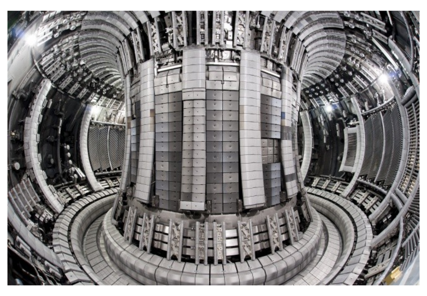
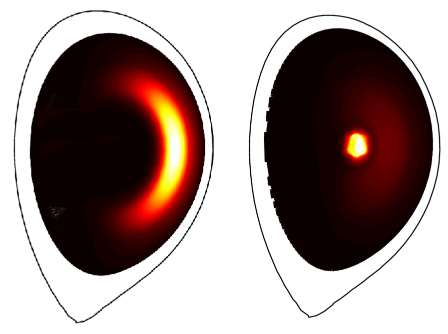
EUROfusion



Predictive multi-channel flux-driven modelling to optimise ICRH tungsten control in JET



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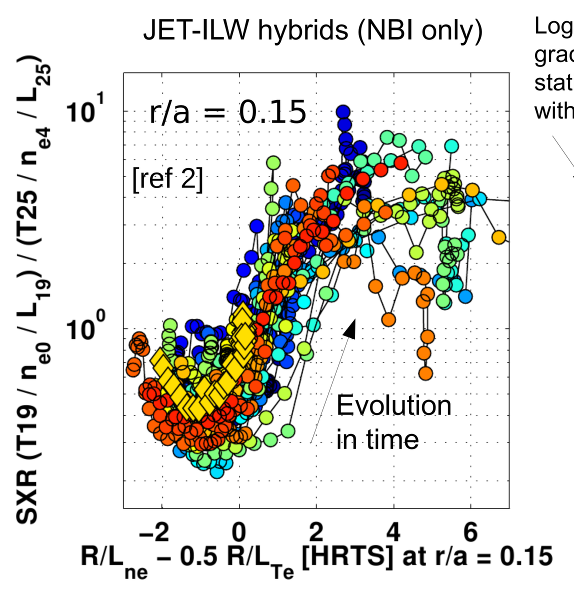
Need to optimise JET-ILW scenarios against W accumulation

- **JET-ILW DT scenarios aim at steady high performance (15MW fusion for 5s) [1]**
- **Scenario development must address 3 connected challenges**
  - ***Maintain tolerable divertor heat loads***
  - ***Control central W accumulation***
  - ***Avoid performance limiting MHD***

Apply state-of-the-art modelling capabilities to guide scenario development

W accumulation driven by neoclassical convection enhanced by rotation



Logarithmic gradient in stationary state with no source

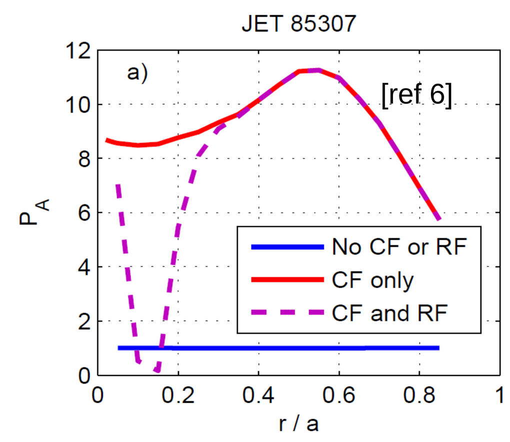
Complex, but benign

Threat: Drives accumulation

$$\frac{R}{L_{nZ}} = -\frac{RV_{Z\,\mathrm{trb}} + RV_{Z\mathrm{NC}}}{D_{NZ\,\mathrm{trb}} + D_{NZ\mathrm{NC}}}$$

