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Deuterium-tritium experiments in JET with the ITER-like wall

J. Garcia

on behalf of the JET Contributors

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JET

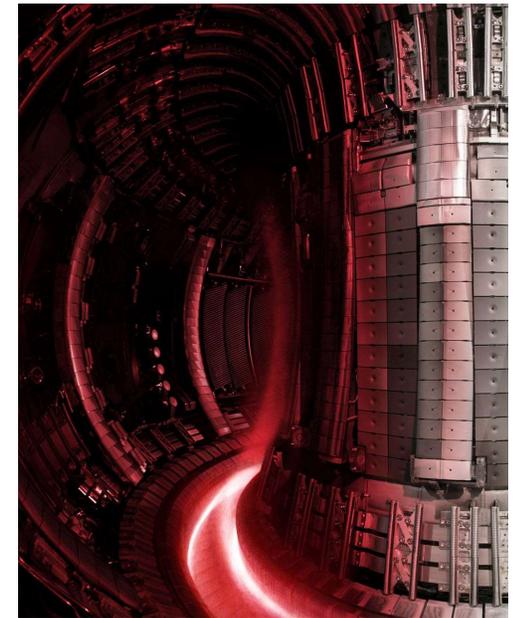
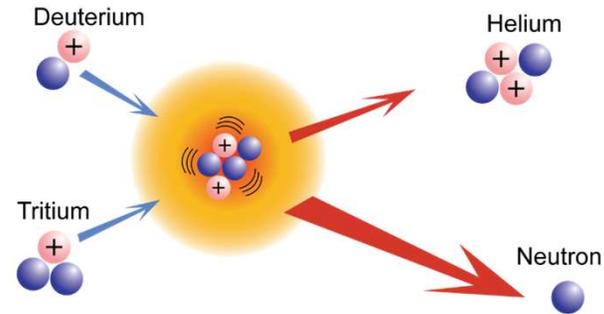


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Outline



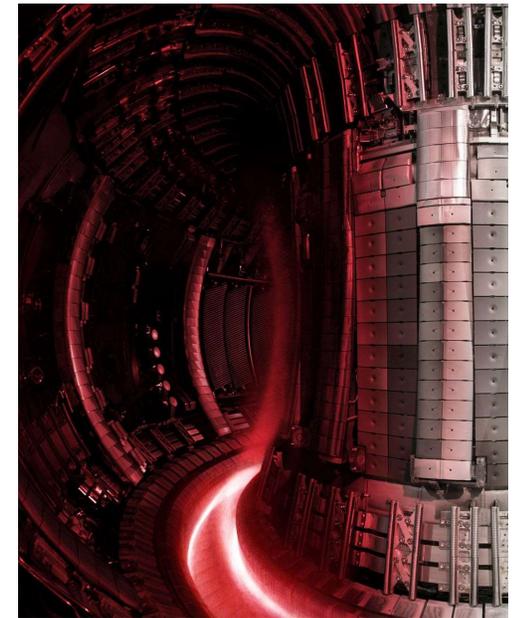
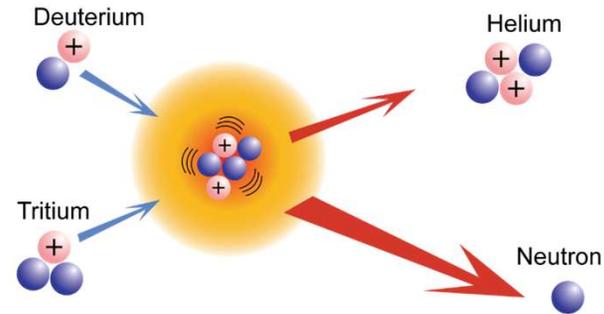
1. Why DTE2 at JET?
2. Fusion production world record
3. Physics studies in support of DT
4. Conclusions



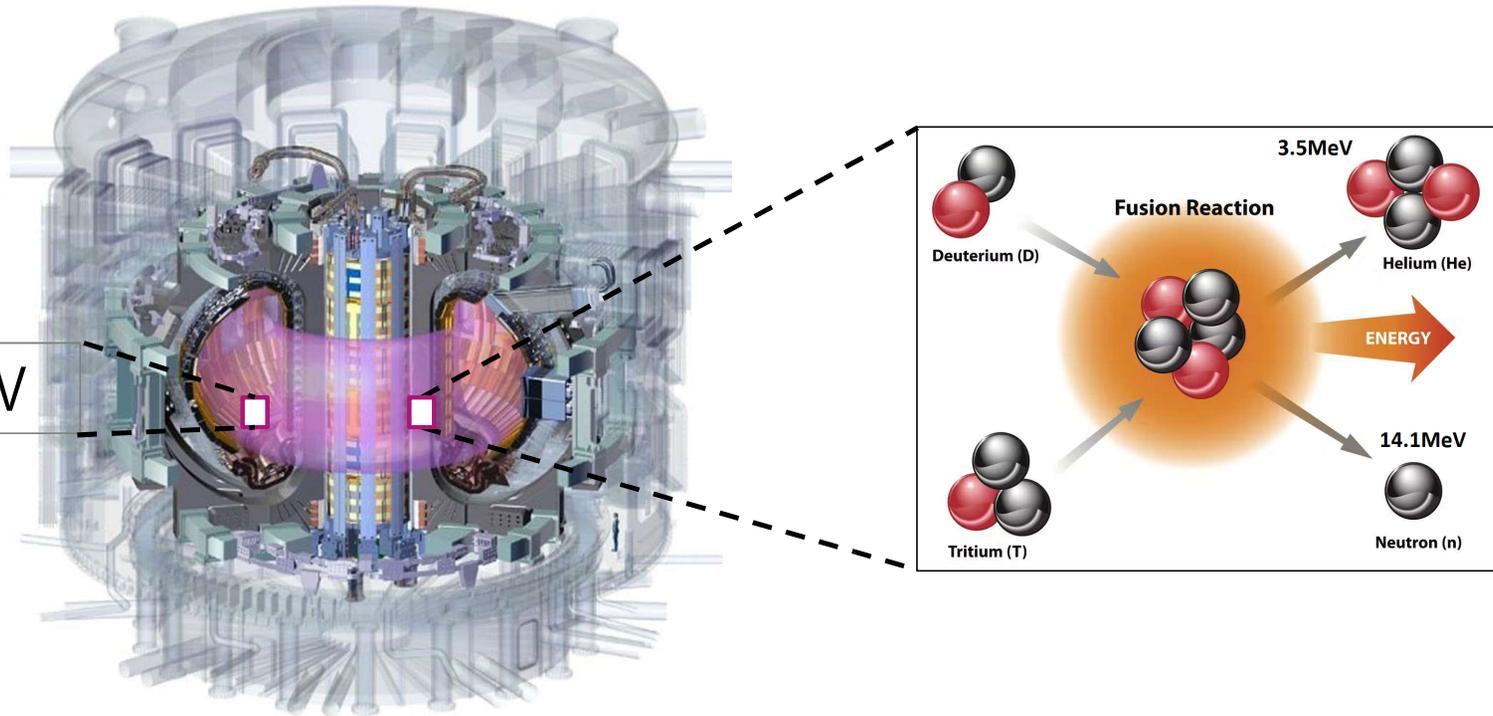
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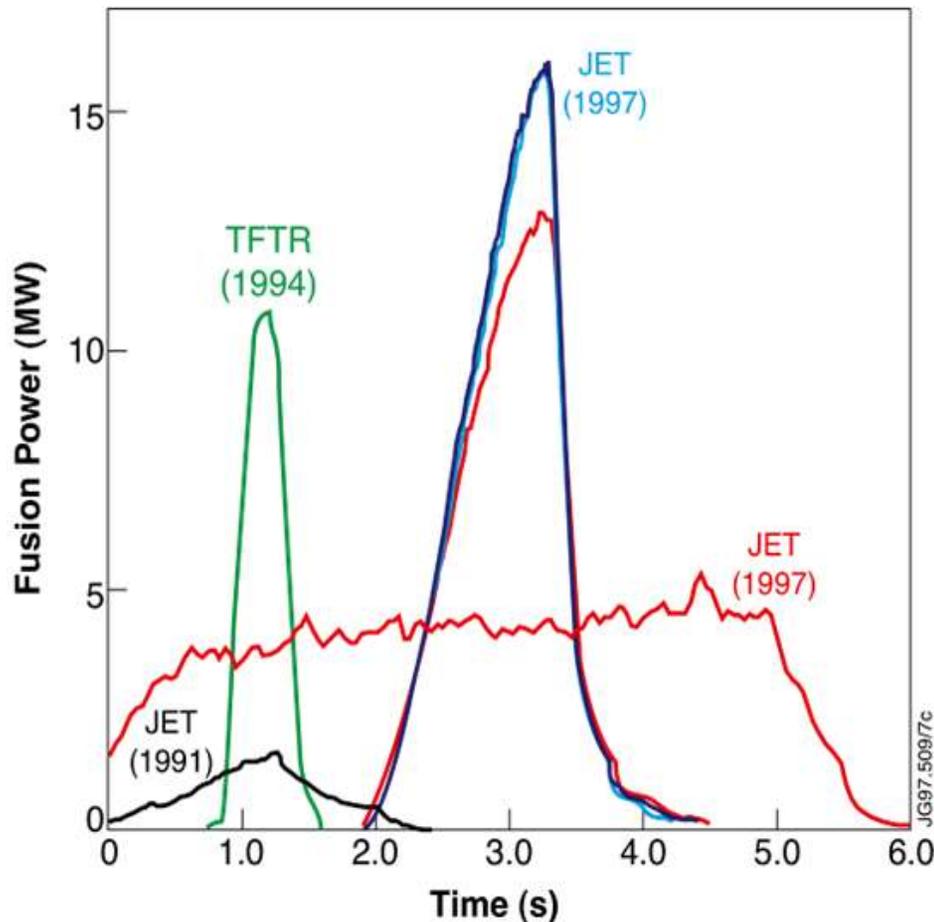


DT plasmas: key pillar for fusion energy production by plasmas



- Fusion produced **3.5MeV alpha particles** → **self heating of plasmas** through collisions
- What we actually know about DT plasmas?

