DTT configurations and associated scientific/technical objectives

F. Crisanti [1,2]

[1] DTT S.C.a r.l., [2] Tuscia Univ.,

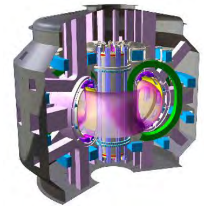
DTT - Research Plan Kick off meeting

08/07/22

Some history…

2015

2017



30th SOFT
2018

2019

Jul 17 European workshop on DTT roles and objectives -> **Eurofusion PEX-AHG**

Dec Apr – Aug 18 Cost revision committee on the “Blue Book” design

Jul 18 First Design review meeting (Eurofusion PEX-AHG recommendations)

Mar 19 European Investment Bank audit (loan approved on April ‘19)

Apr 19 DTT Interim Design Report (“Green Book”)

Apr 19 First call for tender: procurement of the superconducting strands (56,6 M€ - 200 M€ up to now)

Sep 19 The DTT consortium is established

20 – Covid It started the cooperation with W_{PEX} W_{PDIV} and W_{PIE}

Jun 21 DTT organization stepped forward: new President and a more clear structure

DTT Strategy

- **Power Exhaust identified** as a possible **Integrated Physics/technoly** show stopper in the European Road Map
- But how to face this Physical and Technological challenge?
- The Road taken by the DTT team has been to tackle the problem as an integrated Physics and Technology problem.
- Consequently the choice of the Tokamak parameters has been driven bearing in mind the integration aspects
- … **and to see DTT as a "living" facility,** capable to "evolve" to test along its life time new Physics and Technical solution

DTT Strategy

- **Within a reactor the power flowing towards the divertor plates is intrinsically very high**
- … And the more compact (and possibly cheaper) the reactor the more severe is the problem.
- The key figure parameter is P_{SEP}/R
- Obviously in a reactor P_{SEP} is connected with the produced fusion power and R is linked with machine complexity and/or cost
- Within the present technologies $P_{plates} < 20\ MW/m^2$ and $P_{SEP}/R \leq 15$ MW/m
- Energy load is too a severe problem: the discharge must last a time long enough to study this matter
- DTT parameters chosen to achieve these targets in an experiment with physics parameters as close as possible to a reactor

DTT Parameters

- **DTT parameters chosen to have the same edge and bulk dimensionless[1] parameters as close as possible to the ones of ITER and DEMO**

	P_{SOL} (MW)	λ_q (mm)	R (m)	$q_{//}$ (GW/m²)	q_{pol} (GW/m²)
ITER	~90	~2	~6	~1.8	~0.6
DEMO	~150	~1	~9	~5	~2
DTT	~30	~1.5	~2.19	~2.1	~0.7

	ITER	DEMO	DTT
R (m)	6.2	9	2.19
a (m)	2	2.9	0.7
Ip (MA)	15	19.5	5.5
B_T (T)	5.3	5.7	6
<T> (KeV)	8.5	12..7	6.2
<n> (10^{20} m^{-3})	1	0.8	1.7
β_N	1.5	2.2	1.5
ν^* (10^{-2})	2.4	1.4	2.4
ρ^* (10^{-3})	1.7	1.5	3.7
ν^*_{ped} (10^{-2})	6.2	4.5	6.3
P^*_{ped} (10^{-3})	1.6	3.3	1.3

1) Following the Lackner, Hutchinson and Zonca scalings, and confirmed by using Gyrokinetics codes

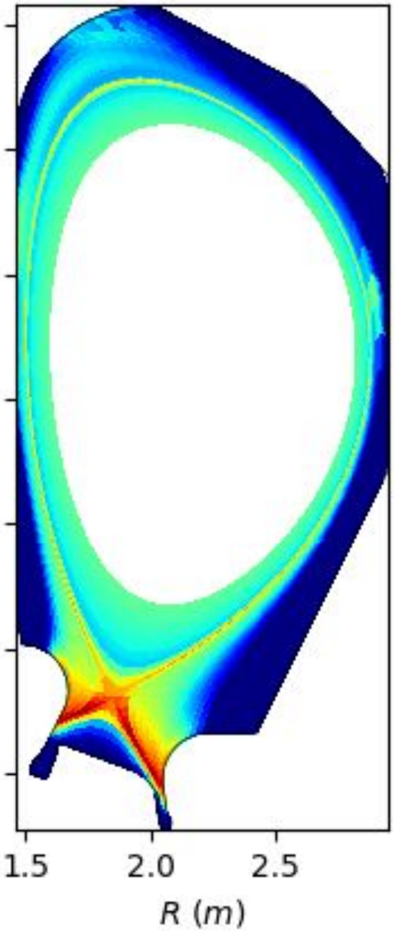
Key points… in temporal order

1) Flexibility in plasma scenarios (different divertor magnetic topologies: $XS_{(tandard)}$, $XD_{(Second\ null)}$, $N_{(egative)}T$
   a) I_p= 2 MA - B_T= 3 T; P_{add} 8-25MW
   b) I_p= 5.5 MA - B_T= 6 T; P_{add} 8-27.5MW
2) Flexibility in density (study the detachment <n>~10^{20} – 2 10^{20} m^{-3}
3) Test modules divertor tested
4) The total heating power (P_{SOL}/R - 7➔15 MW/m)
5) Flexibility in the divertor (geometry and material: open, closed, NX, Liquid metals)
6) Long discharges to face the energy load (at least ≈ 4 time the resistive time)
7) Find a solution ”without degradation” of the plasma performances