Mitigation - large where turbulent transport

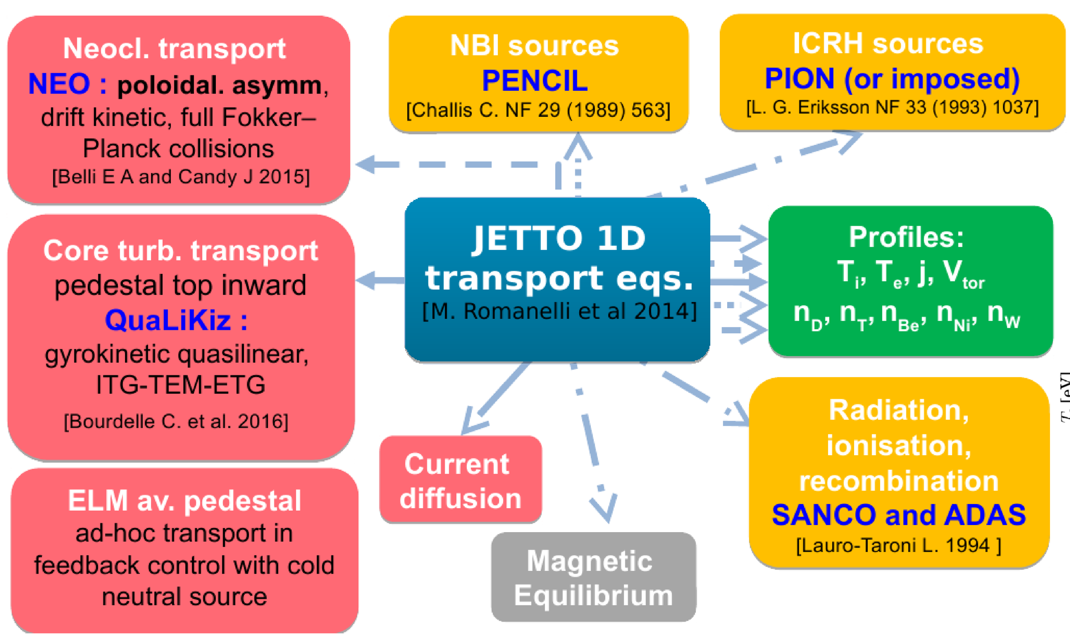
Small, ~ P_A, no Z dependence

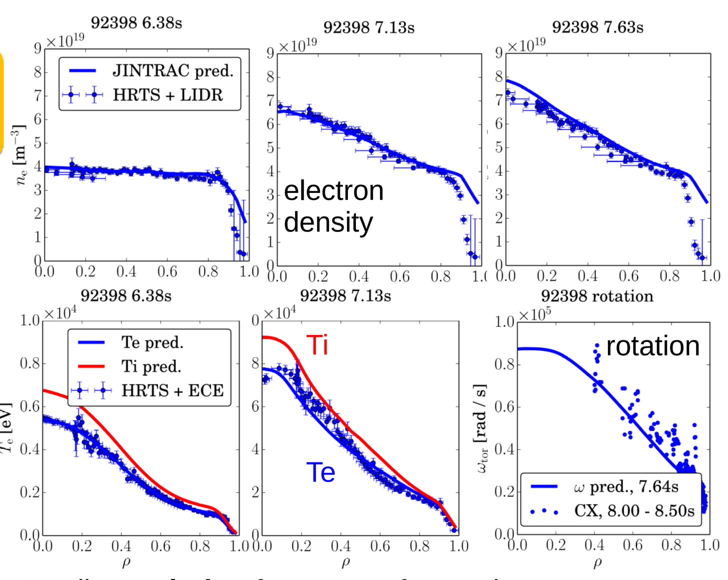


W poloidal asymetries due to rotation enhance neoclassical transport by an order of magnitude [2,3,4,5] but anisotropy of heated minority can reverse the effect [6,7]

$$V_{Z\mathrm{NC}} \propto ZP_A\left(-\frac{R}{L_{n_i}} + \frac{1}{2}\frac{R}{L_{T_i}}\right)$$