D-T in Magnetic Confinement Fusion before 2021

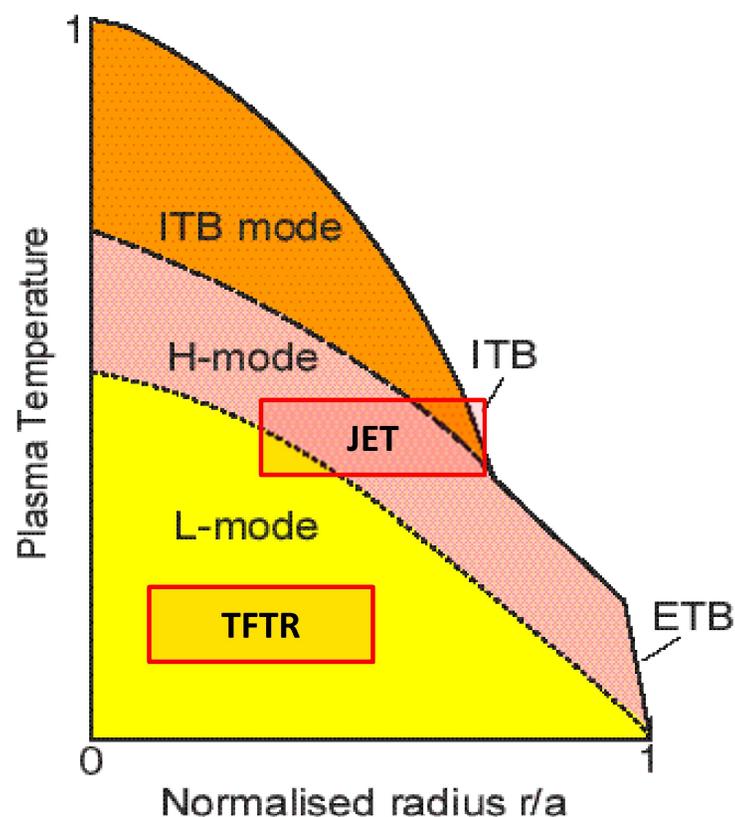


DT experiments were carried out in
1991 (PTE - JET)
1994-96 (TFTR – Princeton USA)
and 1997 (DTE1 on JET)

Clearly demonstrating:

- D-T Fusion production (14MeV neutrons)
- plasma physics effects linked to use of D-T mixture (*isotope effects*)

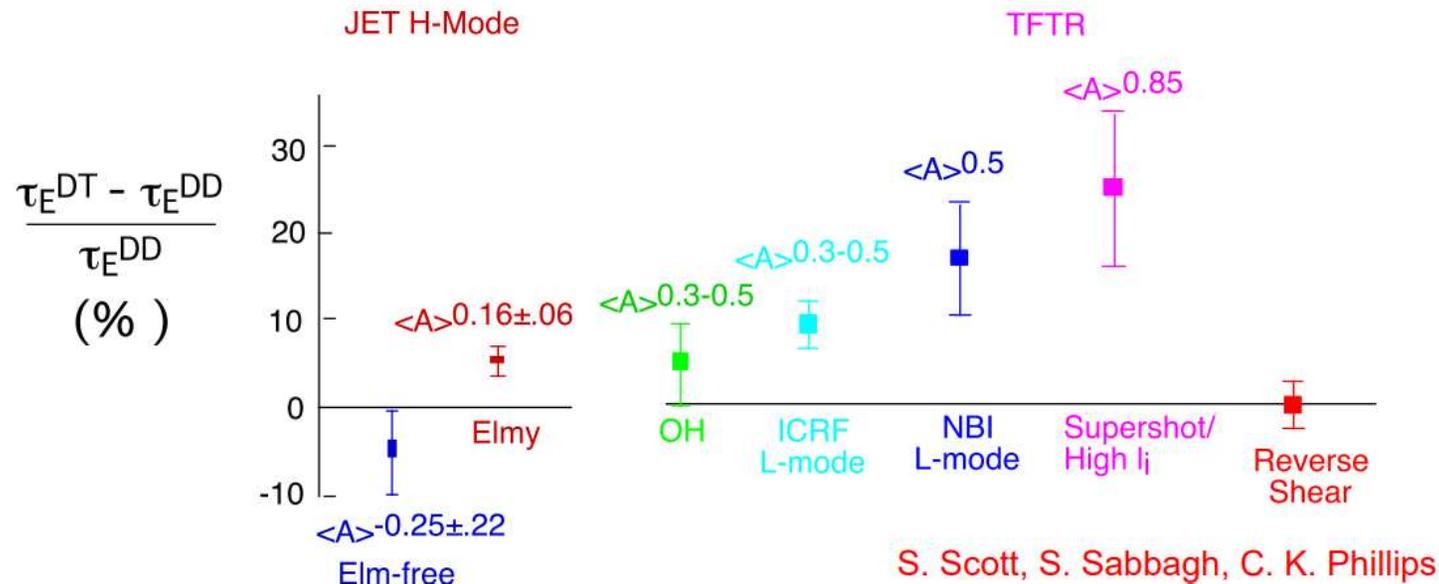
JET and TFTR aimed at different plasma regimes



A variety of tokamak operational scenarios exists

- **L-mode**: low performance, pulsed operation, no need for profile control
- **H-mode**: higher performance, pulsed operation, MHD control needed → **Main ITER Operation**
- **Advanced modes**: higher performance, steady state, needs profile control

DD vs DT plasmas energy confinement time

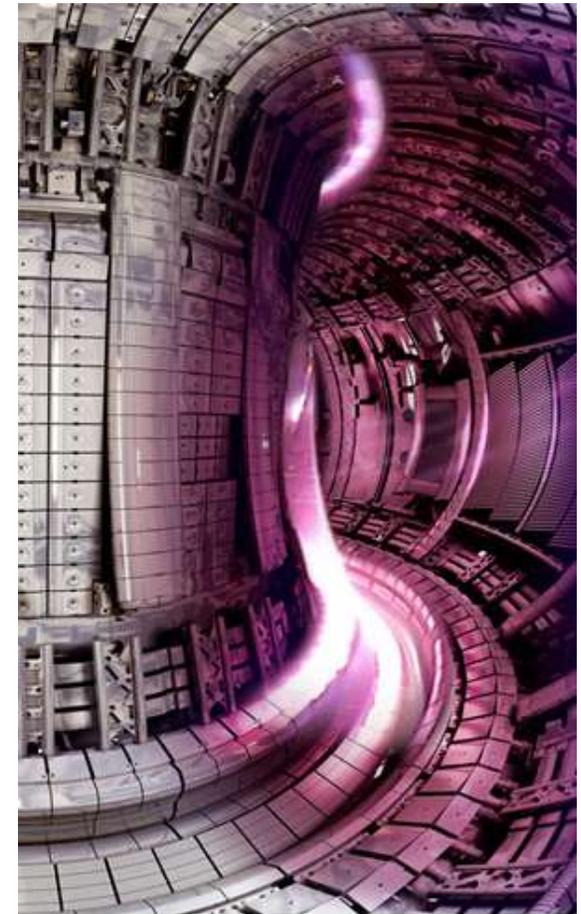


- JET vs TFTR confinement time: *the complete zoo*
- *ITER projection uses:* $\langle A \rangle^{0.2}$
- Are these results definitive and conclusive for ITER?