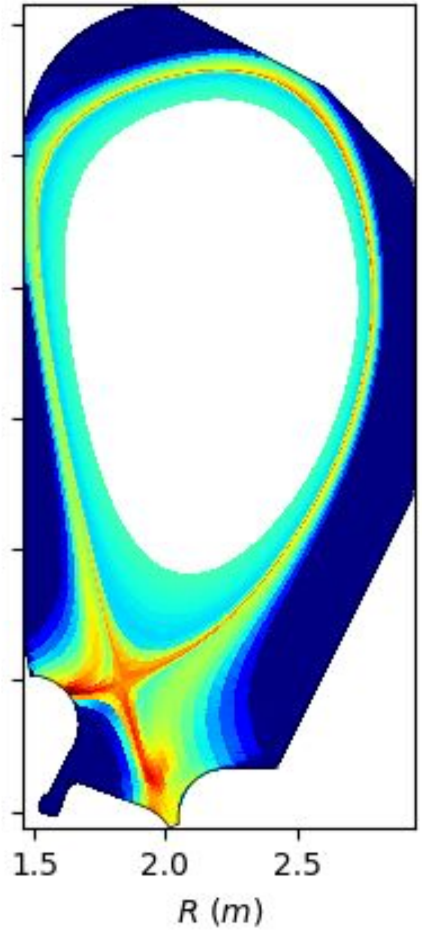
DTT experimental scenarios

Three main scenarios (in priority order) identified

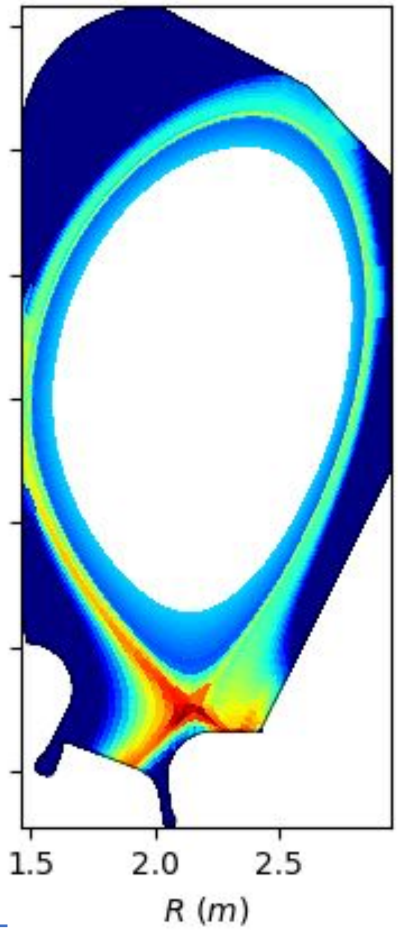
SN 5.5 MA



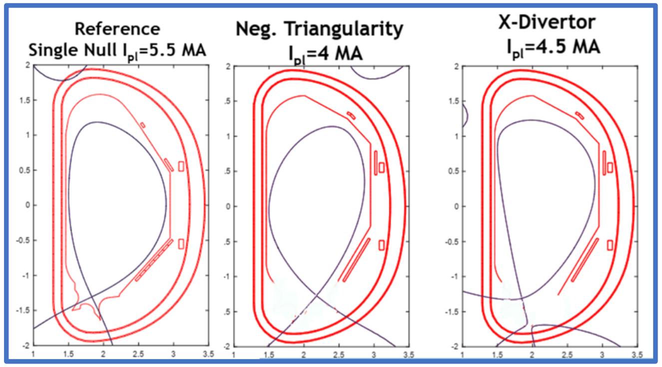
XD 4.5 MA



NT 4.0 MA

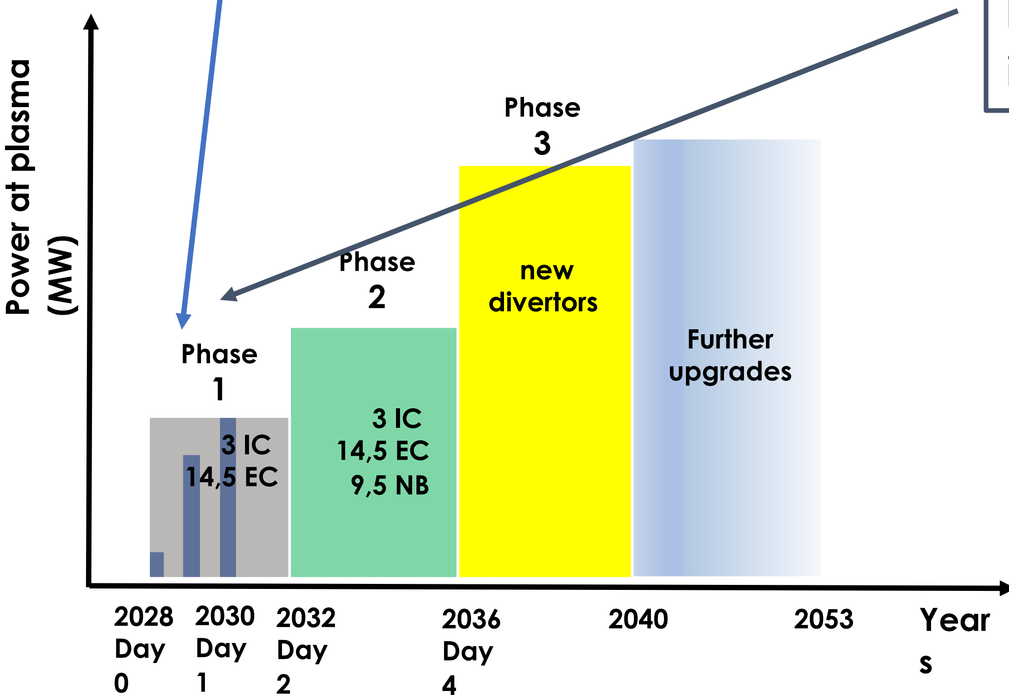


DTT experimental program

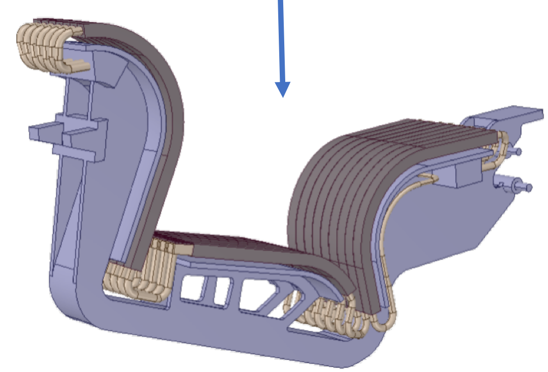


1) In the first phase all the possible plasma scenarios will be tested to identify the most promising following divertors – Day0: I_p= 2 MA - B_T= 3 T ; Day1: I_p= 5.5 MA - B_T= 6 T

The amount of additional heating power to be installed in three steps



First divertor in operation



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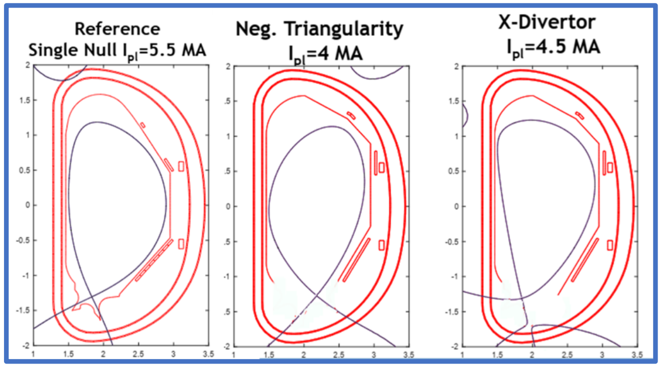

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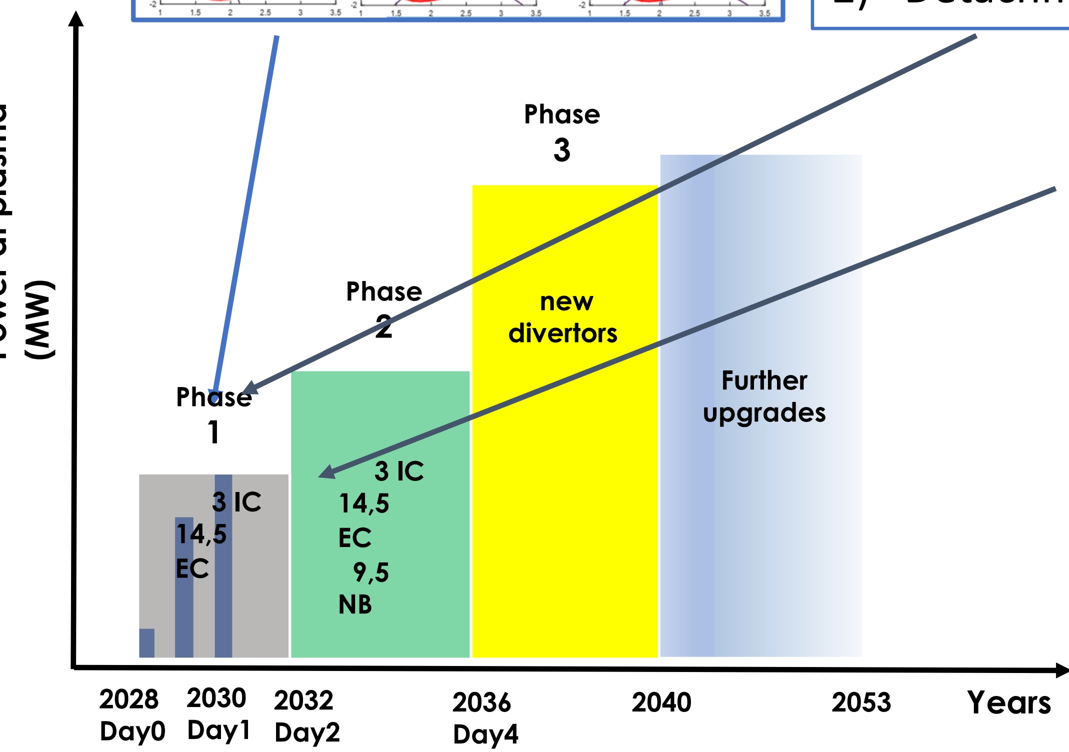
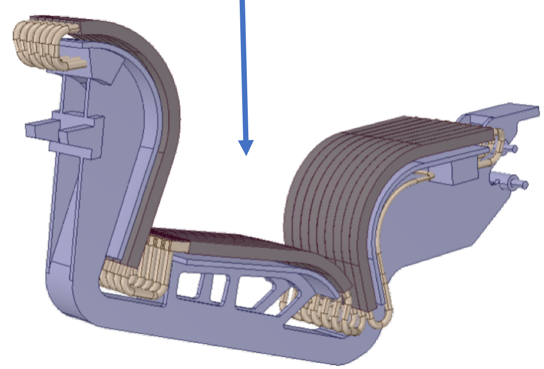
2) Detachment studies (test divertors)

