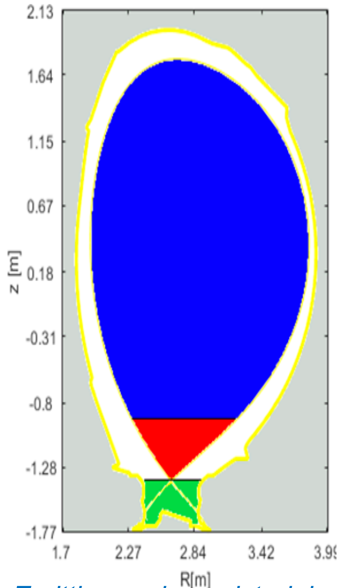
Critical Issues

- ❑ Blindspot and FoV aperture to be assessed ➔ bottom DIV to be prioritized?
- ❑ Not possible to observe the SPs from PORT1, We are exploring different solutions

Fast Camera to study FW, disruptions, and dust ➔ high-speed camera with exposures on the order of 100 ms is under study

Bolometer Cameras

- ❑ *Total amount of radiation*
- ❑ *Radiation patterns which identify the different operating conditions*
- ❑ *Active control of the divertor power exhaust*



Emitting regions pictorial view (JET, Murari, Nuc Fus 2020)

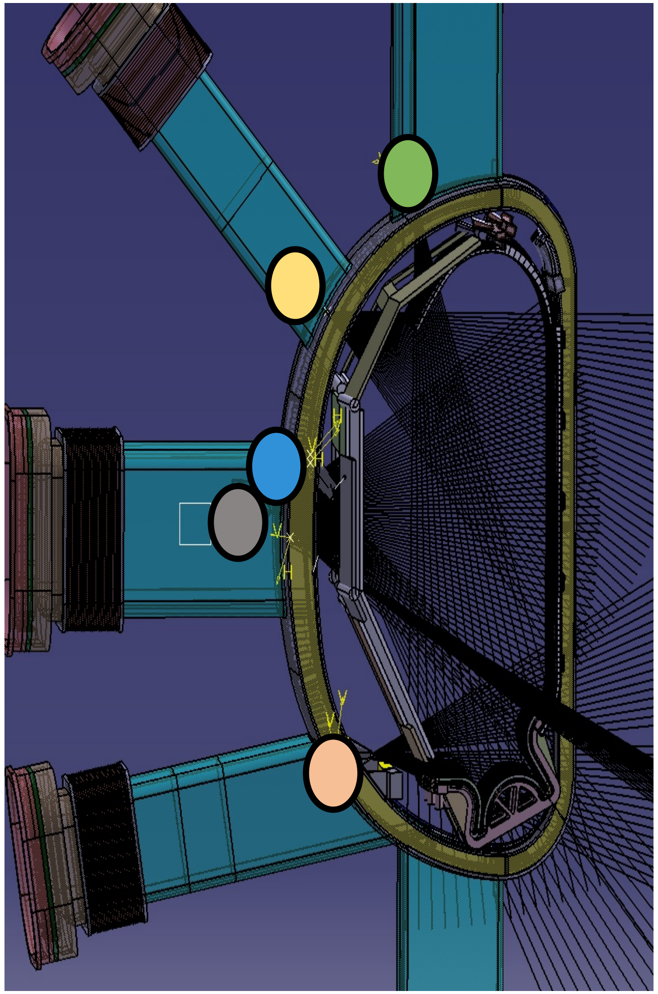
Emission in the divertor region

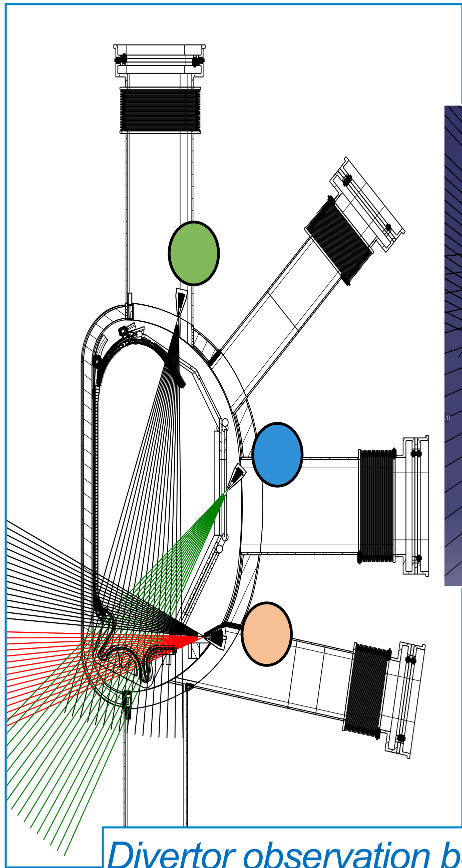
Radiation from the small region above X point

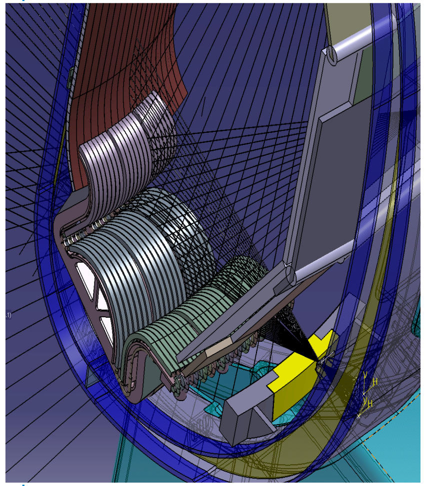
Core radiation

Radiation in the SOL

Rad. power







Divertor observation bolometer arrays, properly control of the detachment

Schematic view of DTT bolometric diagnostic: ~ 170 LOS, to optimize tomographic reconstruction in specific regions

La collaborazione pubblico-privato è strategica per il successo della fusione

- Il raggiungimento dell'obiettivo della fusione richiede un salto qualitativo nel modello di organizzazione che metta insieme enti di ricerca e industrie del settore energia. DTT è la migliore opportunità per sviluppare la collaborazione pubblico-privato in Italia.
- Tutto il know-how necessario per la costruzione è presente in Italia nell'industria, nei centri di ricerca e nell'Università.
- DTT è un'opportunità per un giovane che voglia entrare nel mondo delle ricerche sulla fusione.

Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile
Consiglio Nazionale delle Ricerche
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