DTE1: first DT operation at JET, *unsolved issues*

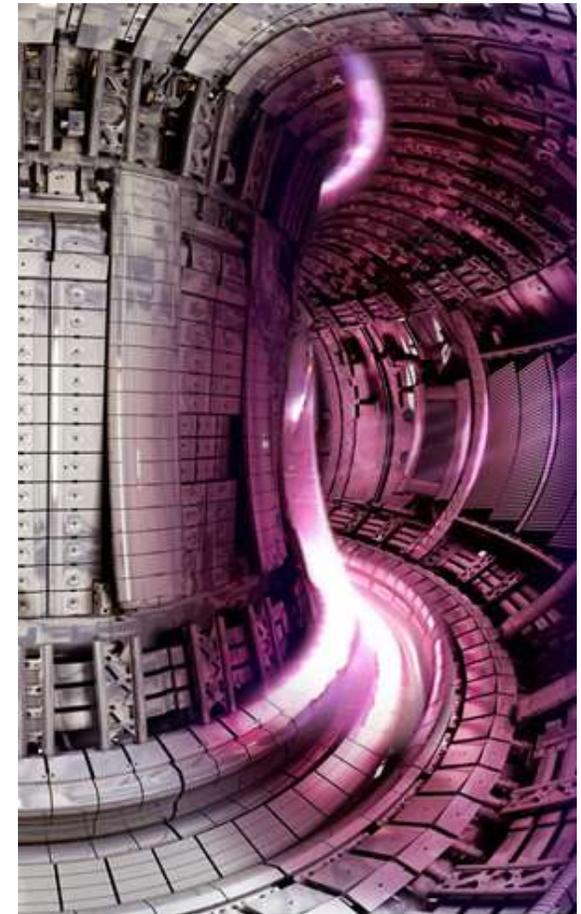
- DTE1 record fusion power plasmas were obtained in plasma conditions less relevant to ITER:
 - very low density
 - $T_i \gg T_e$
 - transient regime





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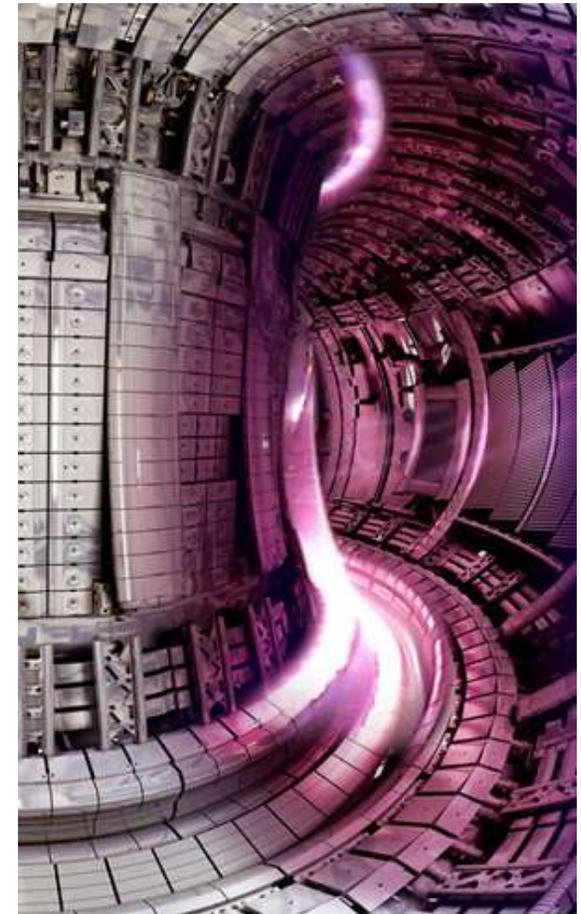
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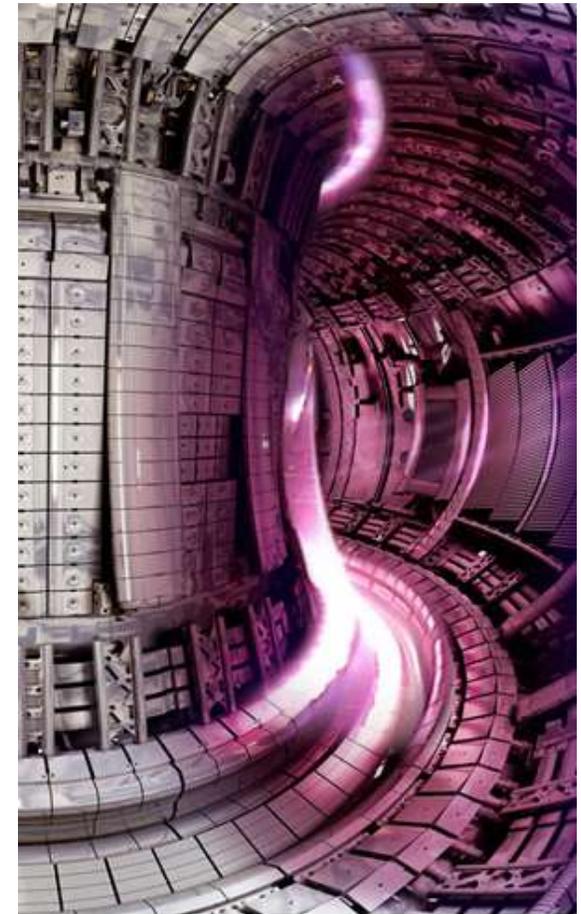
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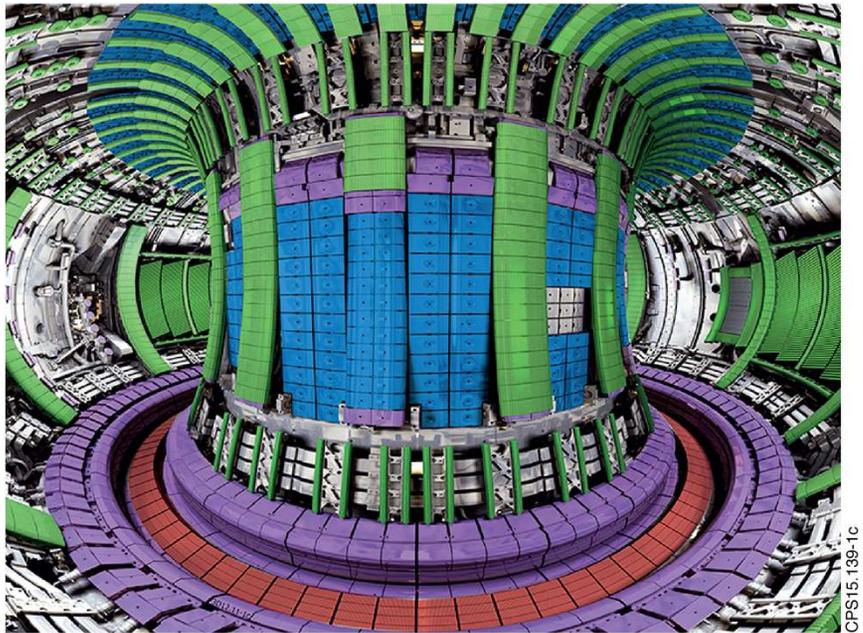


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 - very low density
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 - transient regime
- H-mode plasmas obtained at low power (no high beta plasmas)
- Plasmas obtained in C-wall (high T retention)
- Alpha particle effects weak and difficult to understand

