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Divertor Tokamak Test Facility: Science Basis and Status of the Project

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The new Divertor Tokamak Test facility has taken off. DTT [ ] (Fig.1) is a superconducting tokamak with 6 T on-axis maximum toroidal magnetic field carrying plasma current up to 5.5 MA in pulses with total length up to 100 s. The D-shaped device is up-down symmetric, with major radius R=2.14 m, minor radius a=0.65 m and average triangularity 0.3. The auxiliary heating power coupled to the plasma at maximum performance is 45 MW, which allows matching the PSEP/R values with those of ITER and DEMO, where PSEP is the power flowing through the last closed magnetic surface. DTT is a divertor facility, i.e. it is designed to accommodate a variety of divertor configurations both in single and double null scenarios. In addition to this primary mission dedicated to plasma exhaust in regimes where plasma core and edge behaviors are integrated, DTT will provide a facility for high performance tokamak physics and to address core confinement and stability issues also in negative triangularity configurations, and the management of transient events like disruptions and ELMs. In the last eighteen months the design has progressed steadily, the legal entity for the DTT construction has been established, the 250 M€ loan from the European Bank of Investment given within the EU Juncker Plan has been activated, the first large procurement (superconducting strand) has been assigned, a strong scientific and managerial partnership with the Eni energy company has been established and the team is growing.

Progress in the engineering design. Advances in the design regarded the integration of machine components inside and outside the cryostat. The AISI 316L(N) vacuum vessel is segmented in 18 sectors, each with 5 access ports. The first wall is made by sprayed tungsten plasma facing units mounted on back structural supports that provide connection to the vessel and mechanical resistance against electromagnetic loads. The bulk tungsten single null divertor is made by 54 cassettes and is fully maintainable through remote handling. DTT will be equipped with 18 Toroidal Field (TF) modules, each made of a winding pack inserted in AISI 316L(N) casings. Each pack is made by cable-in-conduit Nb3Sn conductors operating at 43.5 kA with 12 T maximum magnetic field. The superconducting central solenoid and the poloidal field magnet system are supported by the TF magnet (total weight of the superconducting magnets to 440 tons). A layer-wound approach for the central solenoid is chosen and validated. The design of pre-compression bars and of support structures connected to the TF magnet is completed, together with the supports, inner joints and terminations of poloidal field magnets. The whole magnet system is enclosed in a thermal shield attached to the TF magnet. All interfaces are now well defined.

Heating The heating systems will be installed in two stages: a day-1 configuration with 24 MW coupled power and a second step to reach 45 MW. In the first stage 16 MW of ECH power, 3 MW of ICH and one 7.5 MW NNBI injector will be installed. The 170 GHz EC system is designed for a strong power localization and profile control, using fully independent front-steering antennas. ICRH (60-90 MHz) will be based on an antenna with 3.5 MW/m2 power density, shaped to fit the scrape-off layer and with an adjustable radial position and external matching. The NNBI is based on RF plasma sources capable to produce negative ion current of 40A accelerated up to 400-450 keV.

Physics Scenarios. The integrated modeling of DTT plasmas [ ] has been carried out with the JINTRAC suite of codes and covers the region inside the separatrix, calculating the pedestal pressure with EPED1 (Europed code) and fixing the pedestal density to achieve a volume averaged density ~ 0.43 nGW (normalized to Greenwald density). Heating is modeled self-consistently. The region inside the top of the pedestal is modeled with QuaLiKiz or TGLF quasilinear transport models and with NCLASS or NEO for neoclassical transport. Fig. 2 shows profiles obtained for the SN full power H-mode scenario with 32 MW ECRH, 15 MW NBI and 3 MW ICRH using QuaLiKiz for turbulent transport, which is mainly driven by ion-scale ITG/TEM. Core Te peaks at values above Ti due to strong central ECRH and stiff ion heat transport. Density profile is moderately peaked with central density ~ 2⊠1020m-3. The peaked rotation profile with core value of 50 krad/s does not provide significant E⊠B stabilization of ion heat transport. Global plasma parameters for this scenario are βN=1.6, τE=0.28 s, total DD neutron rate ~1.4⊠1017 s-1 (30% thermal). Total radiation is 15 MW. The integrated modeling results are also validated against gyrokinetic simulations, to corroborate the validity of the quasi-linear models in the particular case of DTT.