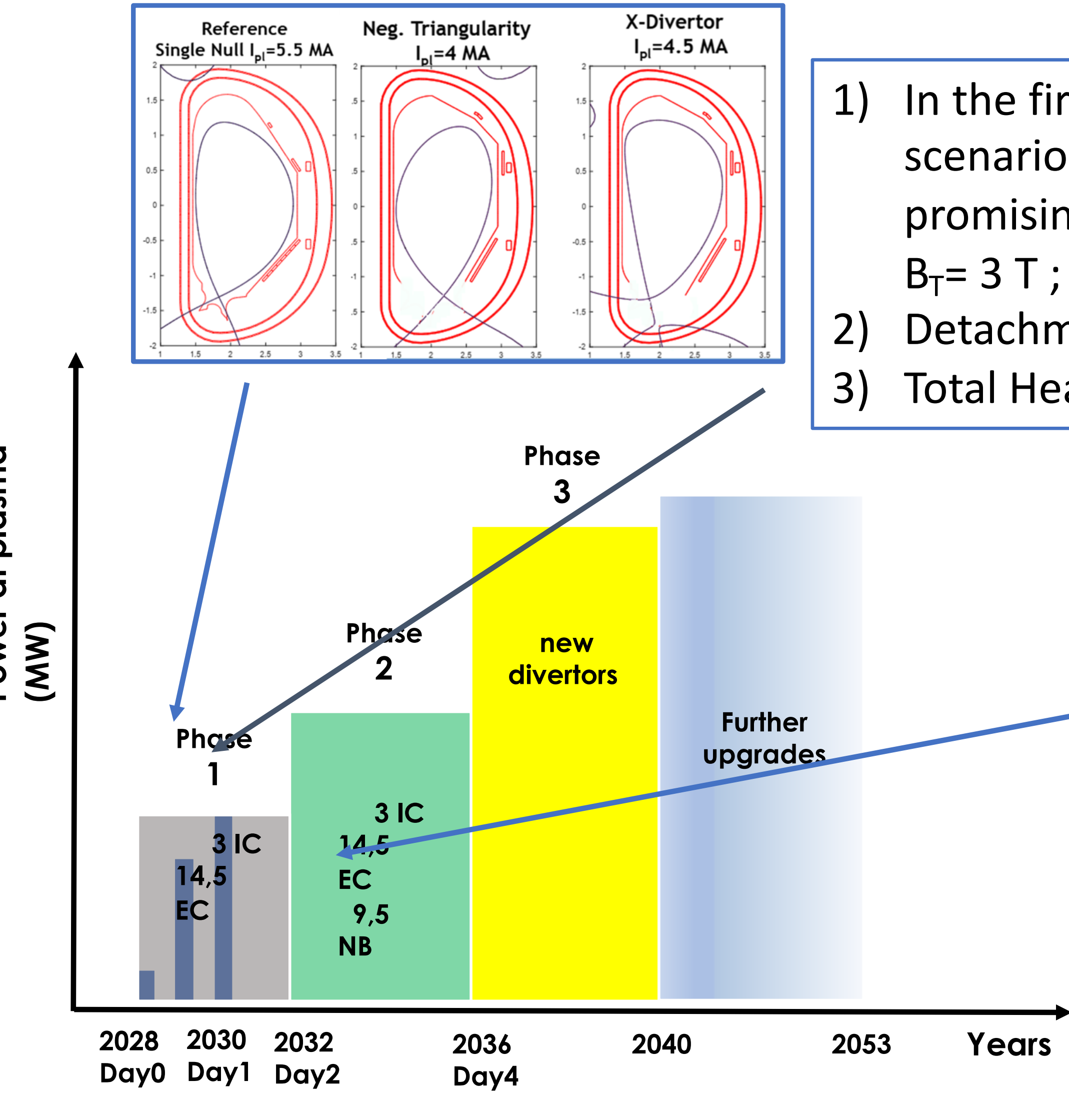


Strong Coperation with DEMO divertor program

Plus divertor test modules ?



DTT experimental program



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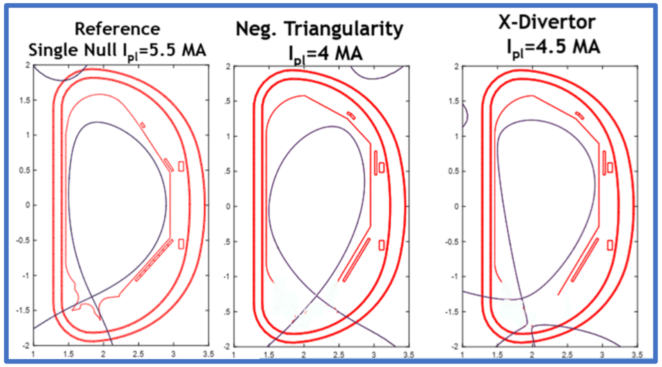
2) Detachment studies (test divertors?)
3) Total Heating

Final choice of the last heating systems

Decision to be taken within DEMO divertor program

DTT experimental program



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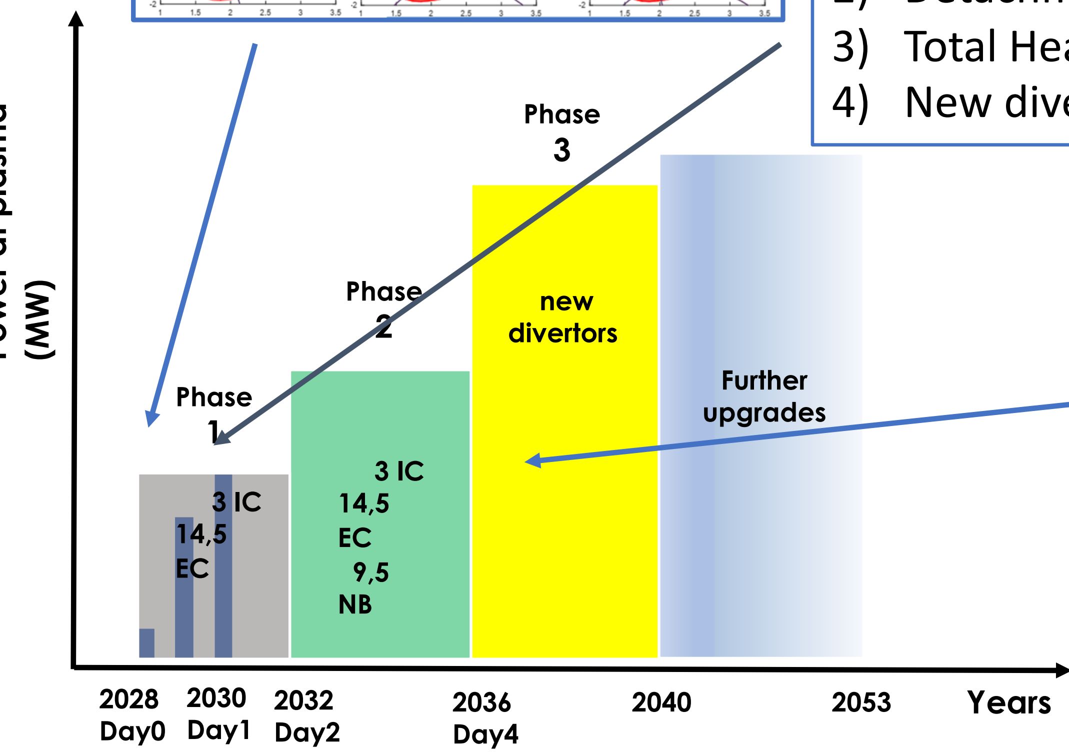
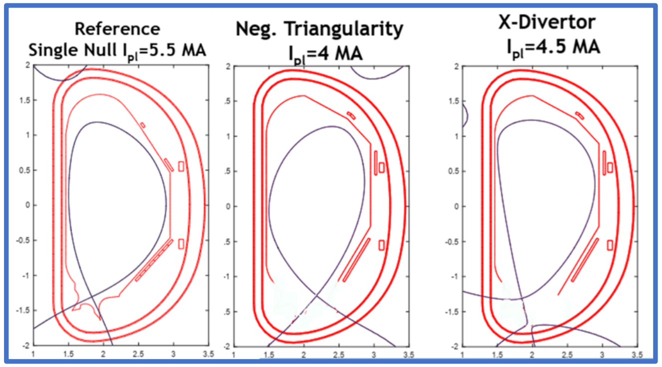
3) Total Heating
4) New divertor



New divertor?