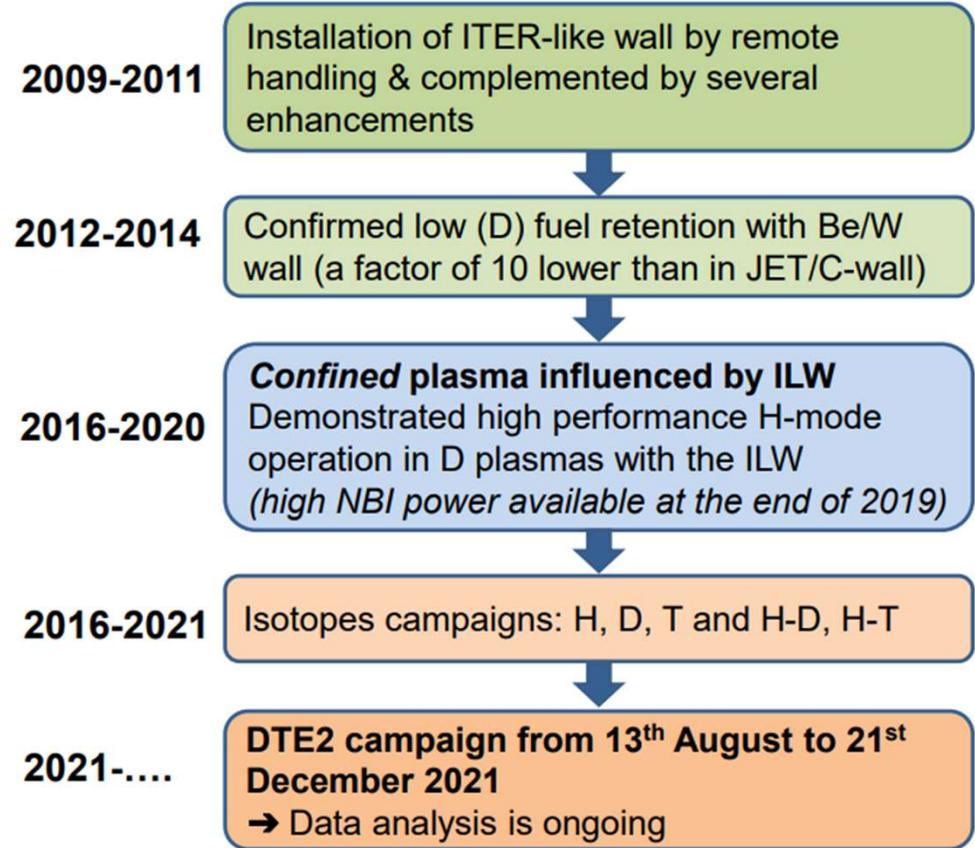


DTE2: Towards ITER relevant plasmas in DT

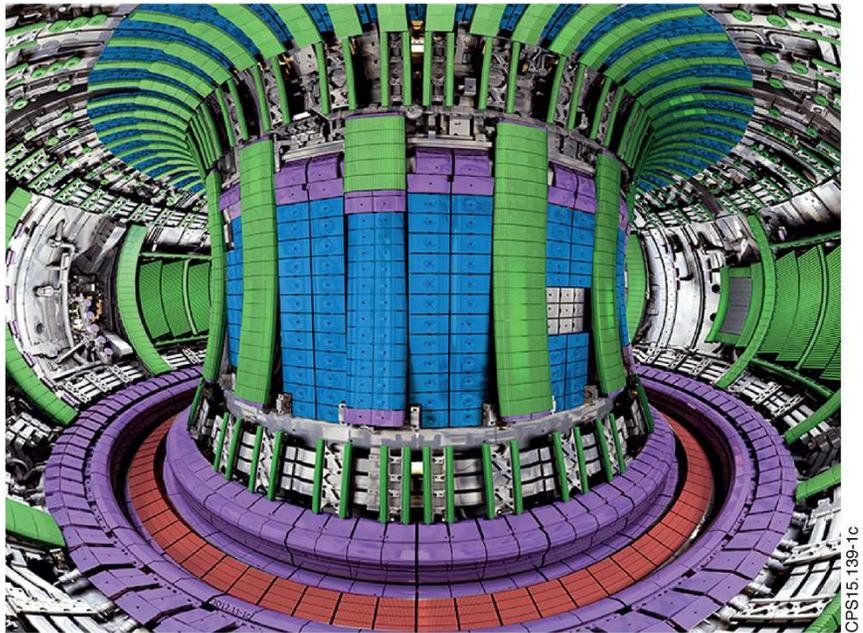


- Bulk Be PFCs
- Be-coated inconel PFCs
- Bulk W
- W-coated CFC PFCs

CPS15.139-1c



DTE2: Towards ITER relevant plasmas in DT



■ Bulk Be PFCs ■ Be-coated Inconel PFCs
■ Bulk W ■ W-coated CFC PFCs

CPS15.139-1c

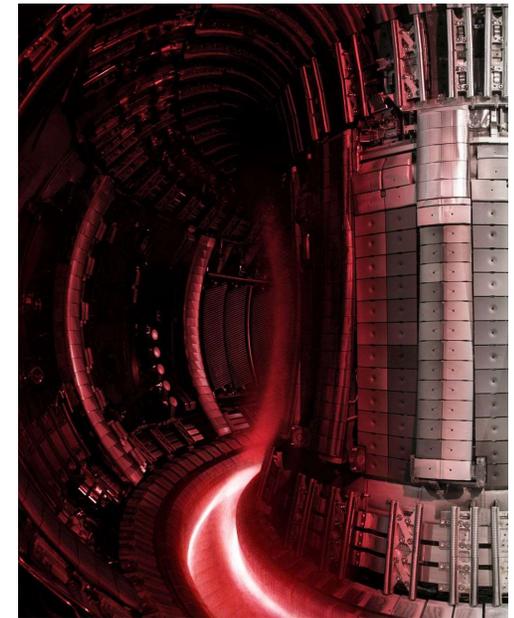
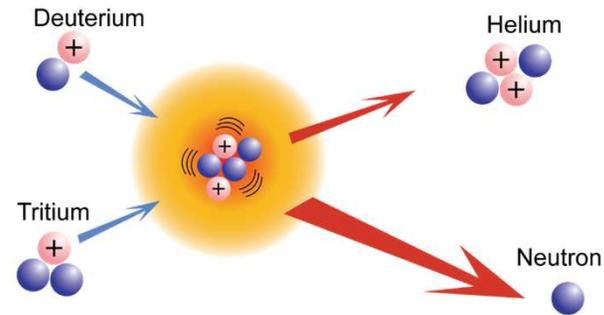
Improved capabilities compared to DTE1:

- ITER relevant wall&divertor
- Diagnostic capabilities
- More heating power
- Disruption prediction and mitigation/control
- RT control schemes
- Sophisticated Modelling

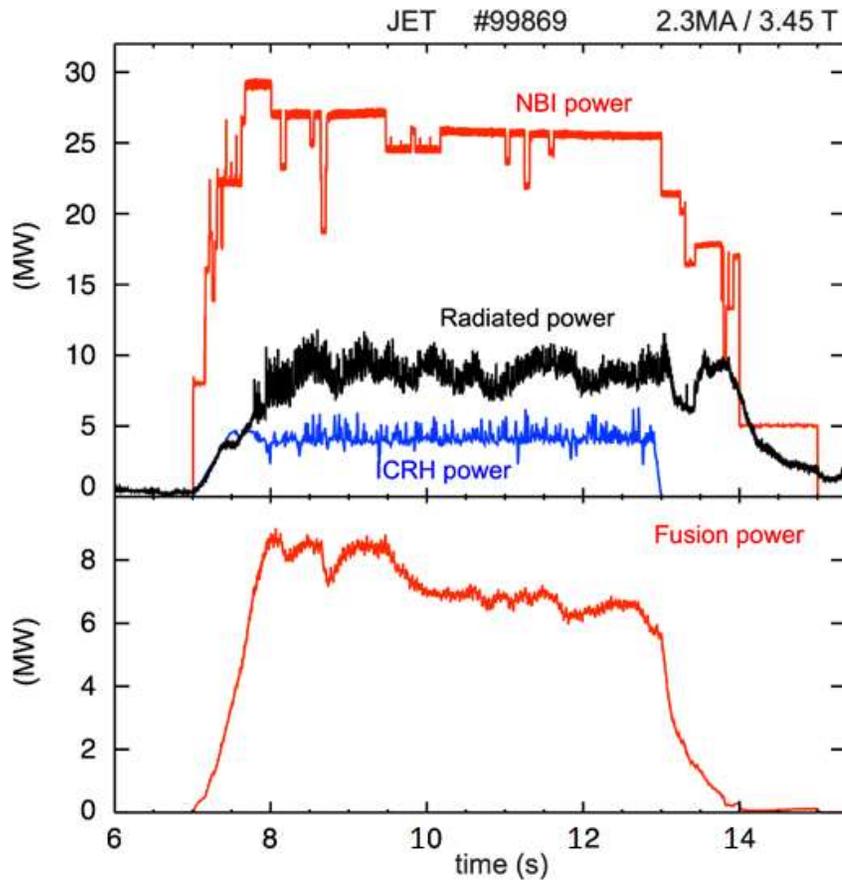
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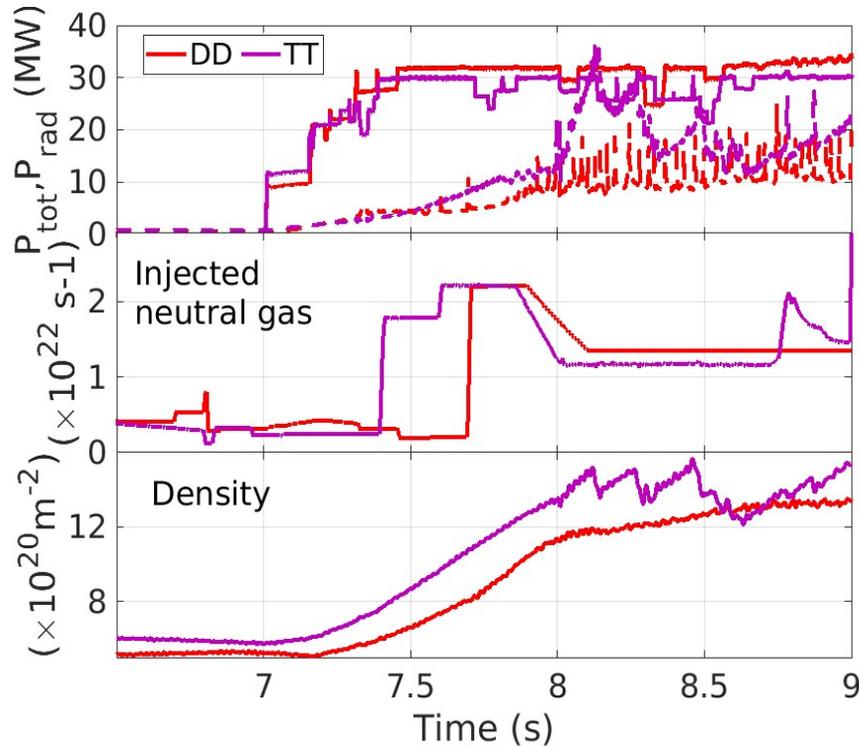
High beta H-mode plasma in 50-50 D-T



[C. Challis EPS2022]

- ‘Hybrid’ scenario plasmas operate at **medium current** and **high β** :
 - ✓ $2.2\text{MA} \leq I_p \leq 2.5\text{MA}$, $B_t = 3.45\text{T}$
- One of the candidate scenarios for ITER
- Had never been tested with T or D-T fuel before
- **High fusion power obtained but highly sensitive to input power**