One crucial issue for the DTT integrated physics approach, based on a proper weak similarity scaling to preserve the spatio-temporal scale hierarchy relevant to ITER/DEMO, is the role of energetic particles (EP) as mediators of cross-scale couplings [ ]. EP transport is a multi-scale process requiring a self-consistent, kinetic, treatment. Extending first-principle-based gyrokinetic simulations to transport time scales is a formidable task. This makes predictive analyses very challenging and calls for reduced descriptions which preserve the necessary physics ingredients. The paper will discuss how DTT is crucial for the validation of such reduced

transport models.
Fast-ion losses due to trapped-precession resonance are estimated with the code ORBIT. Initial ion positions and pitch are calculated with METIS, using a full heating scenario and the geometry of the 400 keV NNBI. The LFS magnetic ripple of the reference SN scenario (δB⁄B~0.42%) gives a small contribution, with up to 0.5% collisionless particle loss in the first ~1000 toroidal transits.
DTT MHD stability will be discussed. Stability of Alfvénic modes driven by energetic particles will be considered using hybrid MHD-Gyrokinetics simulations.
DTT is being designed with a high level of flexibility, in particular as far as divertor scenarios are concerned. From a magnetic point of view the external and internal coils allow to control and optimize the local magnetic configuration in the vicinity of the divertor target [ ]. The reference single null, double null and snowflake configurations can be produced at (or close to) the maximum current of 5.5 MA. A noticeable feature of DTT is that it allows for negative triangularity scenarios with proper divertor. Figure 3 shows a 5 MA single null scenario with δ=⊠0.13 and δlower=⊠0.16 and a double null at 3.5 MA with δ=⊠0.38.
Preliminary 2D edge fluid-kinetic modelling of power exhaust is being done both in pure deuterium and with argon and neon seeding. In pure deuterium detachment is obtained with PSOL~10 MW for single null divertor and at higher values for snow flake configurations (PSOL~15-20 MW). Operation at maximum input power calls for high radiation fractions (Prad/Psol ~ 80-90%), which can be obtained with impurity seeding. Both at low and high separatrix density (ne,sep~0.5⊠1020 m-3 and ~1⊠10 m-3) Prad/Psol ~ 90% can be obtained in single null, double null and snow-flake configurations. Zeff at the separatrix =2.3 is needed for high density single null configurations.
References
1) DTT interim design report (2019) https://www.dtt- project.enea.it/downloads/DTT_IDR_2019_WEB.pdf
2) Casiraghi I., this conference
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4) Ramogida G., this conference