1. Shape?
2. Double null?
3. Negative triangulariry
4. Liquid metals
5. .....

DTT experimental program



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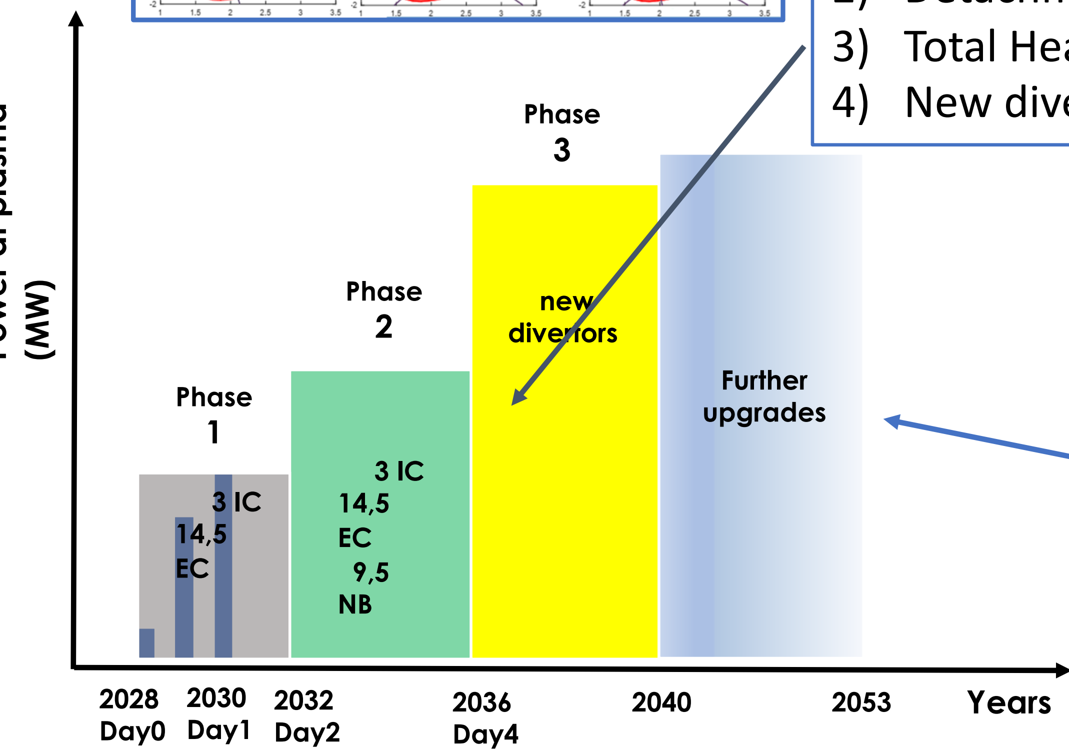


The full experimental program will run in parallel to ITER and JT60SA, consequently a strong cooperation will be mandatory among these three facilities.

In particular for DTT it will be mandatory to assist DEMO in the design of its divertor

Integrated modelling to support the DTT design

…specifically
- the design of **diagnostic systems**
- the estimate of **neutron yields**
- the assessment of **fast particle losses**
- the definition of the **heating mix**
- the design of the **neutron shields**

Integrated modelling allows us to predict **radial profiles** of:
- Te
- Ti
- ne
- J
- power depositions
- P_{rad}
- impurities…

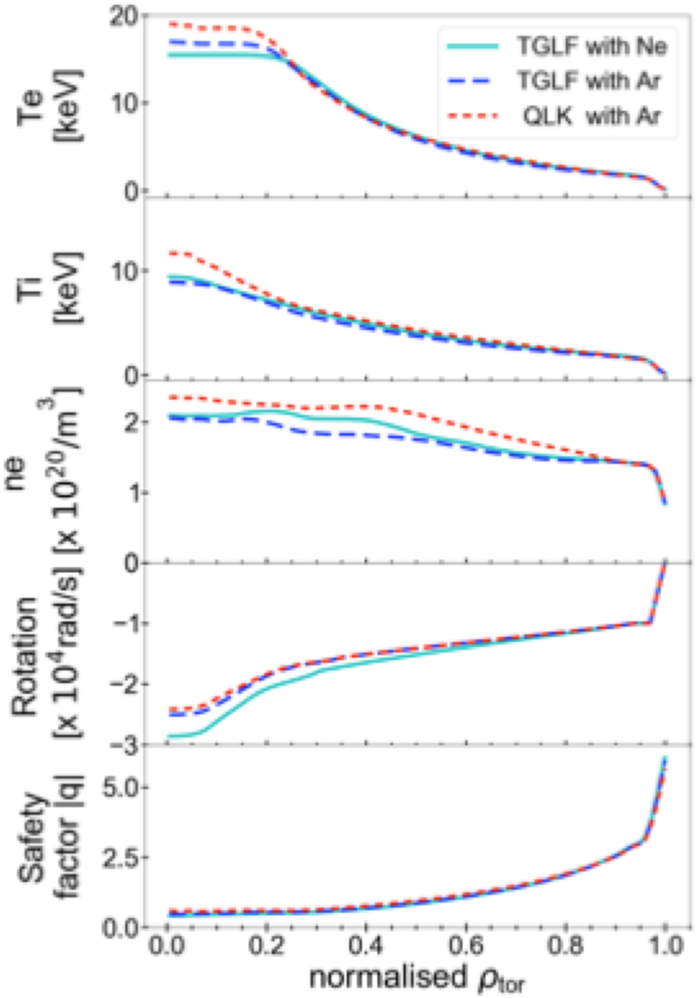
using

state-of-art modules for
- heating
- fuelling
- magnetic equilibrium

&

- **first-principle multi-channel quasi-linear (QL) transport models**

FP with PT flat-top phase



- ➔ Integration with **Scrape-Off Layer** runs
  - $n_{e,sep} = 0.8 \times 10^{20}/m^3$
  - $T_{sep} = 130$ eV
  - Ar or Ne as seeding gas
- ➔ Checked consistency between the control **coil system** capabilities and plasma profiles

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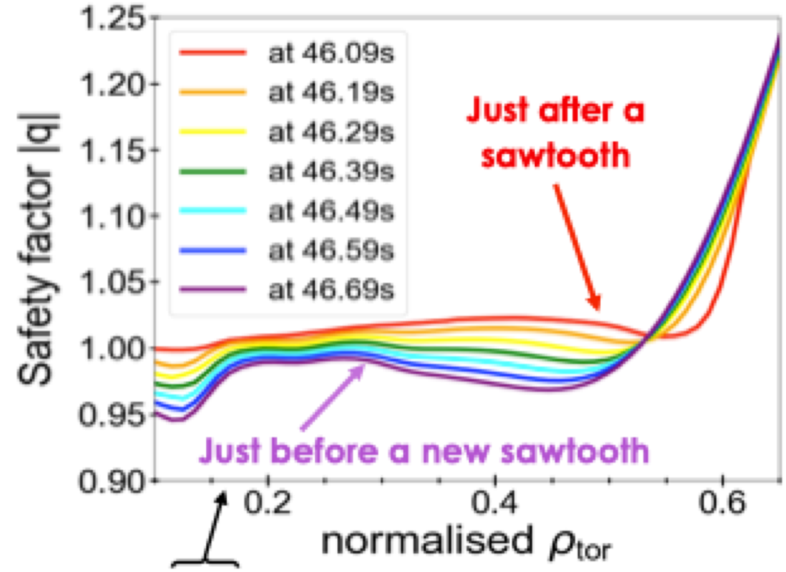
- **Good agreement** between the 2 QL models (TGLF vs QLK)
- Te>Ti over most of plasma radius
- Neutron rate $\lesssim 1.2 \times 10^{17}$ neutrons/s
- $H_{98} = 0.8\text{–}1.0$, $\tau_E = (0.41\text{–}0.45)$s, $\beta N_{tot} = 1.3\text{–}1.6$