Impurity behaviour in DD vs TT: significant differences



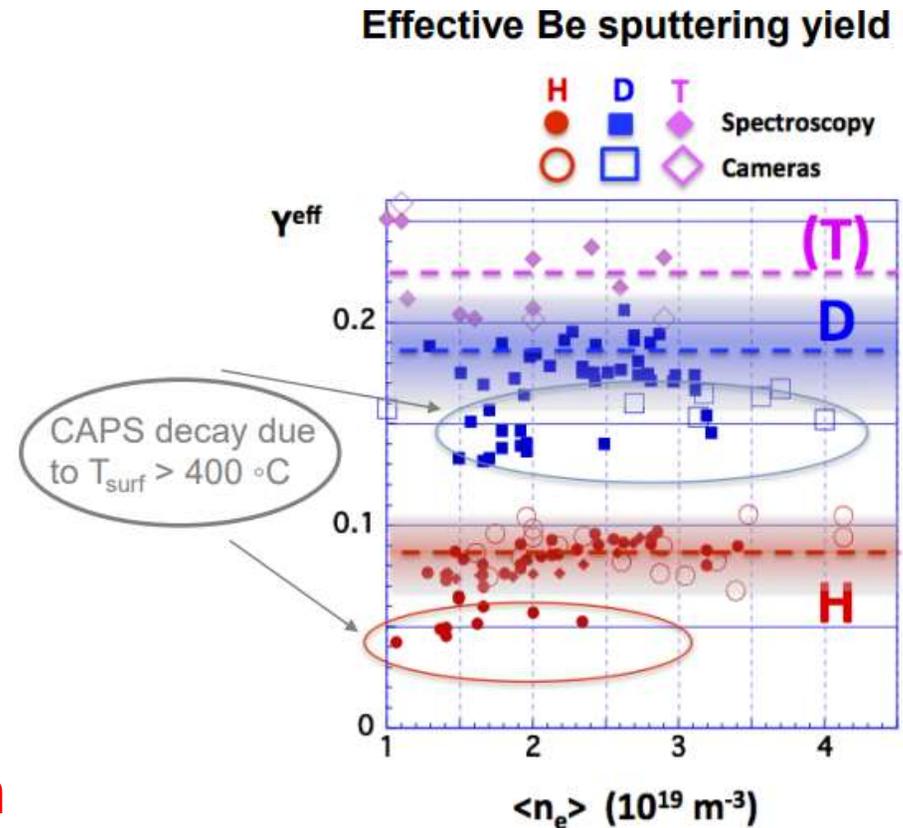
[C. Challis EPS2022]

- Risk of plasma pollution with metallic wall
- DD scenarios highly resilient to high Z pollution [Mailloux NF22] [Field submitted]
- Repeat of DD recipes in TT became challenging
- Transferability of DD recipes to TT and DT might not be straightforward

Measured tokamak Be and W erosion by T and DT fuel

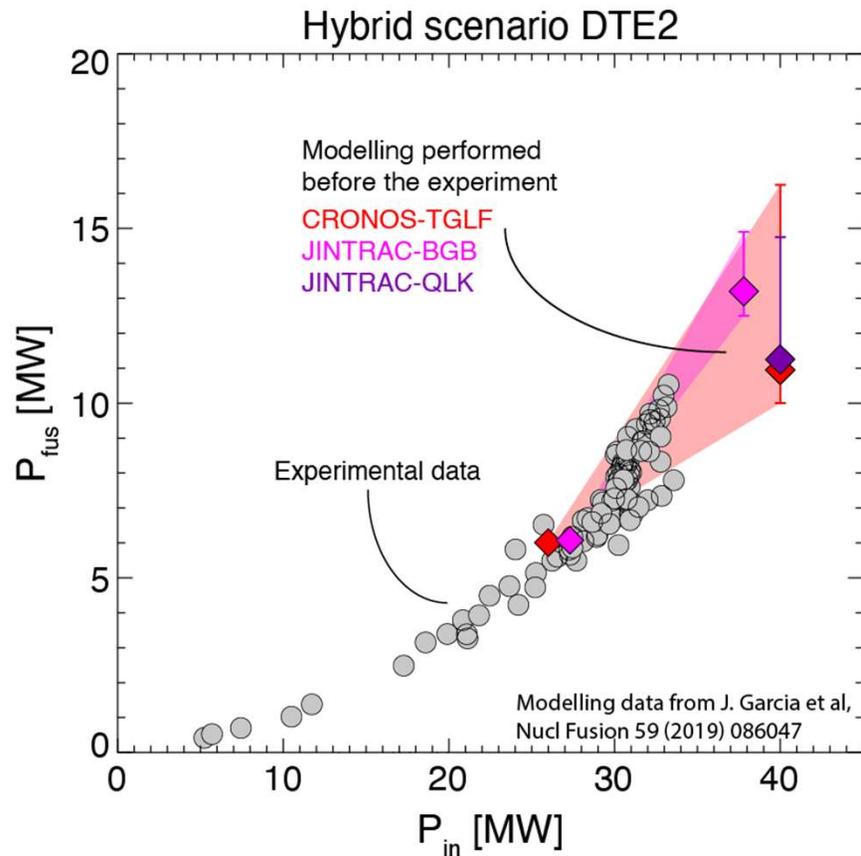


- Erosion of plasma-facing components by tritium → Be, W can pollute and cool plasma
- Observations:
 - Be gross erosion increases with isotope mass
 - Contribution of hydrogen isotopes to total W erosion increases strongly with mass
- Improved predictions of Be and W erosion in ITER



[E de la Cal et al., subm NF]
[D Borodin et al., PSI 2022]

D-T fusion power confirms modelling predictions

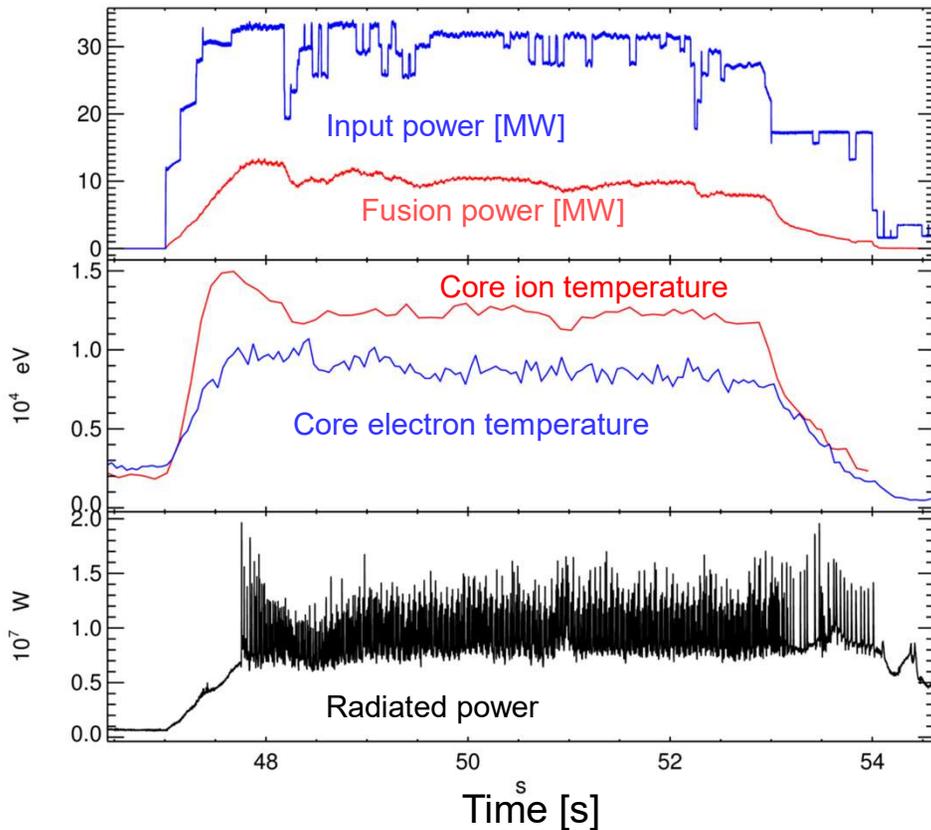


- Strong **predict first modelling** performed since 2010
- **D-T fusion power achieved is in broader agreement with predictions**
- Simplified models can be improved with new DT data.
- **Essential for ITER** and future reactors predictions.

