CONSORZIO RFX
Ricerca Formazione Innovazione

Hybrid reactors based on Reversed Field Pinch (RFP)

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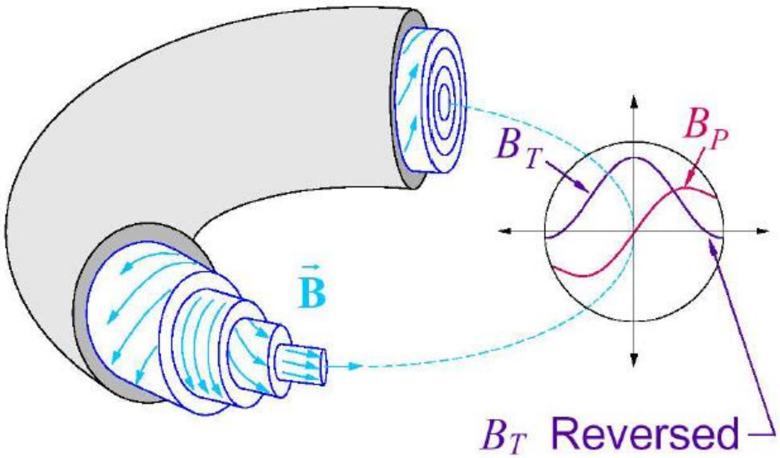
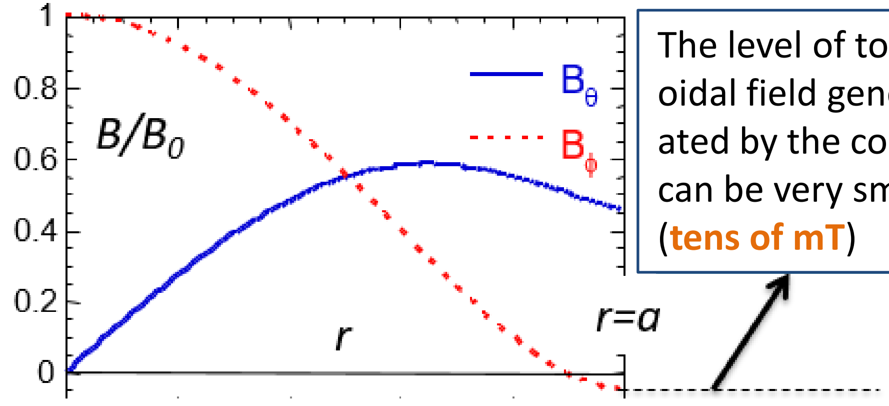
Outline

1. The Reversed Field Pinch configuration
2. The present status of RFP researches: RFX-mod results
3. Conceptual scheme of a hybrid reactor with a Reversed Field Pinch (RFP) as the fusion core
4. Feasibility studies and preliminary design of a pilot FFHR with a three staged approach
5. Studies on RFP FFHR for Tritium production

The Reversed Field Pinch configuration





The level of toroidal field generated by the coils can be very small (**tens of mT**)

- **No** intrinsic **limit** on **plasma current**
  ⇒ **high ohmic heating** due to the slow helical winding of current lines; **burning regime** can be achieved by **ohmic heating** only, without additional heating systems (NBI, RF)
- **Self generated** internal **toroidal magnetic field** by dynamo mechanism
  ⇒ **low value** of the reversed field at the edge generated by TF coils; in a reactor copper coils at room temperature can be used (**no superconductor for toroidal field coils**).
- Configuration **not prone to disruptions** because of the magnetic self-organization
- A **divertor** might **not be necessary**
- **Poorer confinement time** with respect to Tokamak (improvement necessary for a power plant)

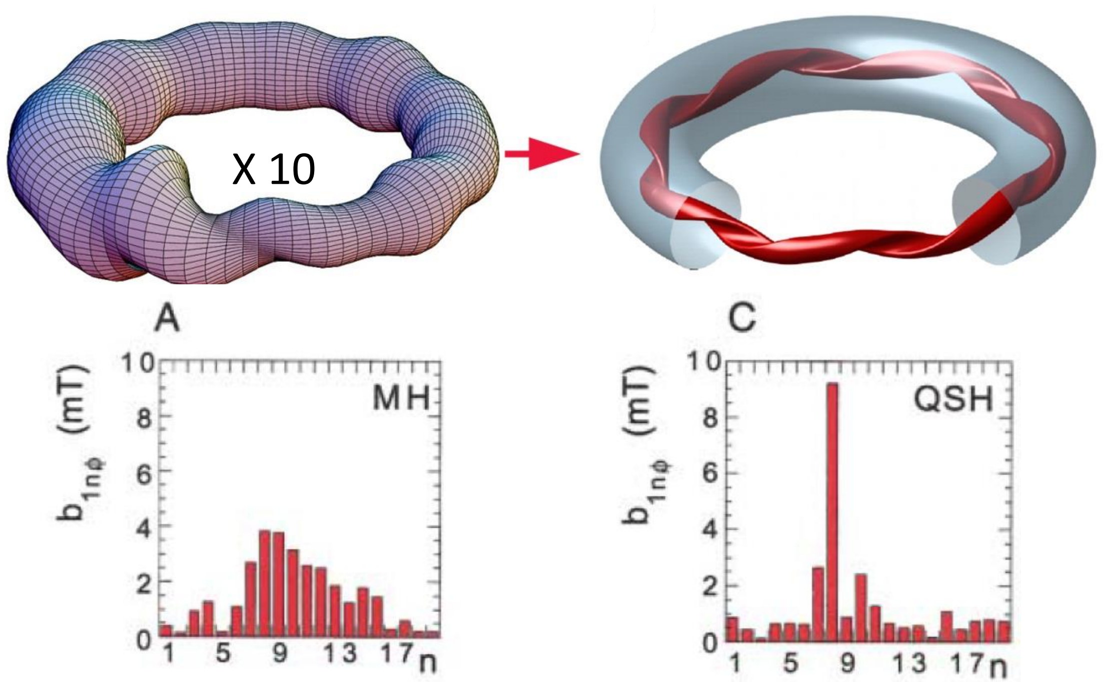
  but **within a fusion core for FFHR ($Q \approx 1$)**