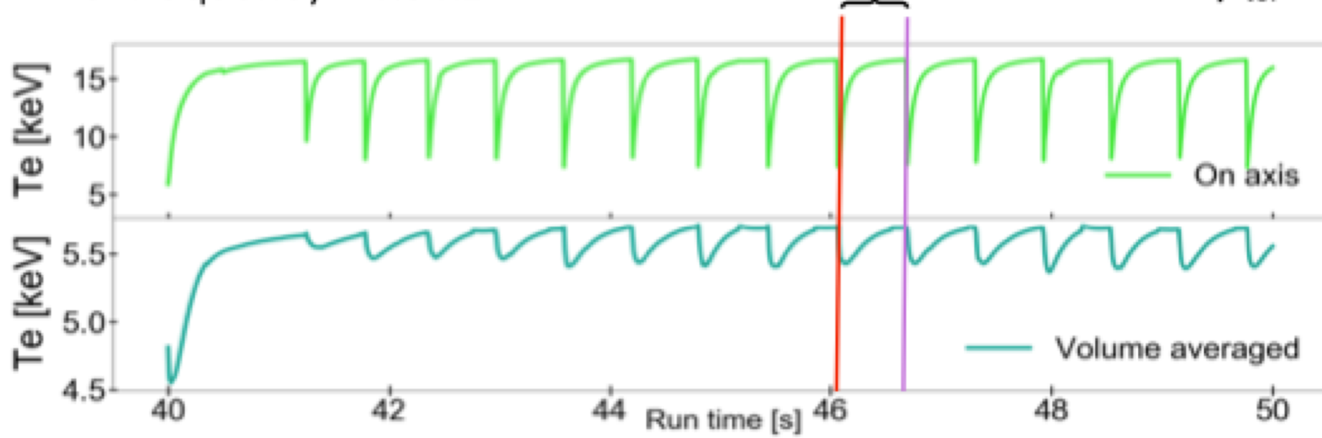
FP runs with sawteeth

We repeated simulations of the FP SN PT scenario with

- the **BgB model** as turbulent transport model
- the **Porcelli model** to trigger the sawteeth (included fast ions)
- the **Kadomtsev model** for reconnection

➔ ST frequency ≈ **1.6 Hz**

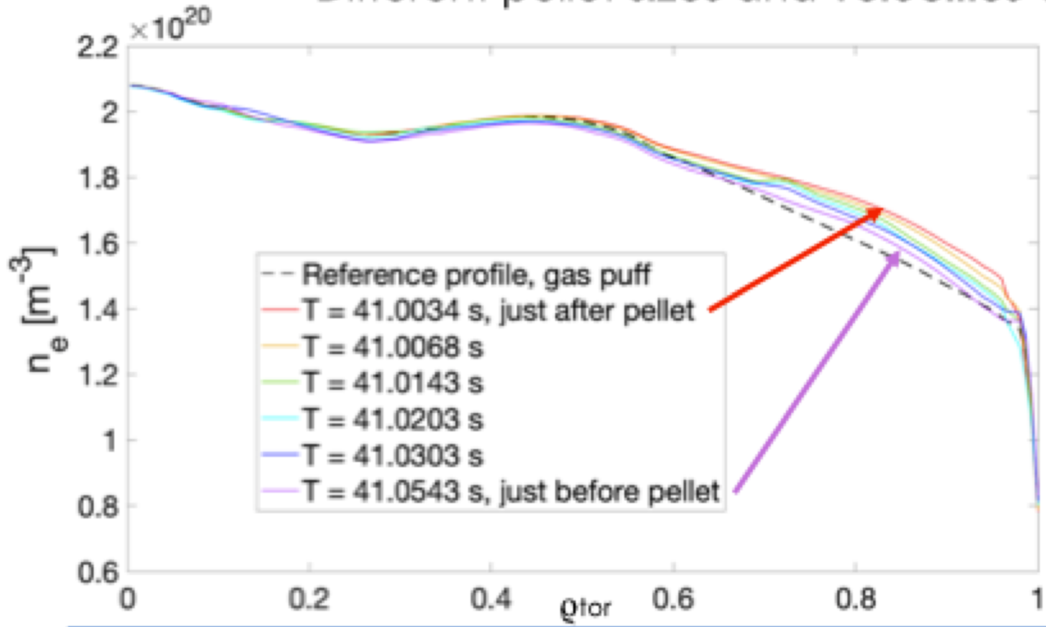




FP scenario fuelled with D pellets

- Fuelling via only gas puffing is unfeasible
  (required neutral flux ~1.3 x 10^{22} particles/s @ separatrix, i.e. gas puffing ~0.9 x 10^{23} particles/s)

- **Fuelling via pellets**
  - pellets modelled by **HPI2**, turbulent transport calculated by **QLK**
  - DTT pellet launcher from **OHFS**
  - Different pellet **sizes** and **velocities** were tested



To sustain a density pedestal of $1.4 \times 10^{20}/m^3$:

- pellet injection frequency of **20 Hz**
- pellet radius of **1 mm**
- pellet velocity of **516 m/s**

main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer

Key issue towards fusion reactors

Compatibility of heat exhaust solutions with good plasma confinement

Actions to mitigate exhaust in general have a negative effect on core performance:

- Increase ne_sep for detachment → approach Grw limit → confinement deterioration
- Impurity seeding → fuel dilution
- ELM mitigation → degraded pedestal

ITER, DEMO: low field devices, large minor radius, low nGrw

→ They operate always near Grw limit

DTT: high field device, small minor radius, high nGrw

→ Large flexibility of operating at various Grw fractions to study effect of edge on core

→ At B_T=3T/Ip=2 MA DTT becomes a low B_T device like ITER and DEMO, and we can compare the two configurations in the same device

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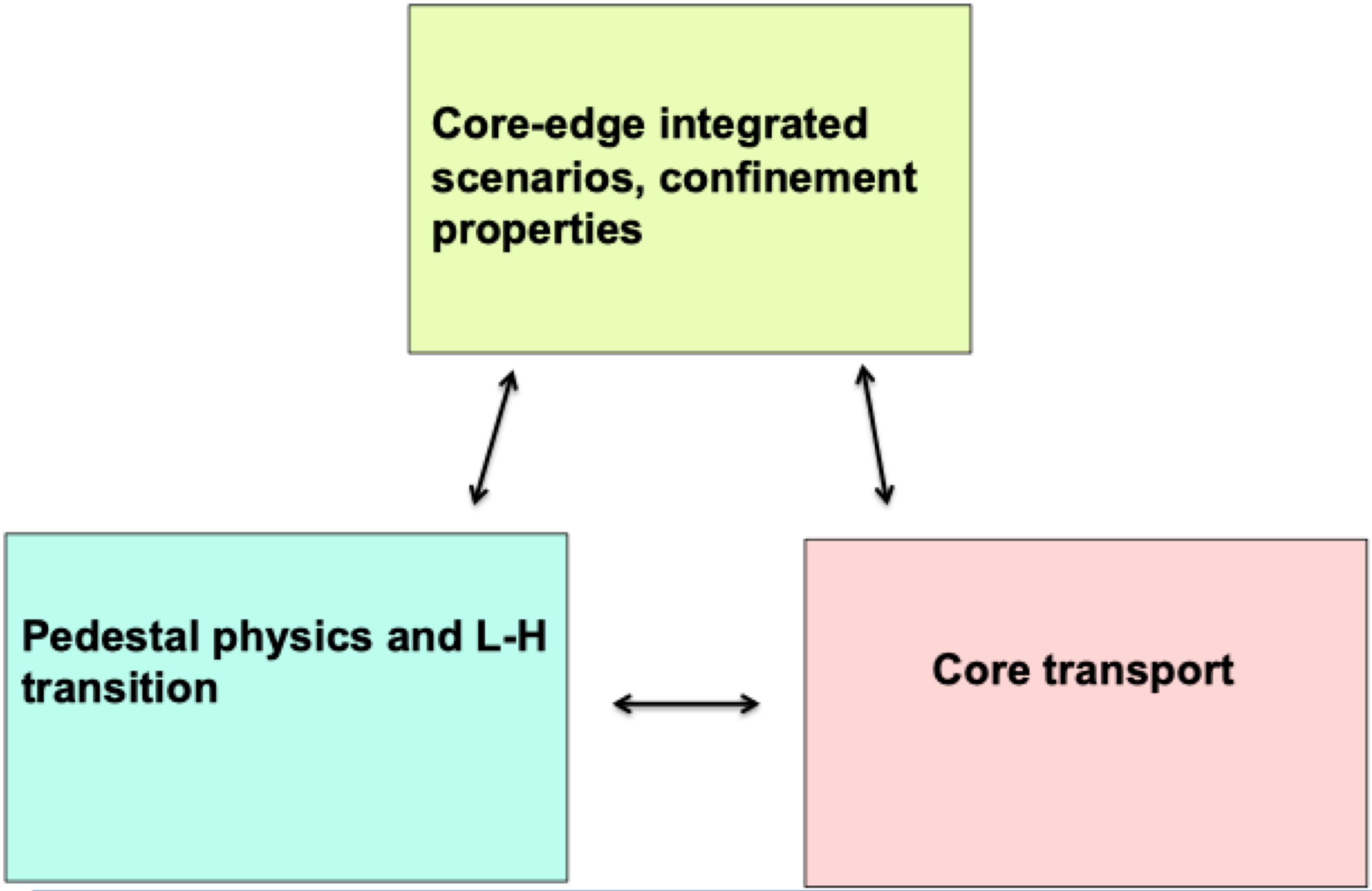
main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer



main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer

Core-edge integrated scenarios, confinement properties

- Regimes with no ELMs or small ELMs, EDA, QCE, I-mode, negative δ
- Impurity seeded detached scenarios at ITER- and DEMO-relevant values of ν^*, ρ^* and β with ITER- and DEMO-like plasma shape (δ~0.5)
- Effects of Grw fractions on edge and core transport
- Plasmas with high density but low collisionality
- Impurity control
- At low B_T and I_p, study of advanced tokamak and Hybrid regimes and of their compatibility with power exhaust solutions

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main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer

Core-edge integrated scenarios, confinement properties

Pedestal physics and L-H transition

- Pedestal physics beyond MHD peeling-ballooning
- H-mode threshold in different gas, effects of divertor and impurity seeding on threshold and pedestal
- Physics of fuelling by gas puff and pellet injection (impact on L-H transition, pedestal and confinement)
- High density and low collisionality
- Effects of high shaping δ~0.5

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(8th July)
18

main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer

Core-edge integrated scenarios, confinement properties

Pedestal physics and L-H transition

Core transport

- Transport in plasmas with dominant electron heating and low torque
- Density peaking at negligible core NBI particle sources
- Ion stiffness mitigation strategies
- Turbulence diagnostics, model validation

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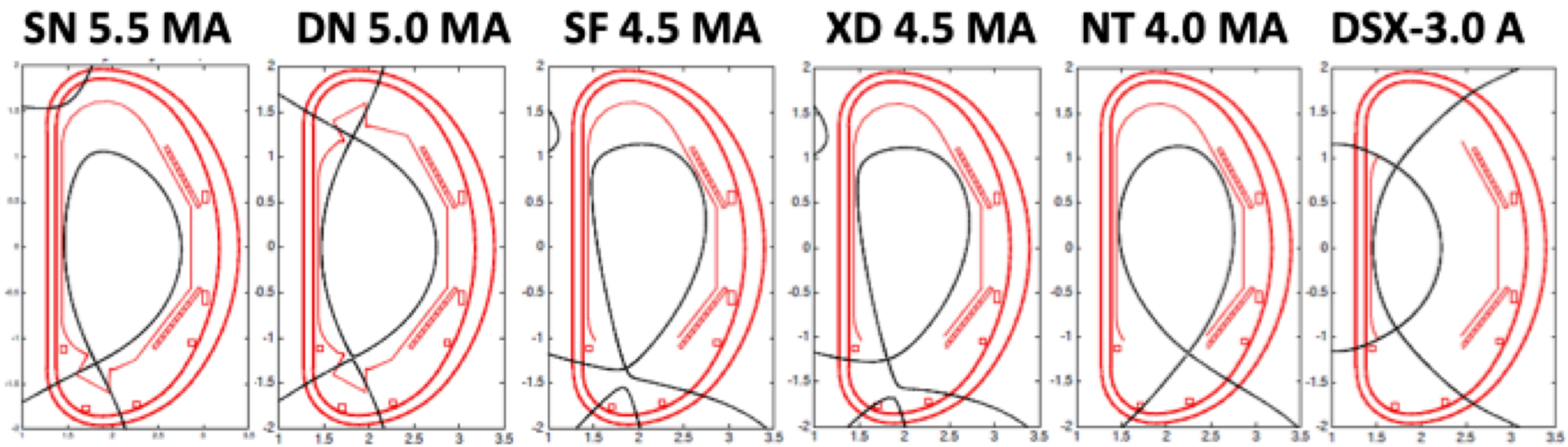
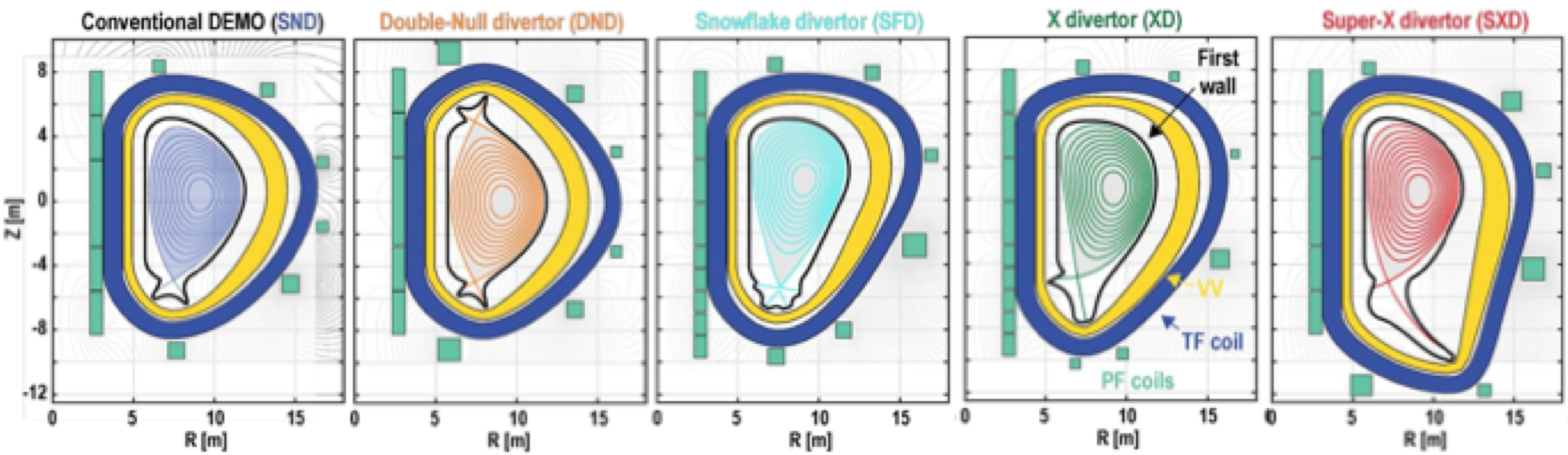
DTT as a step towards DEMO

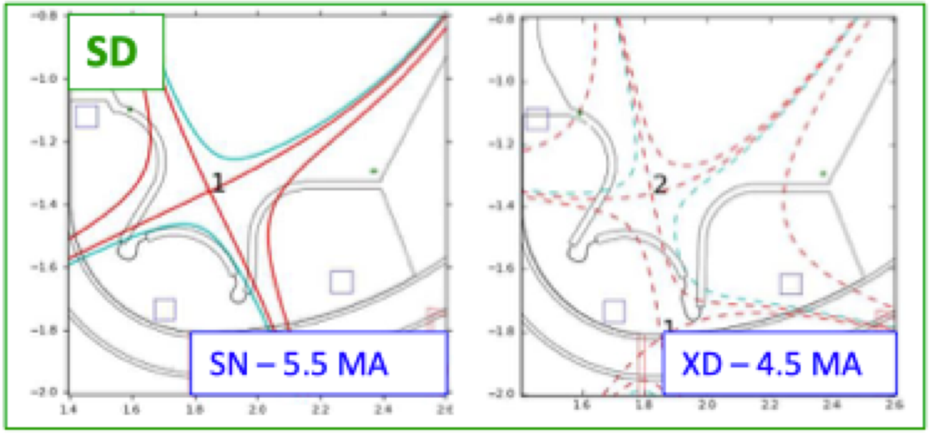




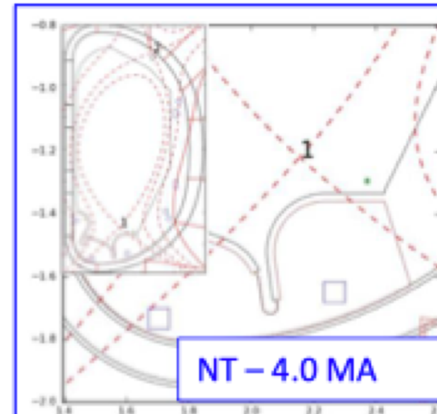
DTT can test all foreseen ADCs DEMO configurations