H-mode scenario with optimized non-thermal fusion power



15%D - 85%T plasma with D-NBI (2.5MA/3.86T)

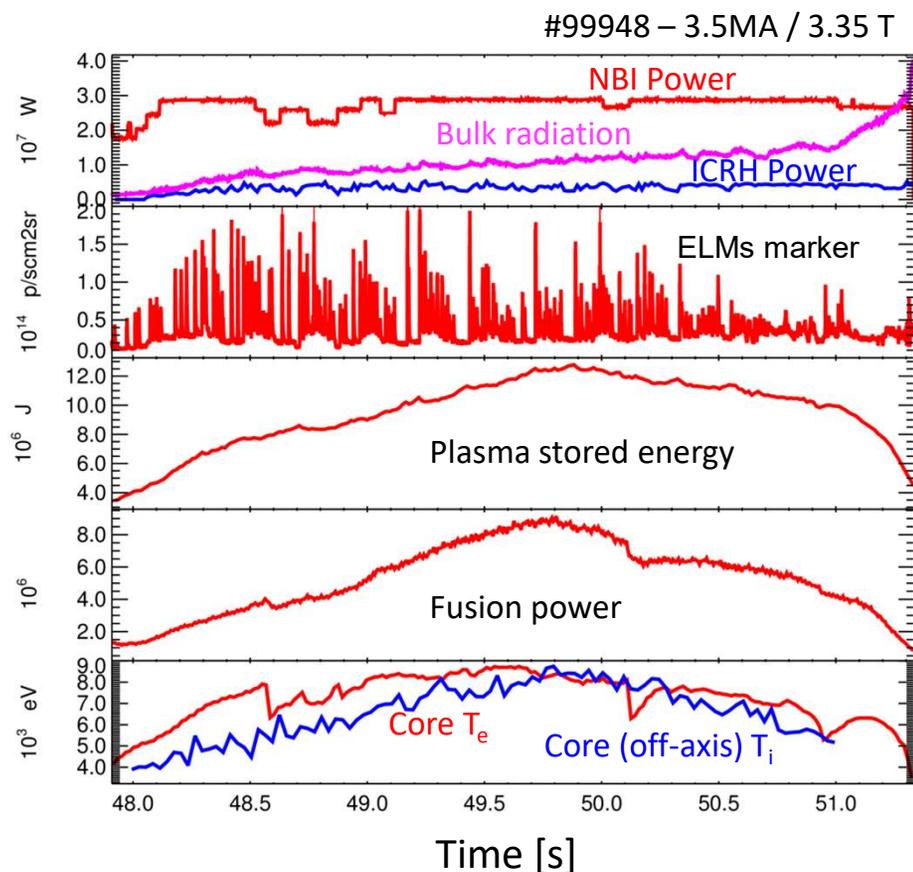


- Plasma composition: 15%D - 85%T
- Max Deuterium NBI heating
- Record steady fusion energy: $E_{\text{fus}} = 59\text{MJ}$
- Non-thermal fusion production dominant

[M. Maslov]

First ever tested on JET or anywhere else

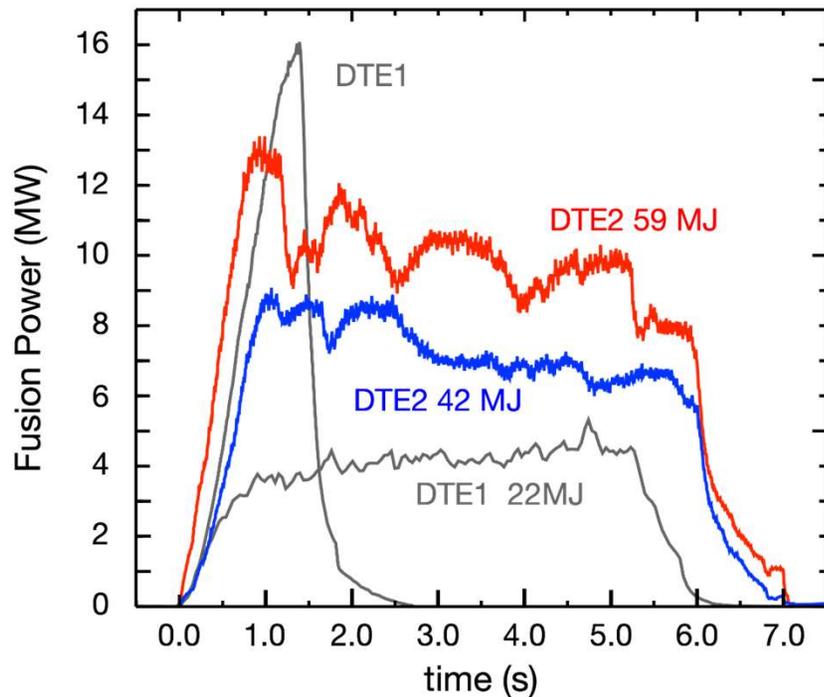
H-mode baseline scenario plasma in 50-50 D-T



[D. van Eester RF topical 2022]

- ‘Baseline’ scenario plasmas operate at **high current** and **medium β** :
 - ✓ $I_p=3.5\text{MA}$, $B_t=3.35\text{T}$
- High confinement stationary plasmas obtained in DD [Mailloux NF 22] [Garcia POP 22]
- **In DT, stopped by too high radiation**
- Under investigation → important to understand for ITER

World fusion energy record obtained in DTE2



- High fusion power plasmas performed in **D-T for the first time with Be/W wall**
- **Confirming predictions** of plasma behaviour
- Confirms expectations for **stationary high fusion power plasmas in ITER**
- Showing the **challenge to transfer operation from DD to DT**

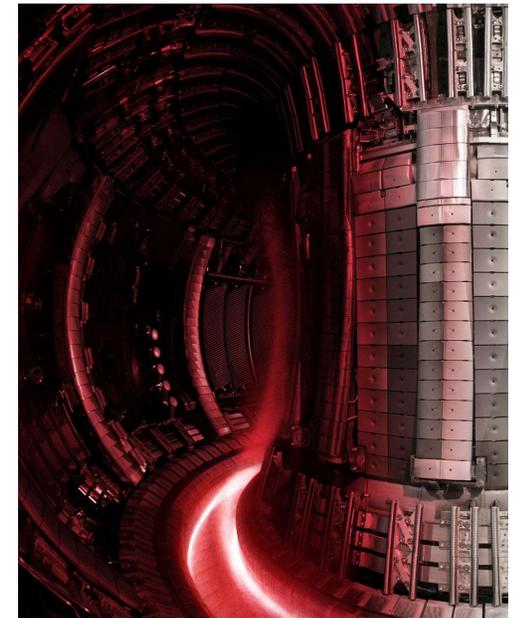
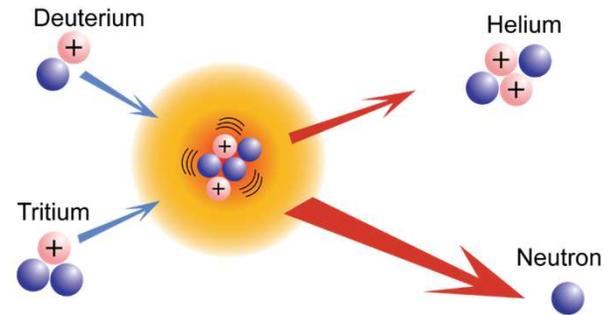
#99869 (2.3MA/3.45T) with ~50/50 DT NBI and plasma

#99971 (2.5MA/3.86T) with D-NBI in T-rich plasma

Outline



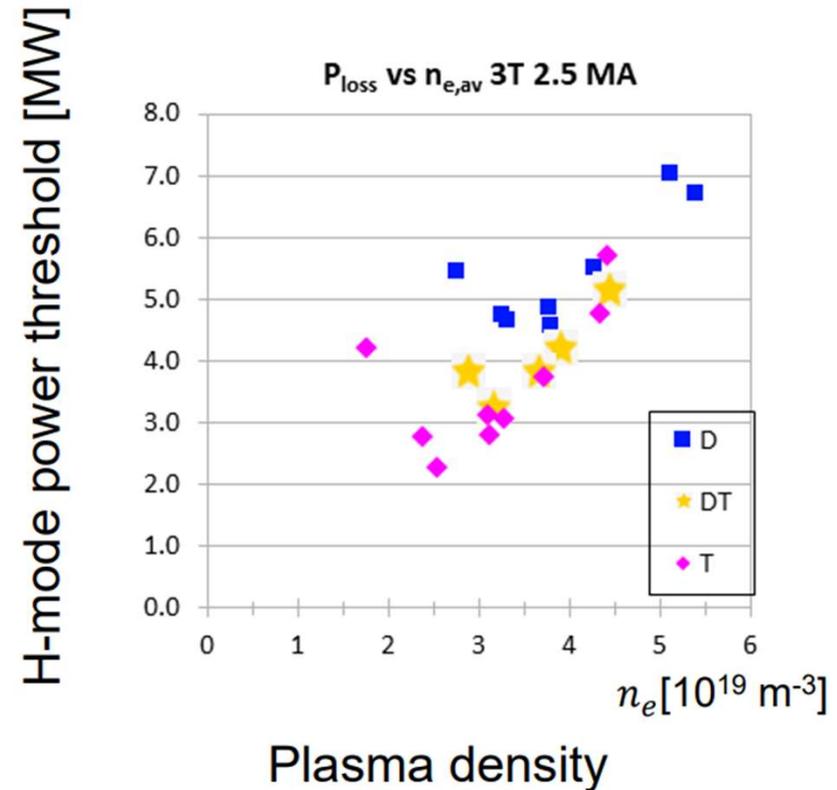
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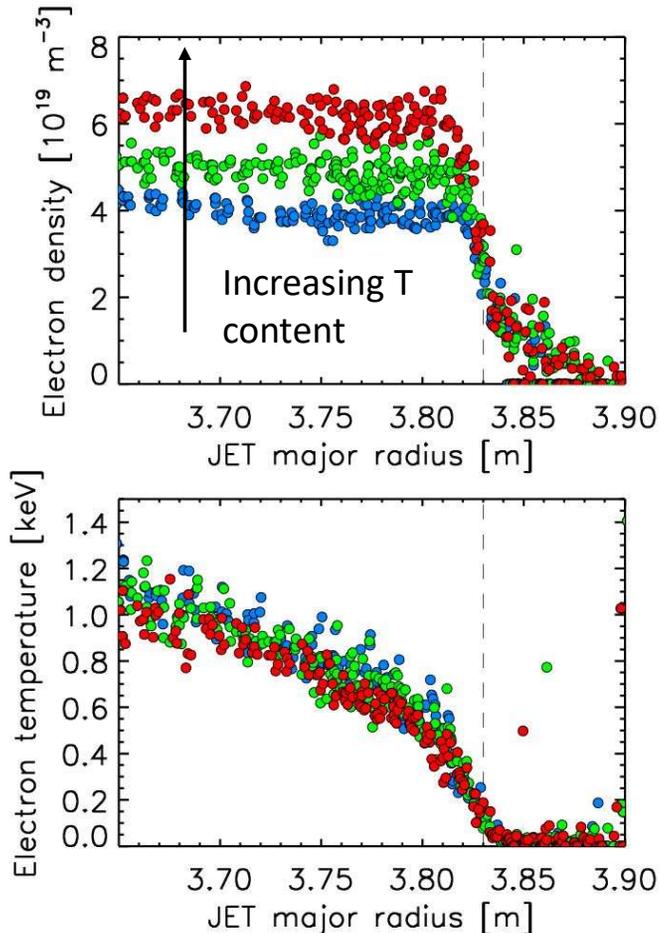
Impact of fuel mass on L-H transition