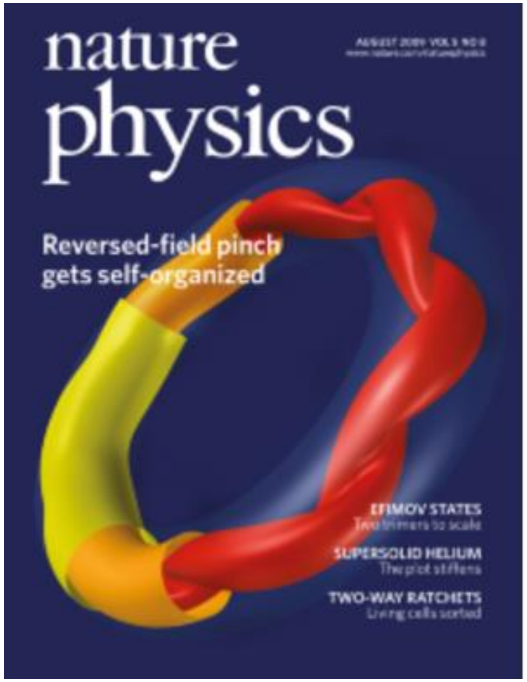
RFP self-organization

At low current RFP is rich of internal resonant MHD modes but at high current the plasma spontaneously relaxes into a *helical equilibrium* where only one saturated mode is present and sustains the configuration.

Turbulent (Multiple Helicity)

Laminar (Single Helicity)





RFX-mod experiment

SIZE:

$a = 0.46$ m, $R = 2$ m

PHYSICAL PARAMETERS:

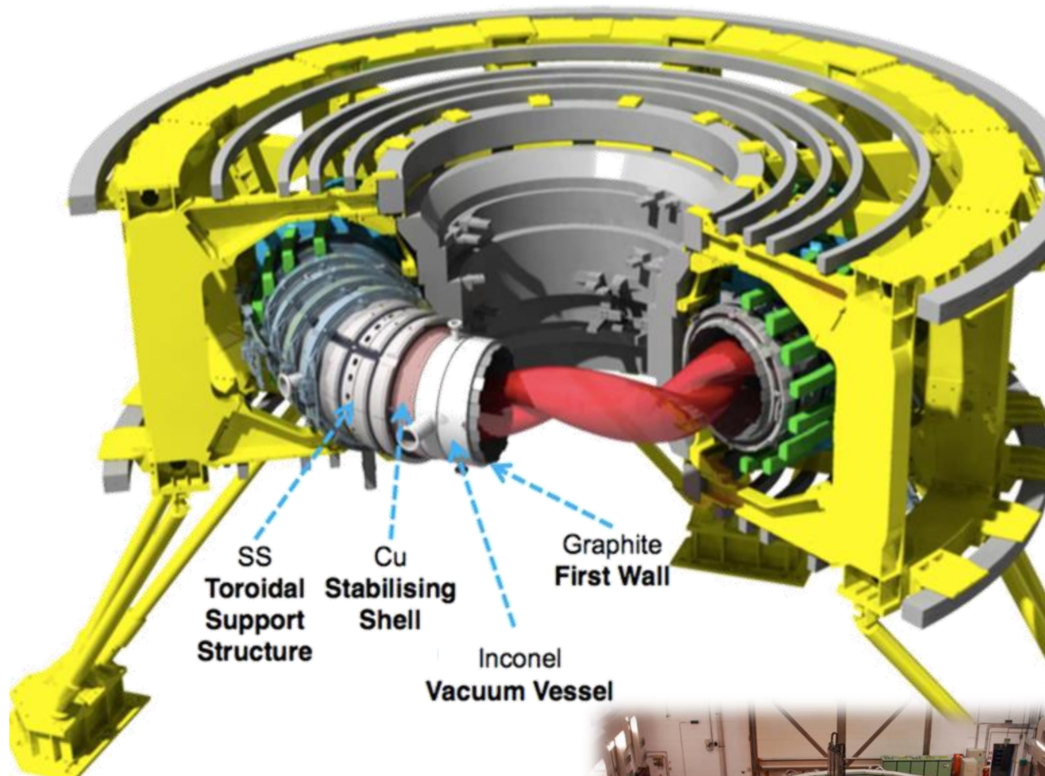
$I_p \leq 2$ MA

$B_t(0) = 1.9$ T

$B_t(a) = -20$ mT

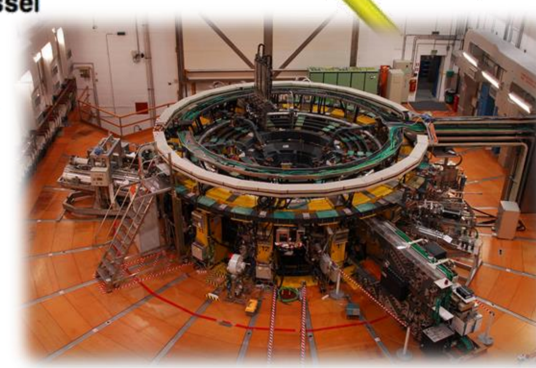
$T_e \leq 1.5$ keV

$n_e \approx 10^{19} - 10^{20}$ m^{-3}

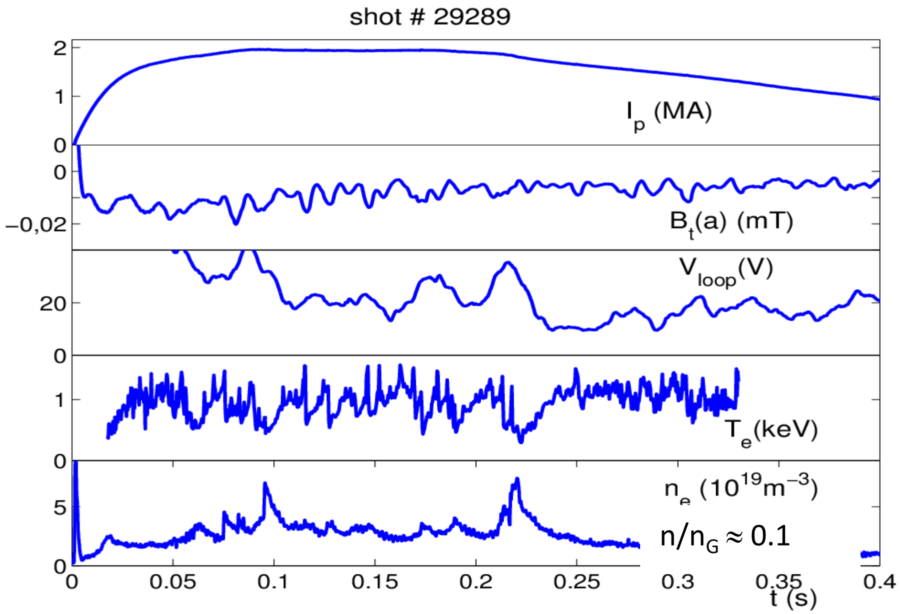


FEATURES:

- Thin conducting shell to limit MHD modes
- Sophisticated coil system for MHD modes control and local PWI reduction
- Pulsed inductive plasma operation

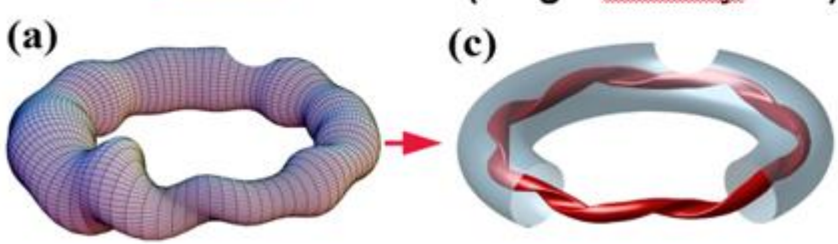


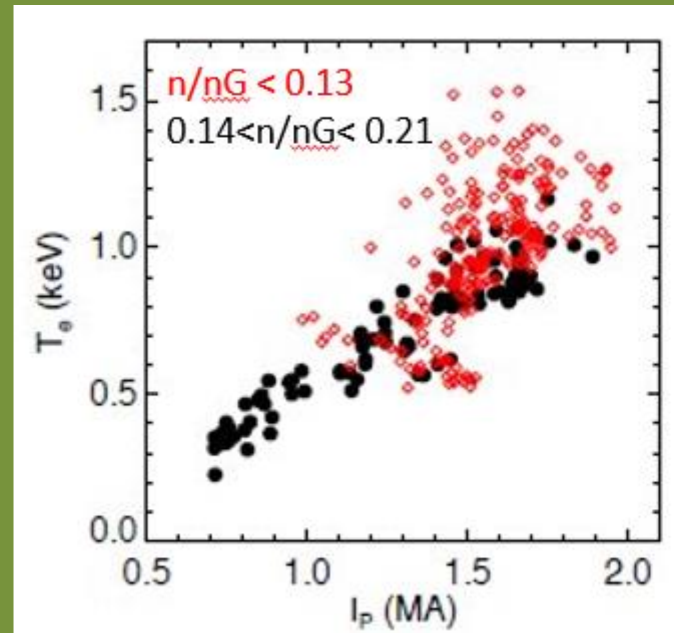
The RFX-mod results



Low confinement → High confinement

Turbulent (Multiple Helicity - MH)	Laminar (Single Helicity - SH)