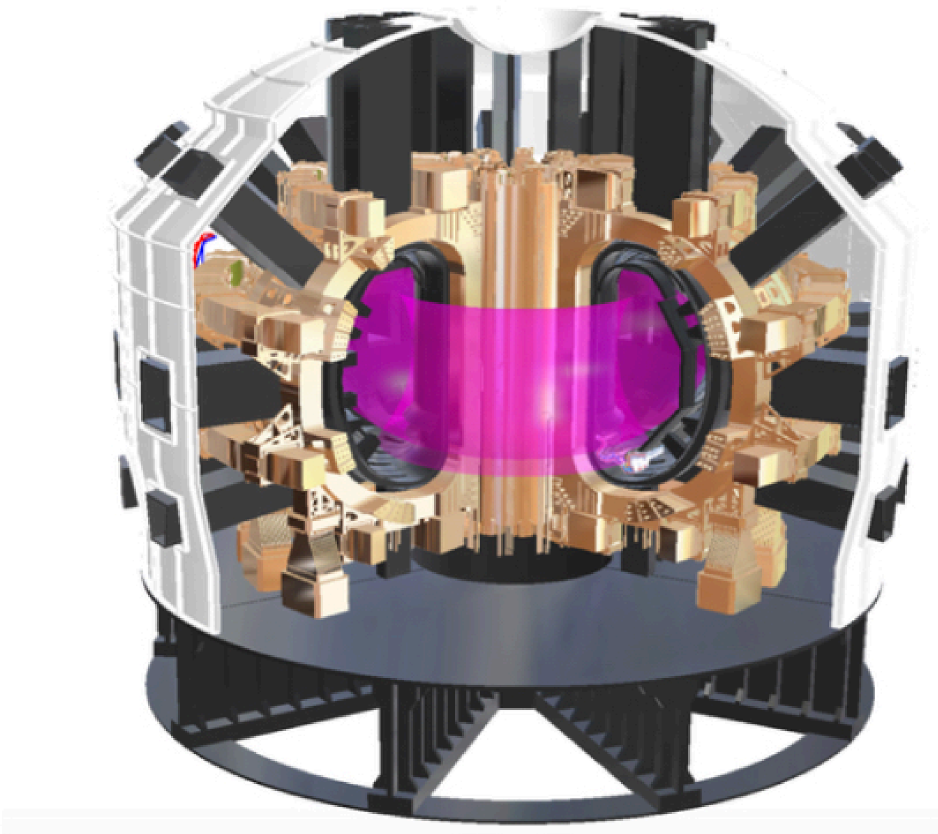

Figure 1

Figure 1:

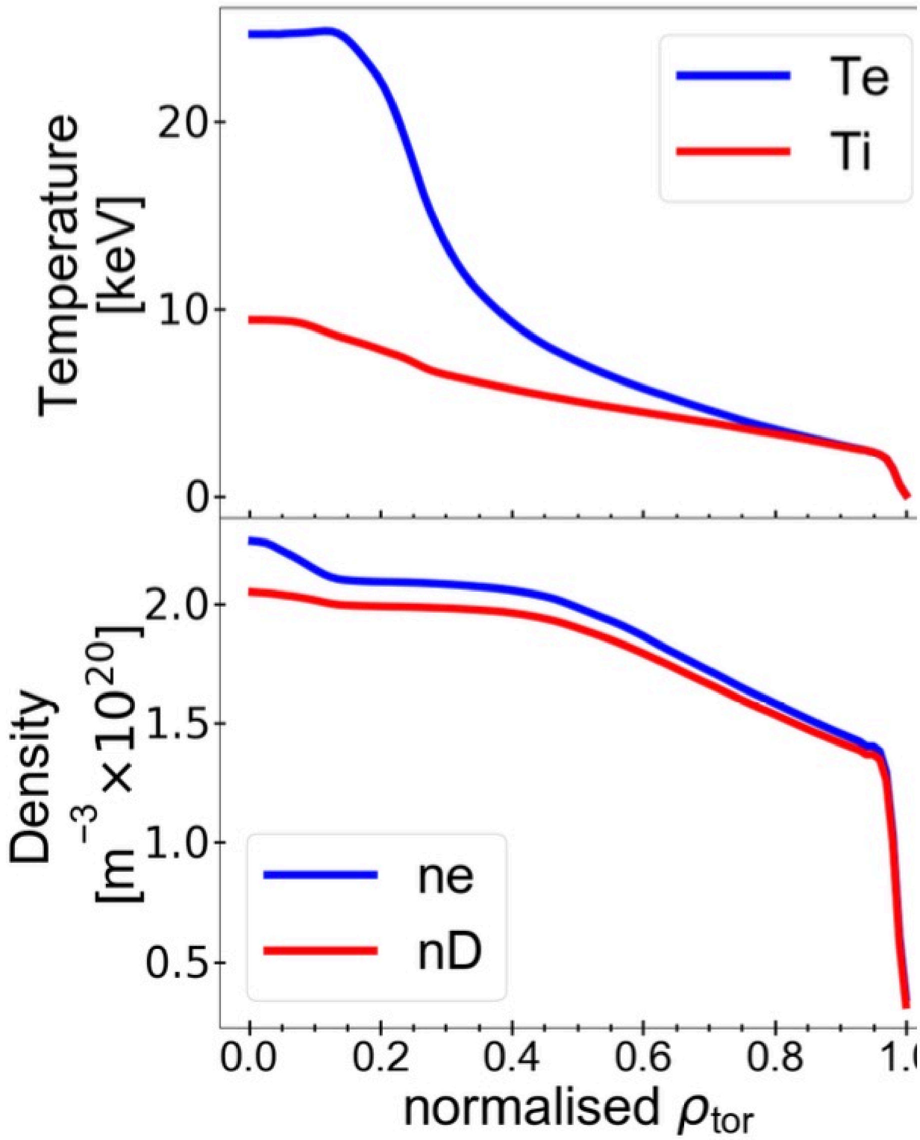

Figure 2

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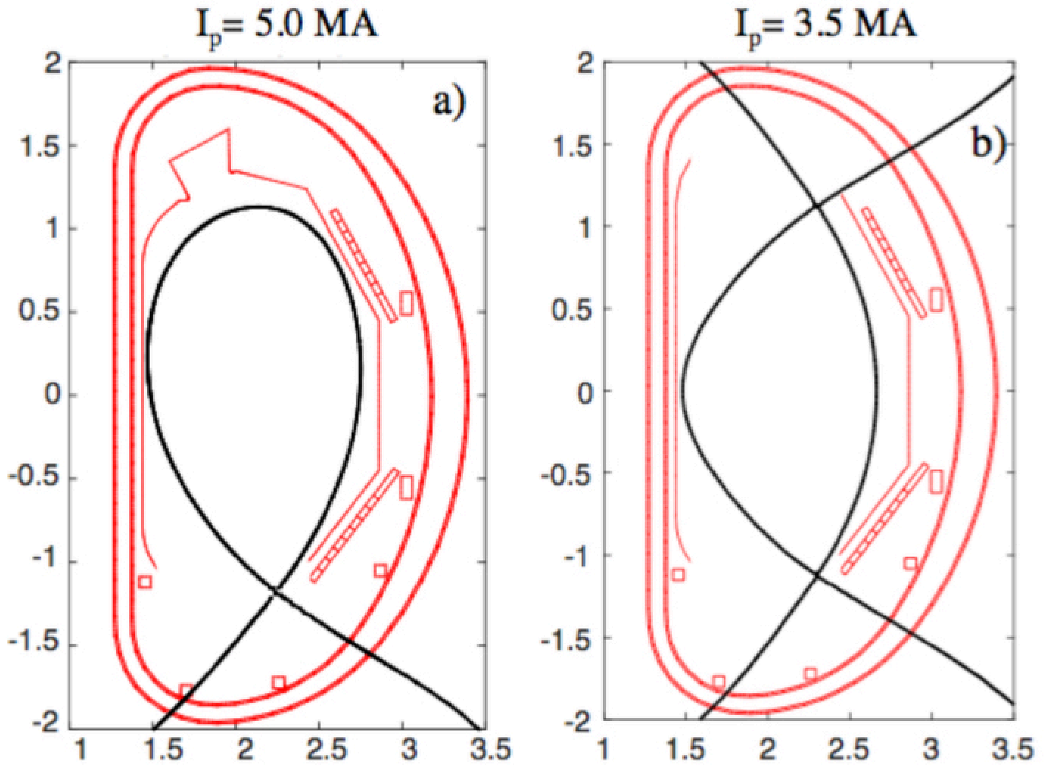

Figure 3

Figure 3:

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