- L-H transition studies are essential to ITER
- $n_{e,\min}$ and P_{L-H} are different in H, D and H+D mixtures at JET [Maggi PPCF18]
- Similar trend found in D vs T plasmas → Lower P_{L-H} for T [Solano NF22]
- DT plasmas are found between D and T



Variation of H-mode pedestal structure with D-T fuel mix



- Increased pedestal density from H to D

[CF Maggi et al., PPCF 2018]

[L Horvath et al., NF 2021]

[P Schneider et al., NF 2022]

- Changes on transport characteristics

[Horvath NF21]

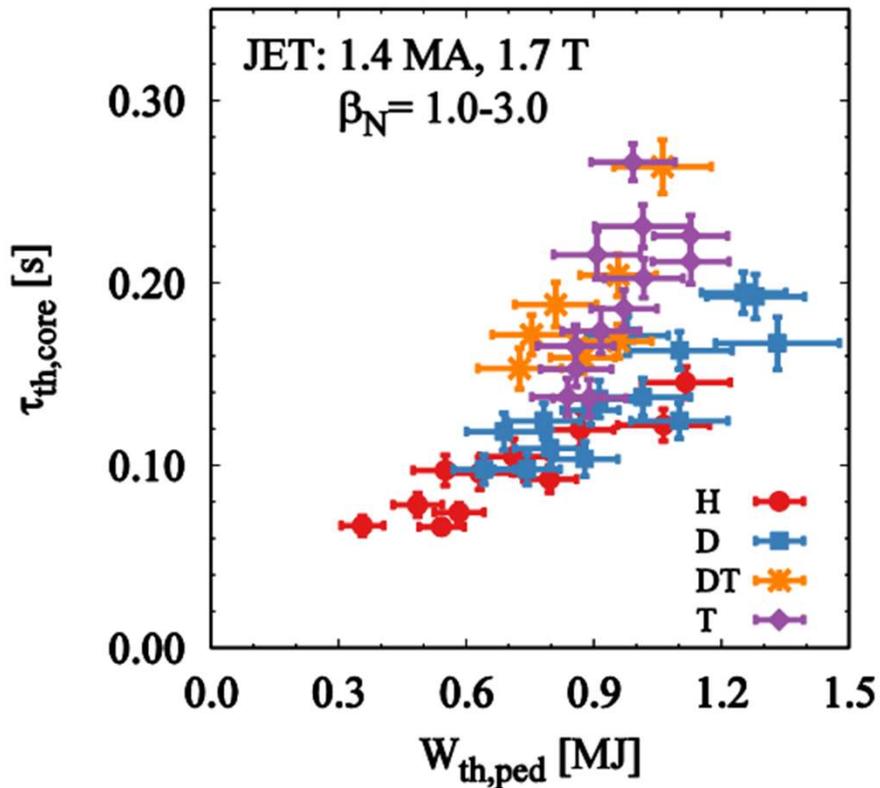
- Pedestal density also increases in D \rightarrow T

- Crucial data for improving ITER predictions

Controlled D-T fuel mix scan at constant β_N
(obtained with feedback control on injected power)

[L Frassinetti et al.]

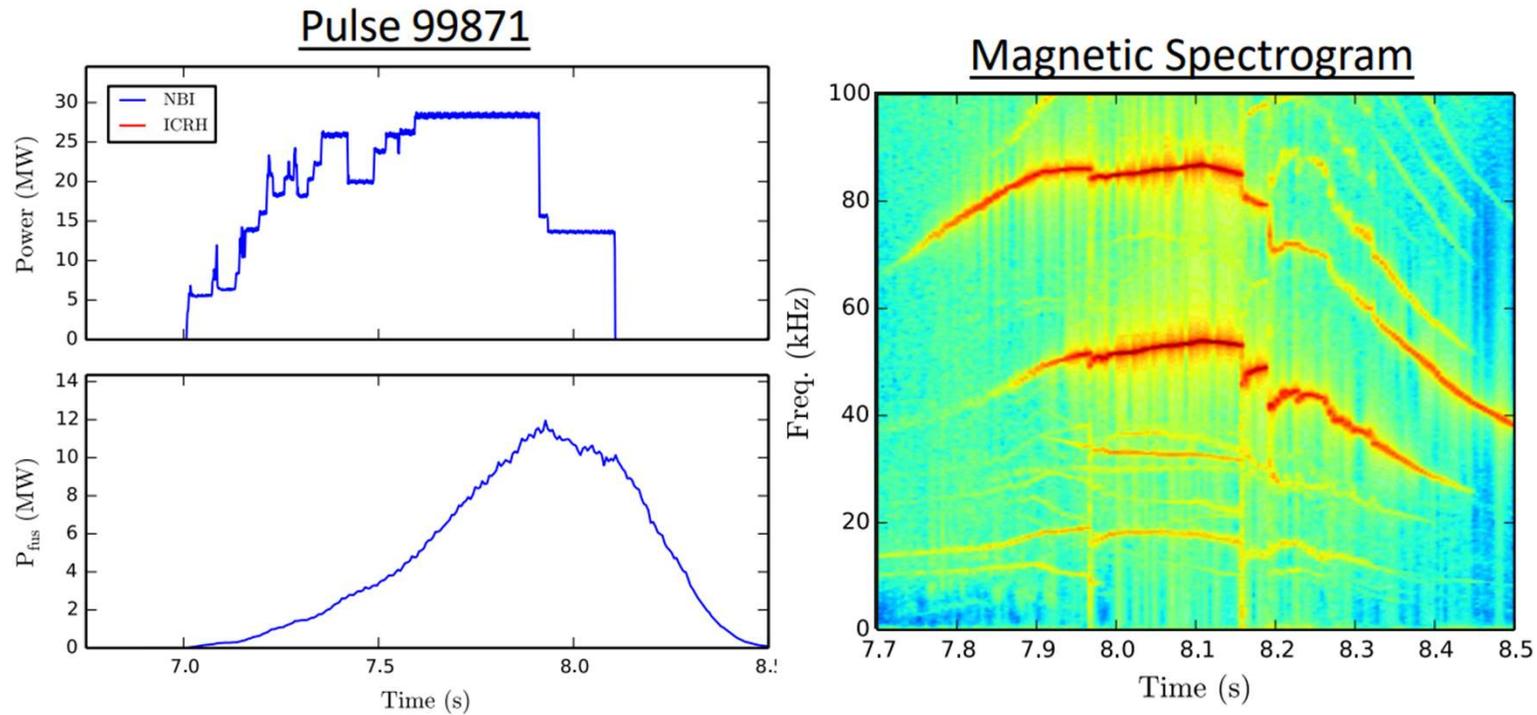
Core energy confinement



- T and DT plasmas show higher core energy confinement than D and H
- Notably at high input power
- In agreement with previous theoretical studies
- Heat transport reduced in D \rightarrow T with:
 - Rotation [\[Garcia NF17\]](#)
 - Beta [\[Casson NF20\]](#)
 - Collisionality [\[Mariani NF21\]](#)