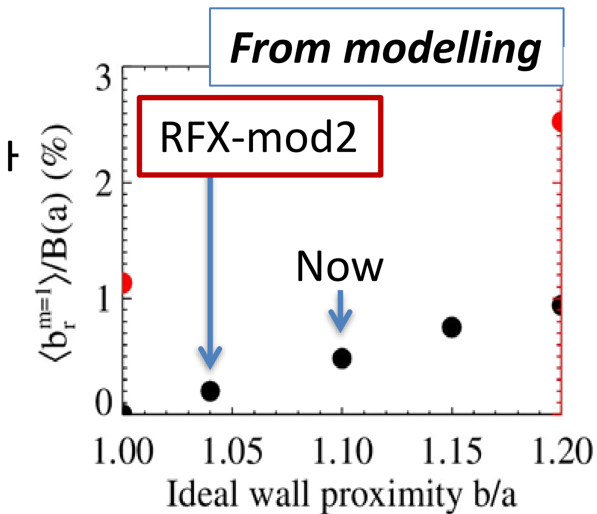


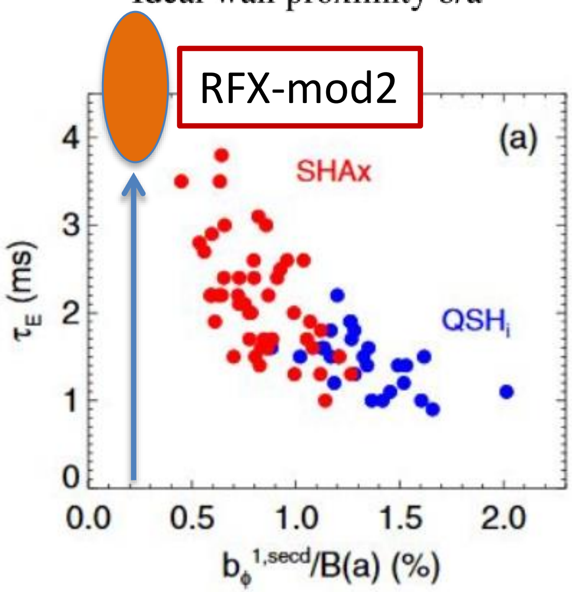
$$T_e \propto j^{1.1}$$

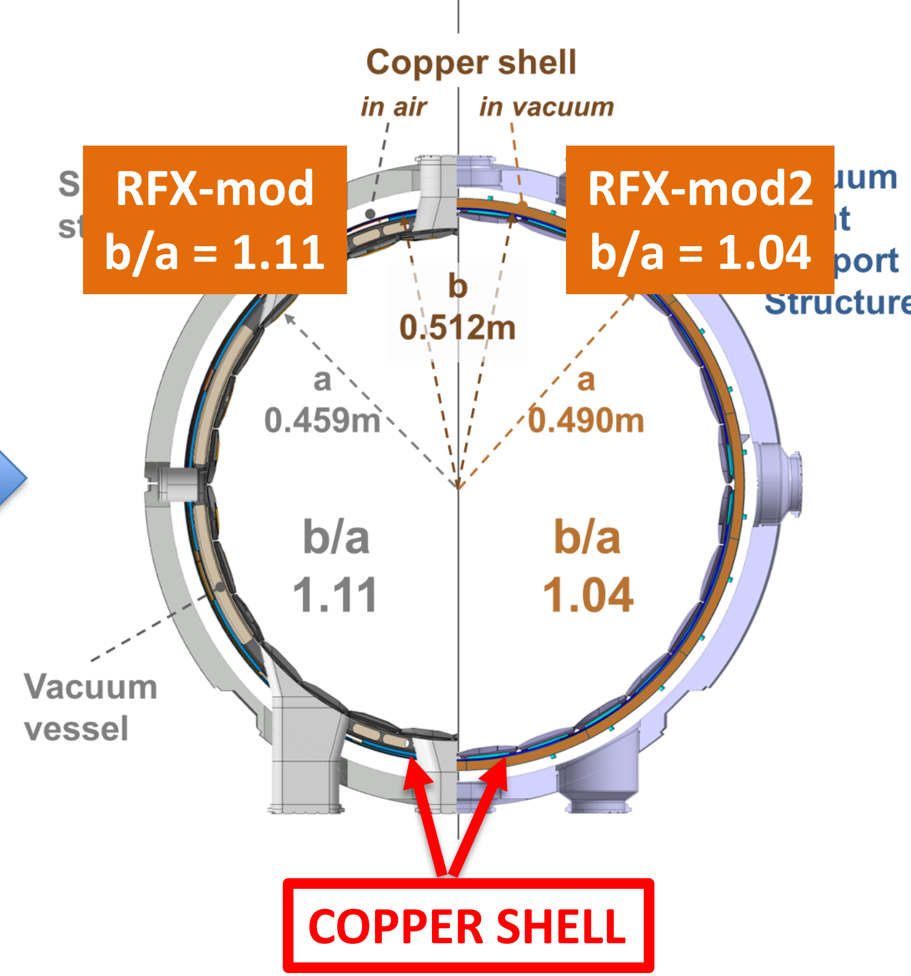
Purely ohmic heating

Towards RFX-mod upgrade: RFX-mod2

Secondary modes reduction → by approaching the plasma to the conducting shell







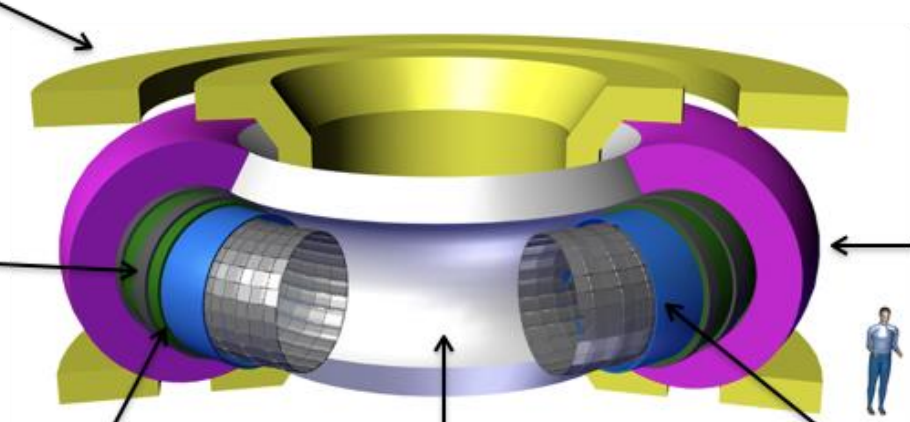
FFHR with RFP as fusion core

The machine layout

Central solenoid and equilibrium coils (superconductive) @ cryogenic temp

Simple machine assembly

Copper toroidal field coils @ room temperature



High accessibility to the blanket for maintenance

Steel vacuum vessel acs as supporting structure

Large space for internal shield

High conductivity shell

RFP advantages and issues

RFP peculiarities

- **Only ohmic heating** to reach fusion condition. **No** additional **heating systems**
- **Reduced toroidal field.** Copper toroidal field coils at **room temperature**
- Superconducting magnetizing/equilibrium coils. Cryostat separated from the plasma torus/TF coils and the **fissile blanket**
- **No divertor** (to be verified)

Simpler solution

- High machine **accessibility for maintenance**