A set of small internal coils will allow **playing with local magnetic topology**

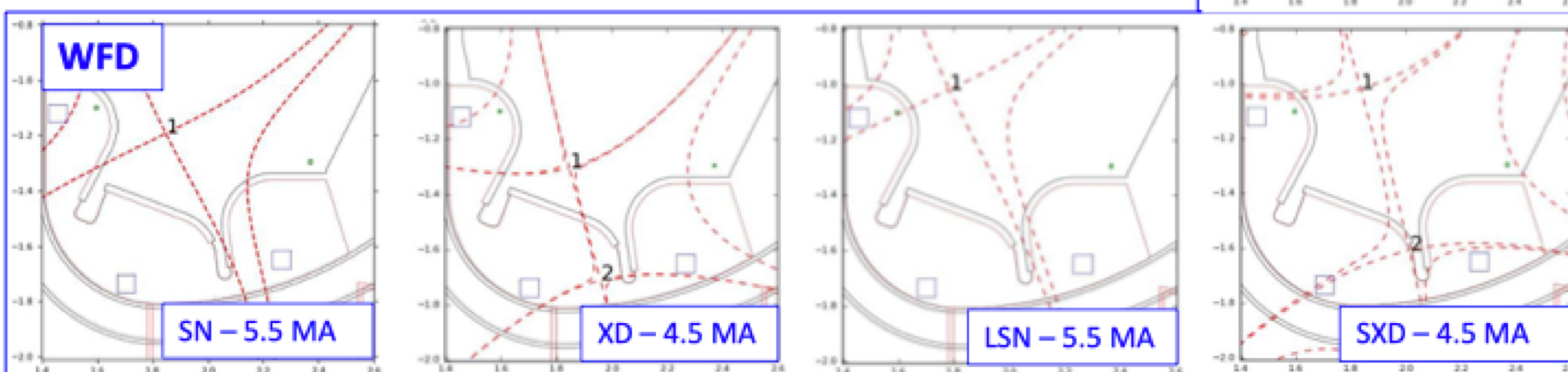
Compatibility with different configurations



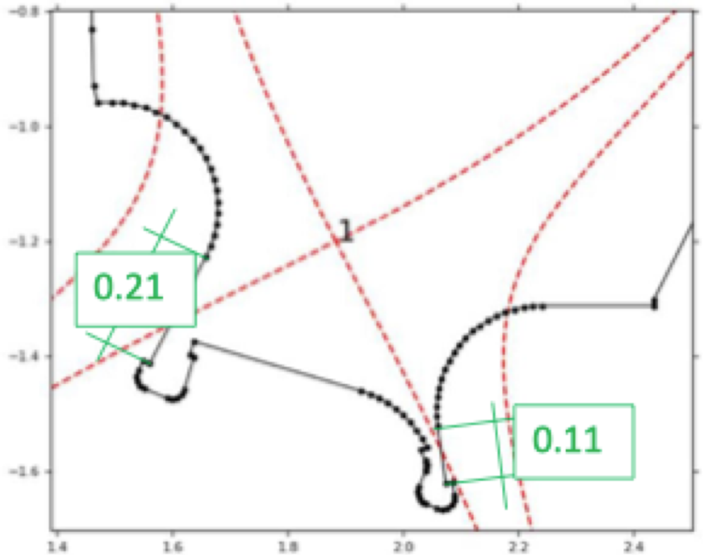
A set of magnetic configurations have been produced for all divertor shapes using coils external to the vessel



- **The SD has divertor parameters similar to present DEMO design**
- **The WFD allows configurations with long external legs (LSN & SXD)**
- **The WFD with an appropriate wall allows negative triangularity configurations**



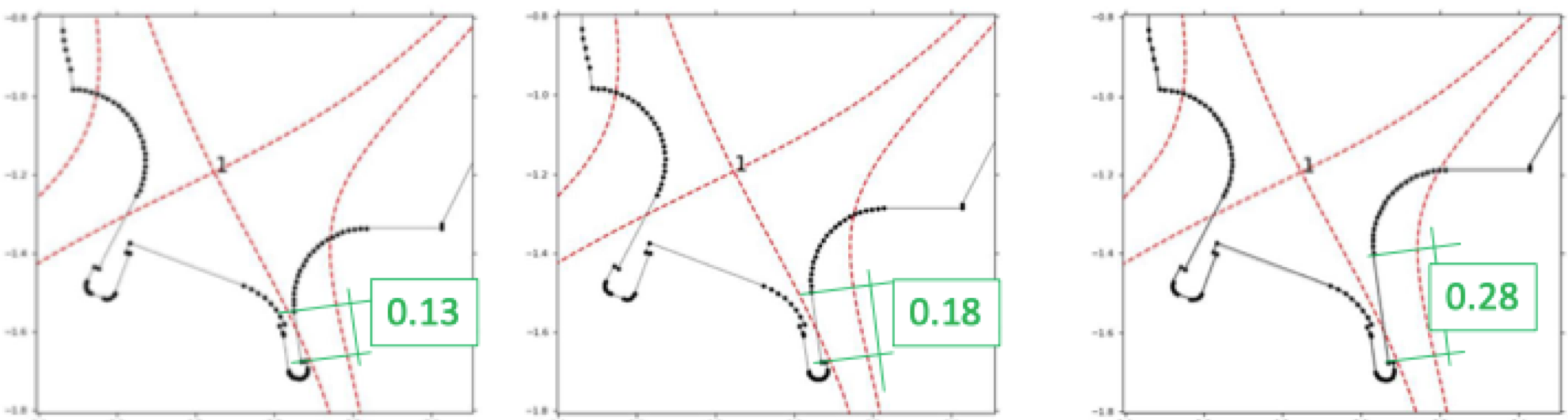
Divertor optimization – outer target length