P. Schneider AAPPS conference 2021

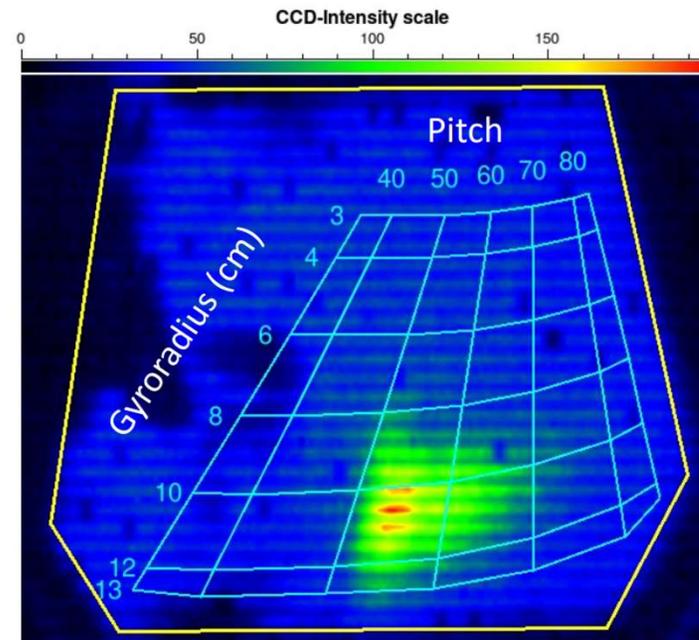
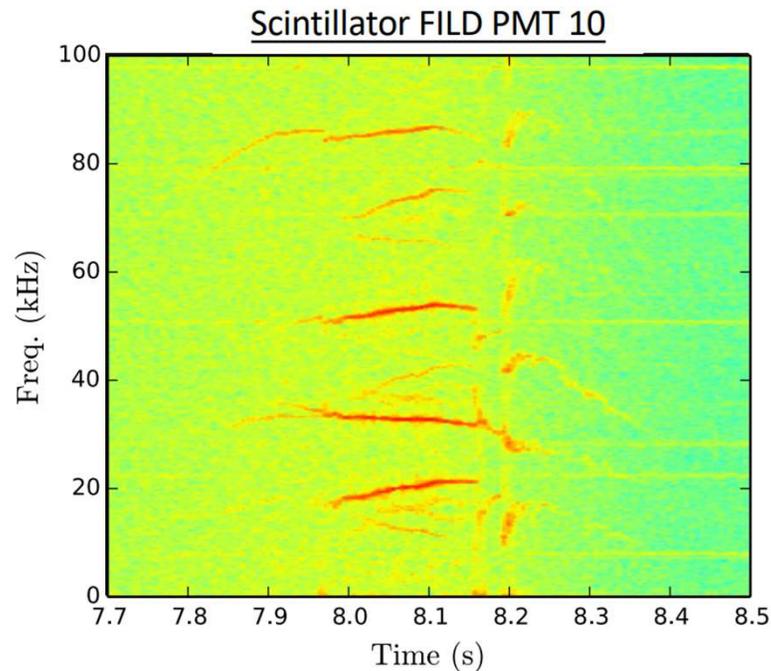
Alpha particle loses and MHD activity



P. Bonfiglio
MF1-I3

- MHD activity destabilized in high fusion power plasmas

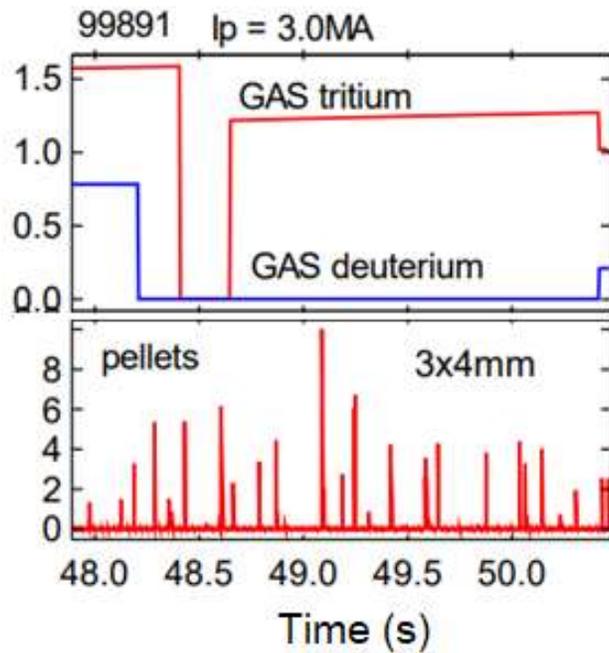
Alpha particle losses and MHD activity



P. Bonfiglio
MF1-I3

- MHD activity destabilized in high fusion power plasmas
- FILD diagnostic: **0.5%-2% alphas lost in MHD events**

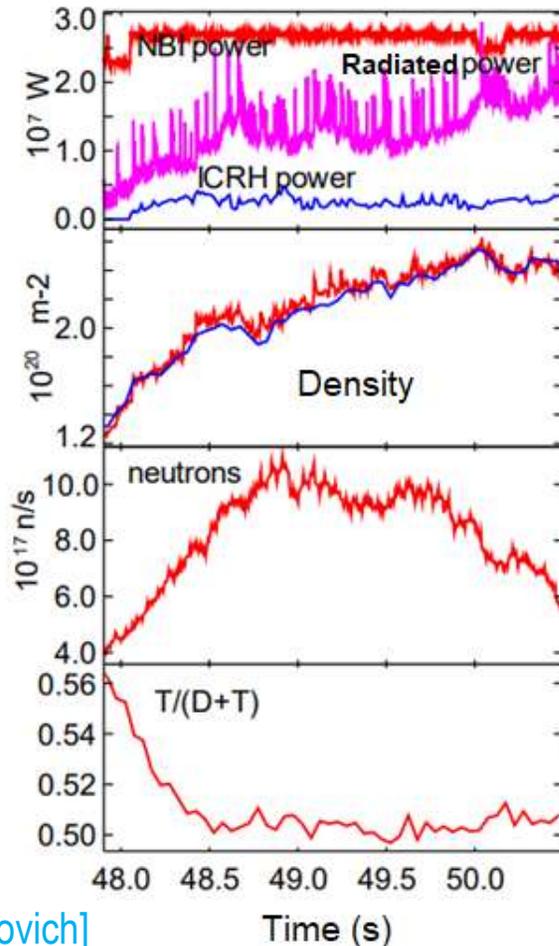
D-T mixture control



[M. Valovich]

- Different D-T plasma fueling tested
 - Neutral Gas Injection
 - Pellets
- Can the 50-50% DT mixture be controlled?

D-T mixture control



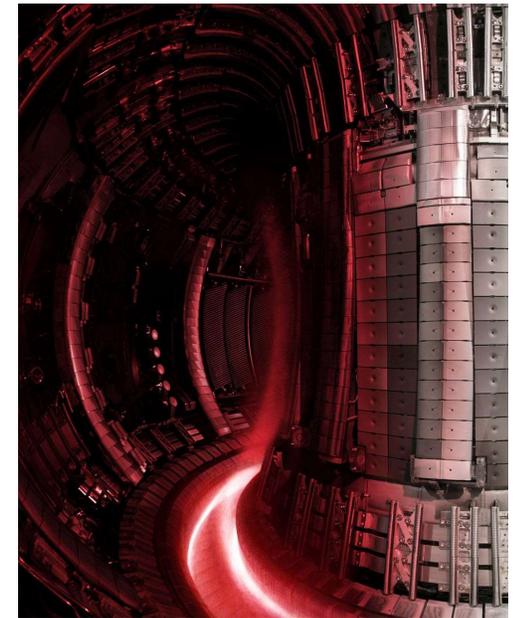
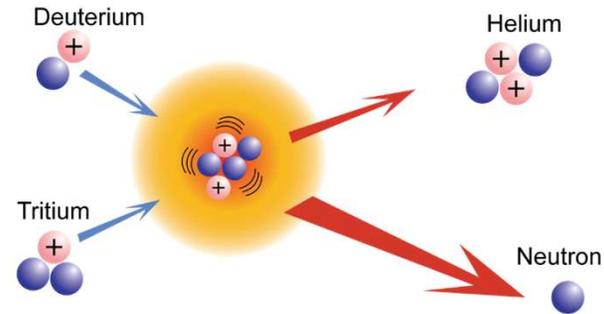
[M. Valovich]

- Different D-T plasma fueling tested
 - Neutral Gas Injection
 - Pellets
- Can the 50-50% DT mixture be controlled?
- 50-50% mix achieved and controlled by adjusting pellet frequency
- High neutron level show potential 50-50% mixture in the core → being analyzed
- **Essential information for ITER**

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JET DTE2 experiments bring fusion energy closer



- Exploiting JET's unique set of capabilities: T handling, ITER-like wall, size, heating & diagnostics enhancements:
 - JET D-T experiments have demonstrated highest ever fusion energy production
 - In conditions closest to ITER as we can with any fusion facility in the world
 - Providing a new set of physics results in DT
 - Confirming modelling predictions for the fusion power, giving confidence for predictions of ITER and future reactors
 - Will help accelerate ITER research plan (risk mitigator for ITER)
- While doing so, we have also trained a new generation of scientists, engineers and technicians, transferring unique knowledge and skills to ITER

List of JET-DT related talks



- S. Mazzi “On the beneficial role of fast ions on microturbulence: from current experiments towards ITER” PL.32
- D. Matveev “Isotope removal and outgassing in JET-ILW” PL.38
- P. Bonfiglio “DT-Alpha Particle Loss Measurements in the JET DTE2 Campaign” MF1-I3
- E. Lerche “Development of a hybrid plasma scenario for D-T experiments in JET-ILW” MF1-I4