- **Large space** for the separated fissile blanket

Reduced investment

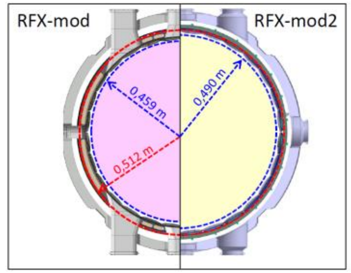
- Limited use of **superconductors**
- No additional **heating**
- **No divertor**

Issues

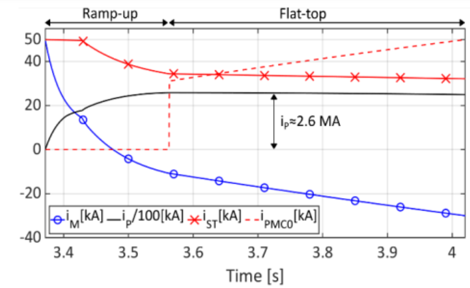
- Only medium size machines. **Scaling laws to be assessed**
- **Plasma-wall interaction** with increased plasma current
- **Quasi Single Helicity** evolution with plasma current
- **Plasma refuelling**
- Power, impurities and helium **exaust**
- **Inductive continuous operation**

From RFX-mod to the Hybrid Reactor

RFX-mod
2005 – 2015
2MA – 0.5s – 1.5keV

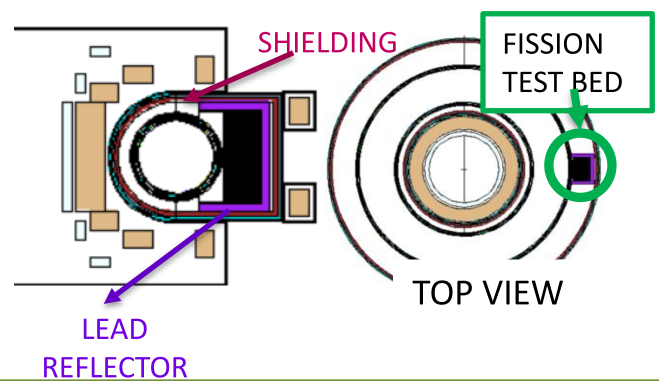


RFX-mod2
Improved performances
Underway construction

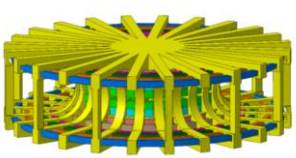


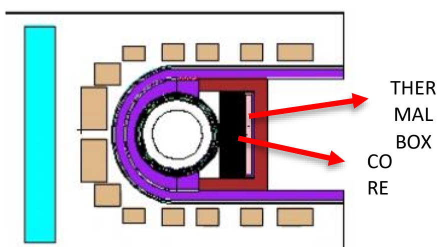
RFX-mod2 with increased current (2.6 MA)
Design under way

Pilot FFHR with reduced performances
Feasibility studies in progress



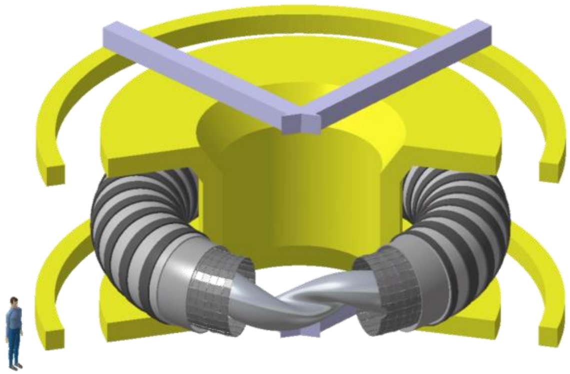
Fusion-Fission Hybrid Reactor for
Tritium generation
Feasibility studies in progress





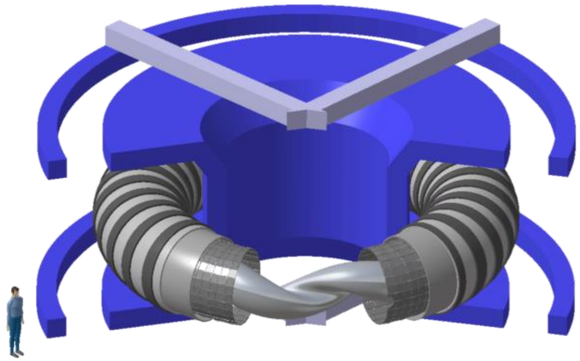
Staged approach of a pilot experiment
(R=4, a=0.8, I_p=12MA)