External target is very short

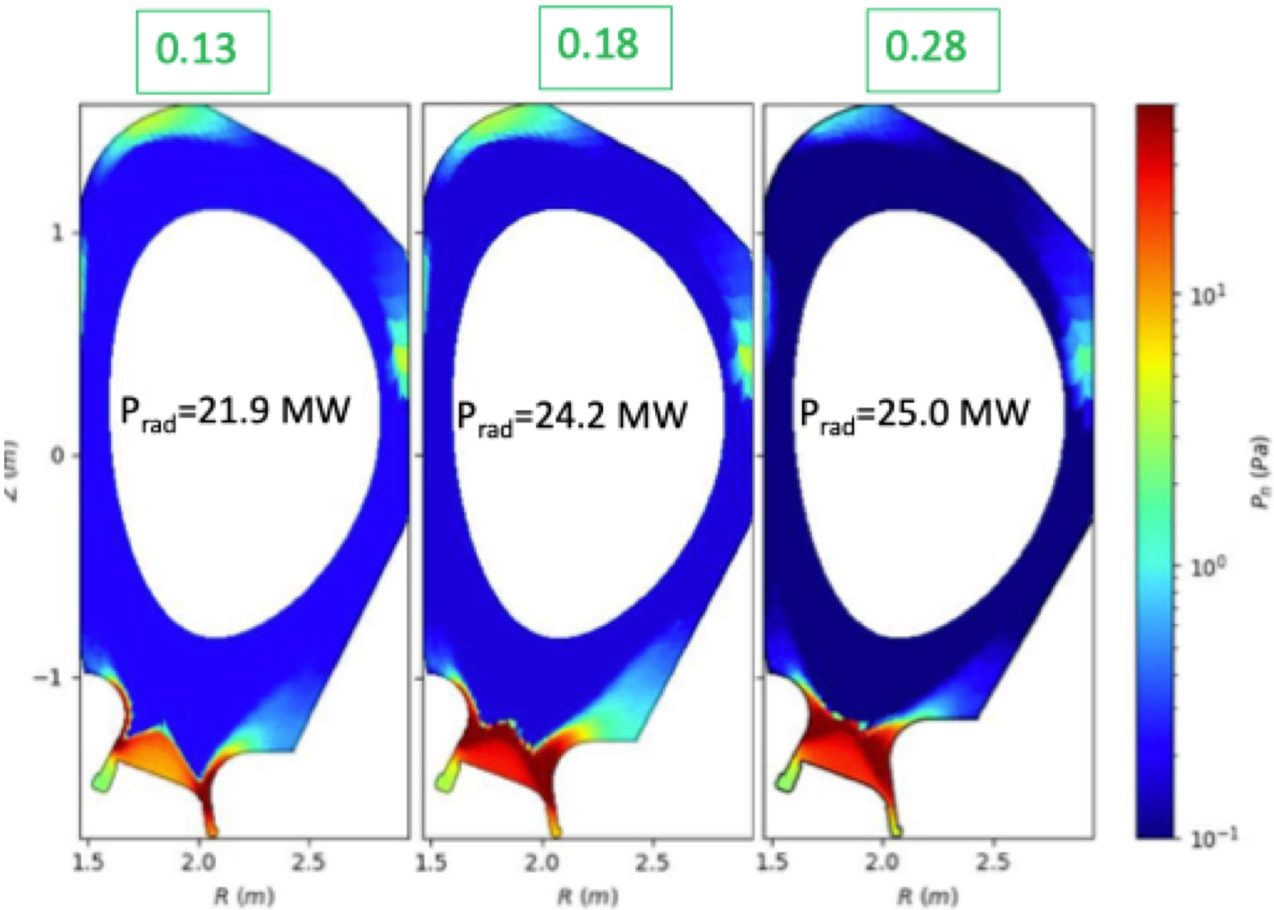
- This reduce maximum sweeping amplitude
- Reduces divertor neutrals closure
  - In SN partially compensated by pumping slot
  - Less in XD & SXD
- But it allows NT @ up to 4.5 MA

➢ Three different divertors have been considered to asses the effect outer target length:
Starting from **old** reference one it has been increased by 5 and 15 cm



Divertor optimization – outer target length

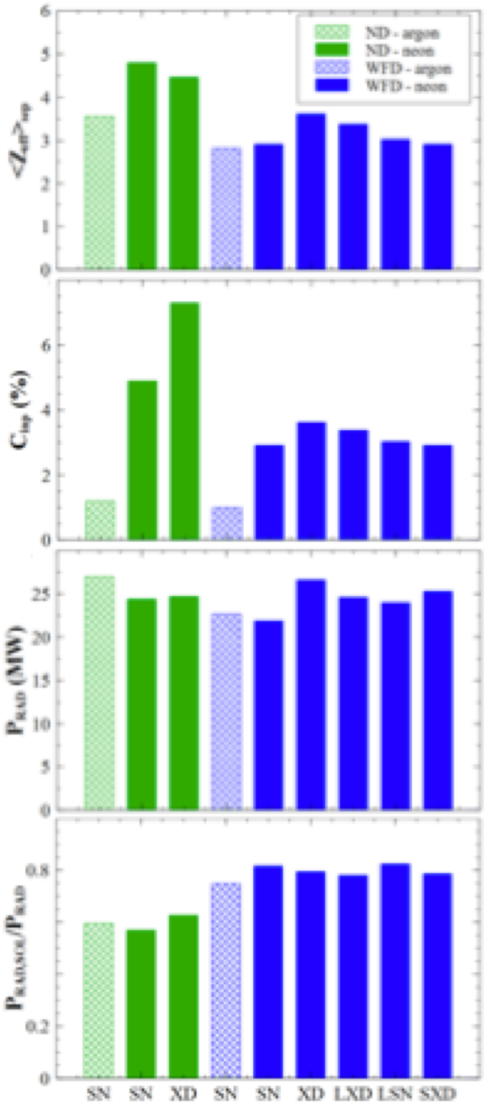
SN comparison with Seeding



At full power & fixed separatrix density n_{sep}=8·10^{19} m^{-3} with neon seeding

- Same result for L=13 & 18 cm
- **At L=28 full detachment has be achieved ➔strong decrease of requested puffing**
- But result could mostly related to small differences in P_{rad} ➔different detachment

Comparison with seeding



Full power modeling with P_{IB}=30 MW at fixed separatrix density $n_{sep}=8\cdot10^{9}$ m^{-3} with neon (and argon) seeding to achieve detachement

- **The wide flat divertor performs better than the standard divertor in SN and XD**
- Argon performs better than neon in terms of $\langle Z_{eff}\rangle_{sep}$ and impurity concentration (C_{imp}) for both divertors
- **In the wide flat divertor SXD provides similar result than SN**
- **The wide flat divertor performs relatively well for all configurations**

Shape selection conclusions

- A divertor shape able to accept many magnetic divertor configurations has been studied and optimized by the edge code SOLEDGE2D
- The Wide Flat Divertor provides better exhaust performance than a standard narrow divertor for a wide range of configurations
- The selected Wide Flat Divertor can provide reliable operations for SN and XD configurations in pure deuterium at reduced power and at full power with impurity seeding
- The better performances of the Wide Flat Divertor seem related the bigger radiating volume and the better target to leg angle in the standard SN configuration

DTT Research Plan Team

Expert Groups	RO	Institute	Applications
EG-1: DTT scientific exploitation strategy	Flavio Crisanti	DTT / Univ. Tuscia	10 + all the RO
	Piero Martin	RFX / Univ. Padova	
	Gerardo Giruzzi	CEA	
EG-2: Divertor and SOL physics	Marco Wischmeier	IPP/Garching	19
	Emmanuelle Tsitrone	CEA	
	Paolo Innocente	Consorzio RFX	
EG-3: Plasma scenarios and associated modelling	Paola Mantica	CNR/ISTP Milano	17
	Clemente Angioni	IPP/Garching	
EG-4: Heating, current drive and fuelling	Carlo Sozzi	CNR/ISTP Milano	13
	Pietro Vincenzi	Consorzio RFX	
	Dirk Van Eester	FZ-Juelich	
EG-5: MHD and fast particles, theory	Gregorio Vlad	ENEA	16
	Eric Nardon	CEA	
EG-6: Fusion technology developments	Sebastijan Brezinsek	FZJ	19
	Christian Day	KIT	
	Giacomo Dose	Univ. Roma Tor Vergata	

Eventually the participation call was quite successful… even thinking that the work is on a "voluntary basis"

CEA	AMU	EPFL	IPP	FZJ	KIT	NCSRD	ERM /KMS	Univ. Tor Vergata	Univ. Tuscia	CNR/ ISTP	Univ. Milano Bicocca	Polit. Torino	CREATE	ENEA	RFX
24	3	3	4	9	1	2	1	1	1	9	4	3	1	10	15

Total number of submissions	91
Italian / non Italian	44/47
Countries	6
Total number of Institutes	16
Non Italian Institutes	8

- Two remote meetings with all the RO have been done in October
- First meeting in person of all the RO planned in Frascati next 16-17/11
- Mean time all the RO have contacted the group people, consequently they will arrive with some proposal of the activities
- The target of the meeting is to homogenize all these proposals and to come out with a coherent activity plan
- A very first preliminary document should/could be worked out for the European facilities review during spring 2023

"SUMMARY"

1) Flexibility is the most important key point in DTT
2) DTT is a facility designed to tackle the integrated Physics and Technology power exhaust problems
3) Within the Physics the fundamental point is the integration between the edge and the bulk plasma with no dimensional parameters meaningful for a reactor
4) In doing this DTT will support all the future big experiments (ITER…)
5) MUST work in parallel with (and possibly drive) the DEMO design evolution
6) **DTT aims to be a facility worlwide open**