**1st phase:
RFP plasma physics investigation**



- Magnetization and equilibrium by copper coils @ room temp.
- Reduced volt-second and plasma current
- Double swing - Single pulse

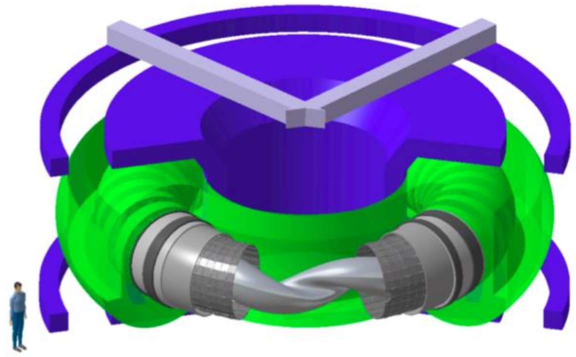
**2nd phase:
Technological issues investigation**



Superconducting magnetizing/equilibri-um coils

- Plasma current up to full performances
- Double swing - Pulsed continuous operation

**3rd phase:
Operation of the pilot experiment with D-T**



- Nuclear site
- The nuclear shield is added.
- Reduced size test beds for irradiation of fissile material

Staged approach of the pilot experiment

Same basic machine, diagnostics and auxiliaries systems in all phases with successive modifications and improvements

→ (cost & time saving and machine optimization)

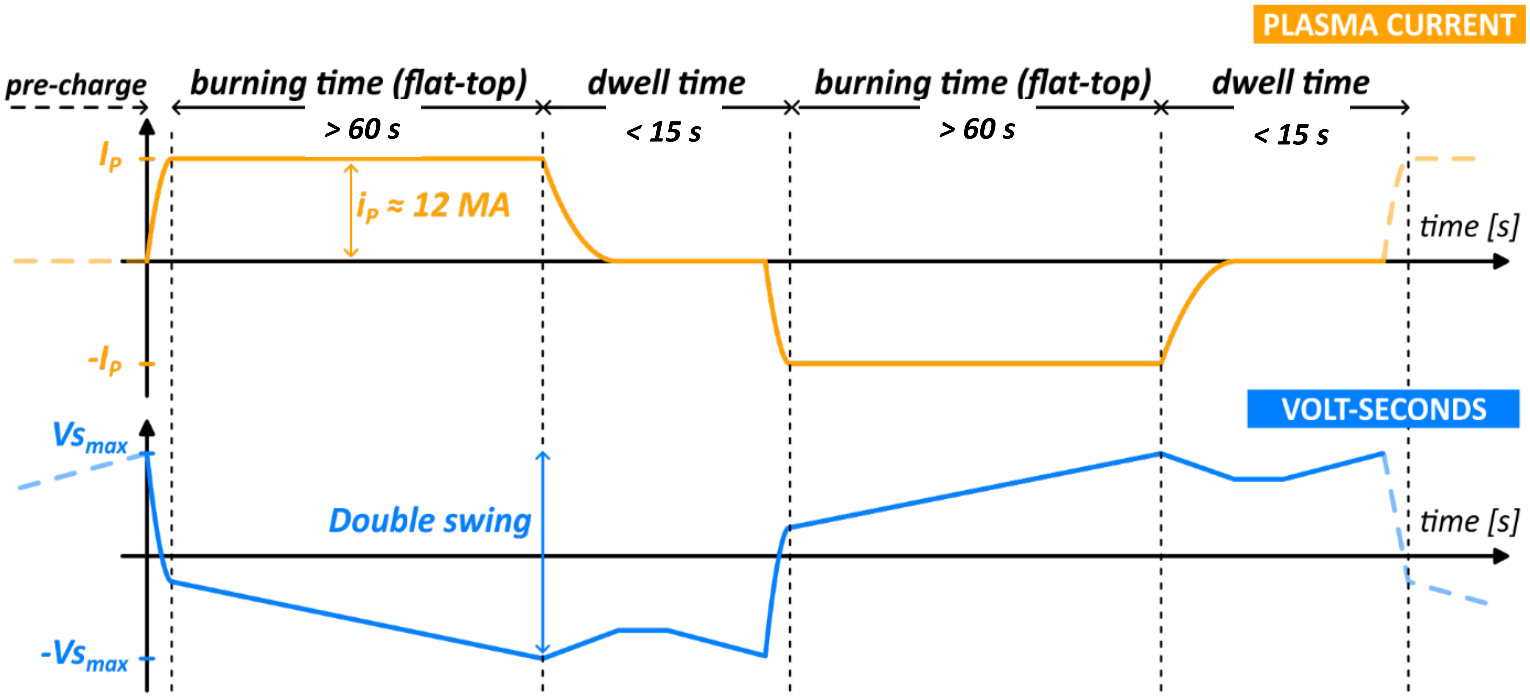
Phase 1 – Assessment of **physics issues** in a room temperature machine with reduced performances: I_p = 6-8 MA, single shot, t_{pulse}= 4-8 s, Te=4-6keV (basic plant systems)

Phase 2 – Assessment of **technological issues** up to full performances with superconducting coils: I_p = 12 MA, continuous pulsed operation, t_{pulse}= 15 s, Te=9.4 keV

Phase 3 – Operation of a pilot **experiment with D-T in a nuclear site** (shielding, Tritium systems, test beds with fissile fuel).
Neutron flux: $15\ 10^{12}$ n/s

Continuous pulsed operation

- Inductive operation can't sustain steadily the plasma current in a fusion machine.
- The RFP reactor will be operated in **double swing mode** and with continuous pulses
- **Plasma current reverses** between the pulses
- Steady state plasma current and neutron production (> 60 s) well longer the dwell time (< 15 s) in the RFP FFHR



Pilot RFP – FFHR

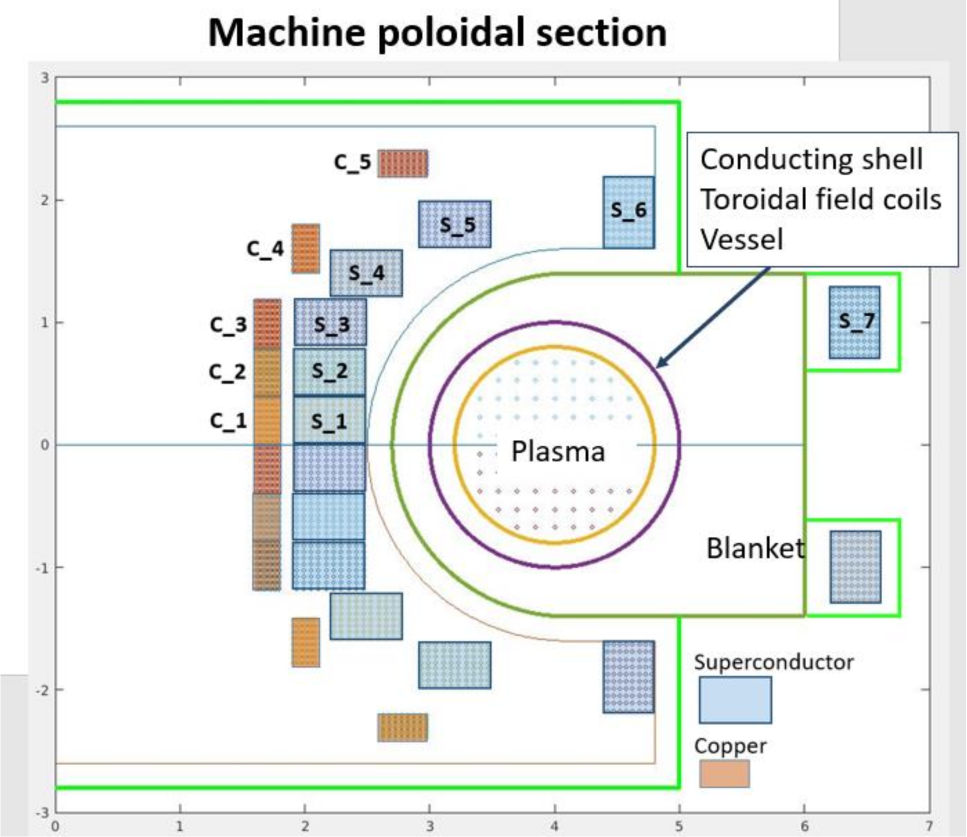
Preliminary feasibility studies

Double poloidal field coils adequate to the operation of a RFP machine

- Loop voltage >200 V during the breakdown
- Initial fast plasma current rise (20 MA/s)
- Maximum plasma current of 12 MA
- Flat-top duration > 10 s
- Flux swing about 300 Vs peak-to-peak
- Magnetic field derivative in the superconductor < 2.5 T/s

7+7 Superconducting coils
5+5 Copper coils

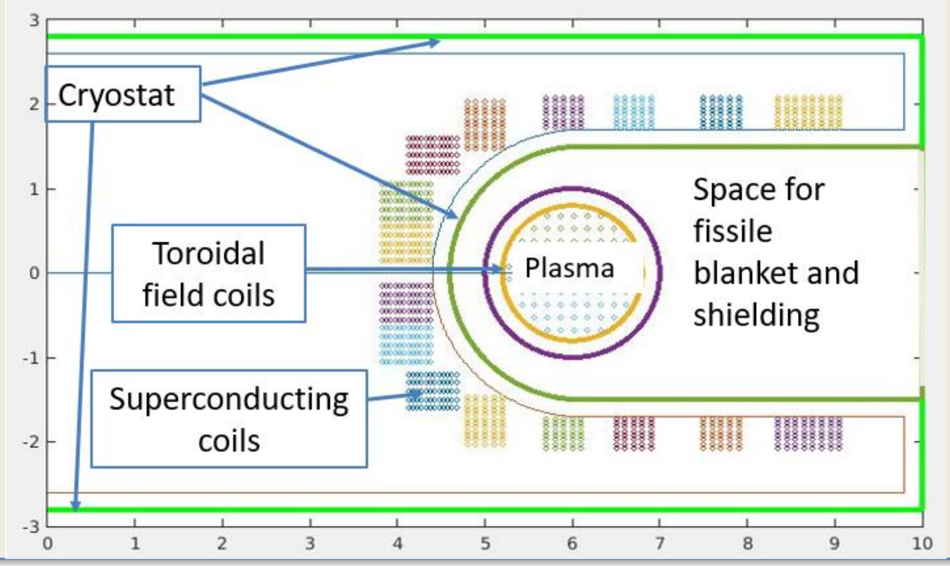
Dimensions: R=4m, a=0.8m



Tritium generation

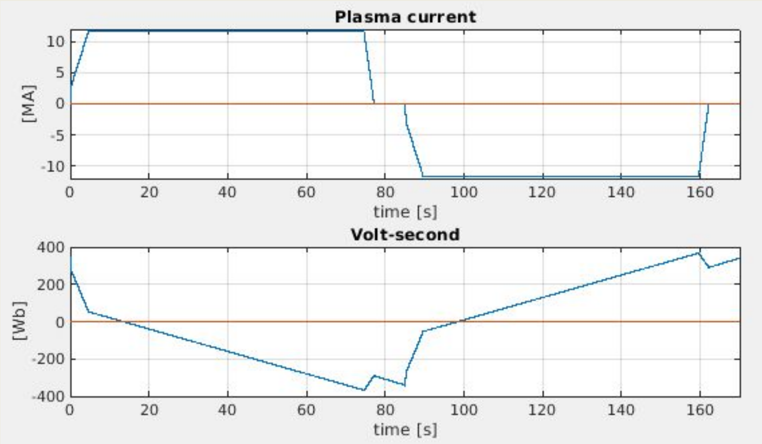
Machine section and performances

$R = 6$ m
$a = 0.8$ m
Plasma current = 11.6 MA
$T_e = 11.3$ keV
$P_{ohmic\_heating} = 70$ MW
$P_{fusion} = 108$ MW
$n = 3.8 \times 10^{19}$ neutron/s
$n_{flux} = 20 \times 10^{12}$ n/(cm²· s)



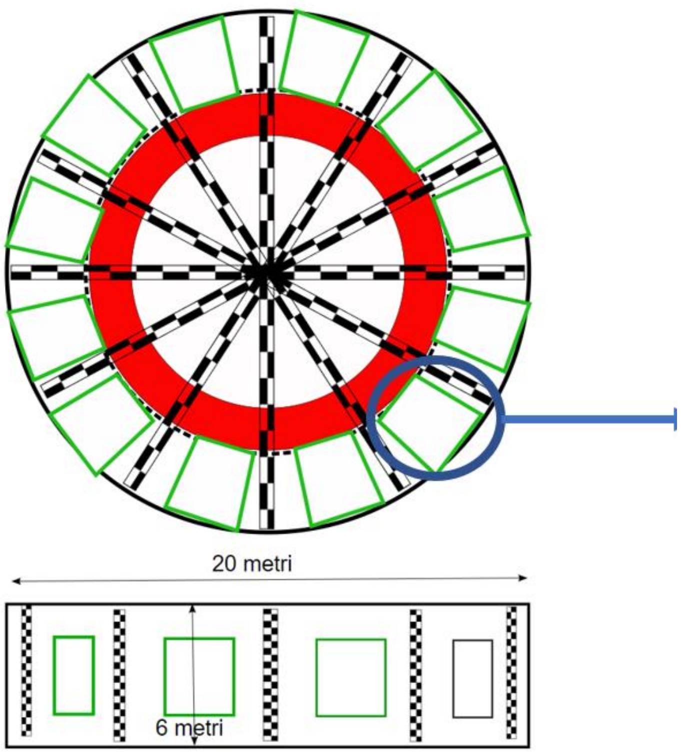
Continuous pulsed operation

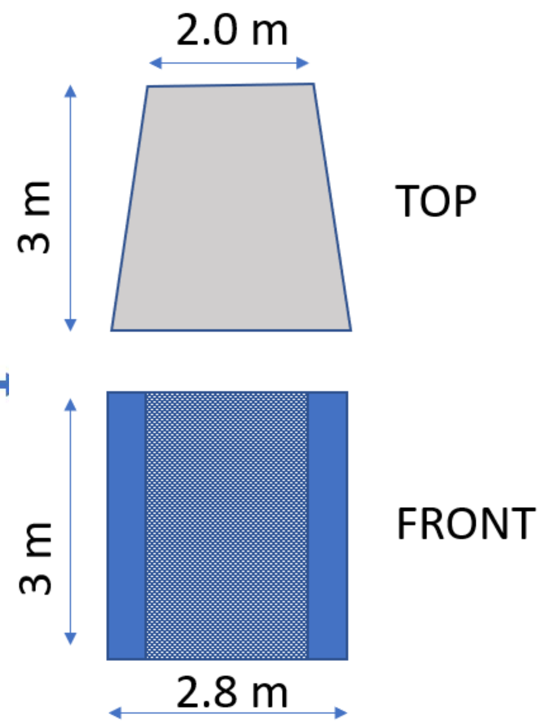
$T_{burn} = 70$ s
$T_{dwell} = 15$ s



Tritium generation

Layout and fissile blanket





- 12 fissile modules arranged around the torus
- Fissile modules completely detached from the fusion plant, easily accessible

Machine top and side views

Top and front views of the fissile module

Researchers involved in the feasibility studies are from the Institutions:

- Consorzio RFX - Padova
- ENEA-Dipartimento FSN - Frascati
- INFN, Sezione di Genova – Genova
- Università di Padova – Padova
- Dipartimento di Ingegneria Industriale, Elettronica e Meccanica, Università degli studi Roma Tre - Roma
- GeNERG, DIME, Università di Genova – Genova
- Dipartimento DIAEE, Università degli Studi di ROMA "La Sapienza " – Roma
- Aix-Marseille Université, CNRS, PIIM, UMR 7345 – Marseille (France)