Integrate first-principle models to predict 9 channels self-consistently





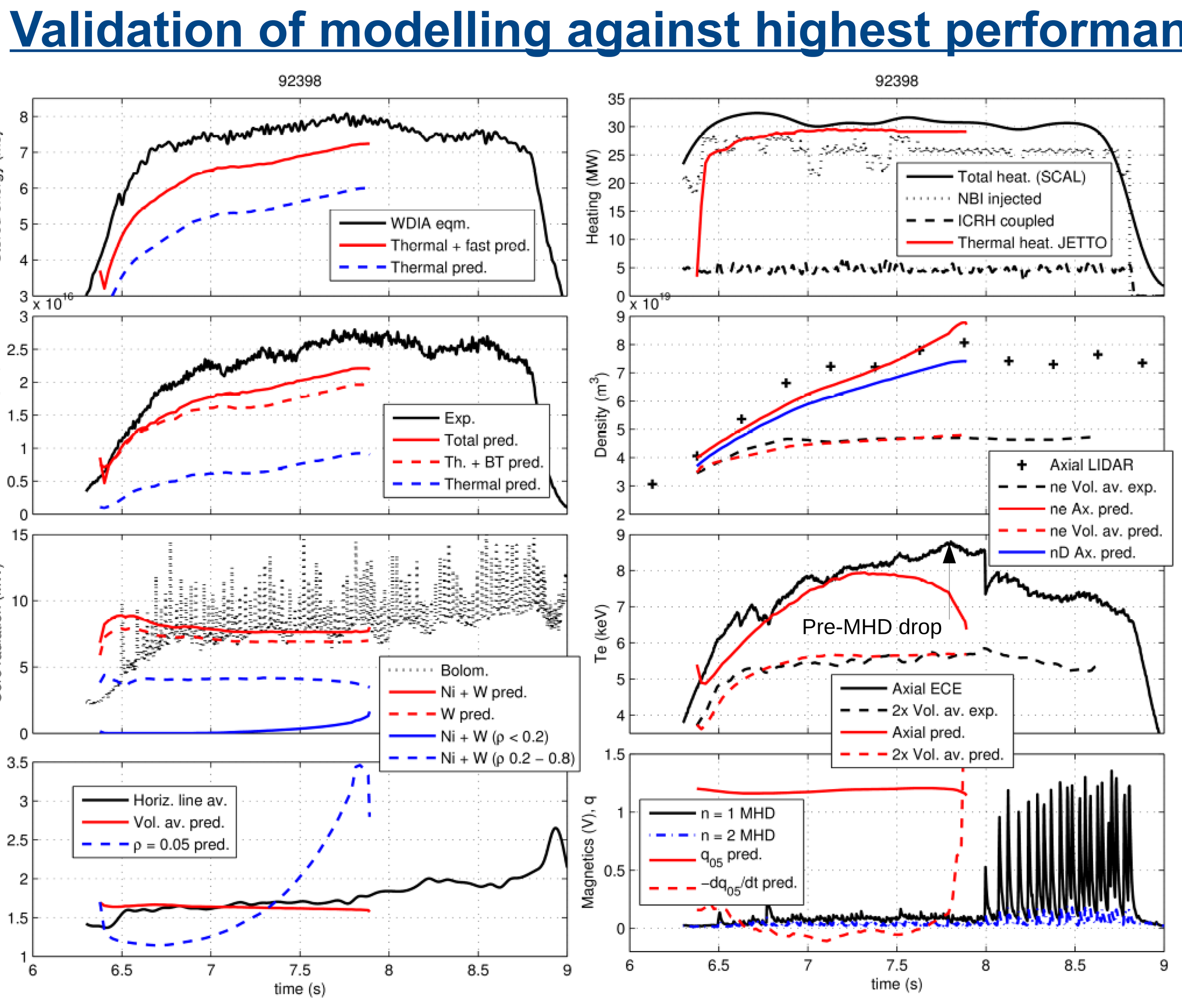
Predict **evolution** from start of H-mode

Core fully predictive using only first principle models [5]

Timescale of density rise well predicted

Rotation well predicted with symmetry breaking model

Validation of modelling against highest performance hybrid discharge

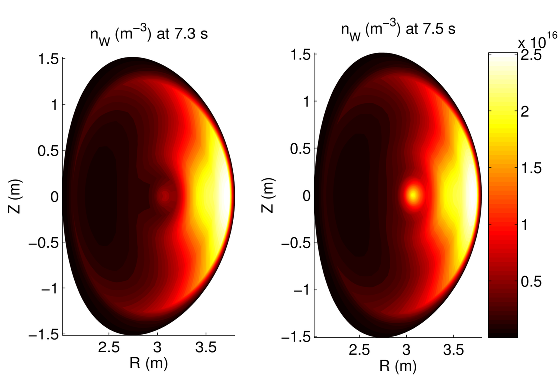


Bt = 2.8T, Ip = 2.2 MA

H_{98} = 1.3, τ_E = 0.17s

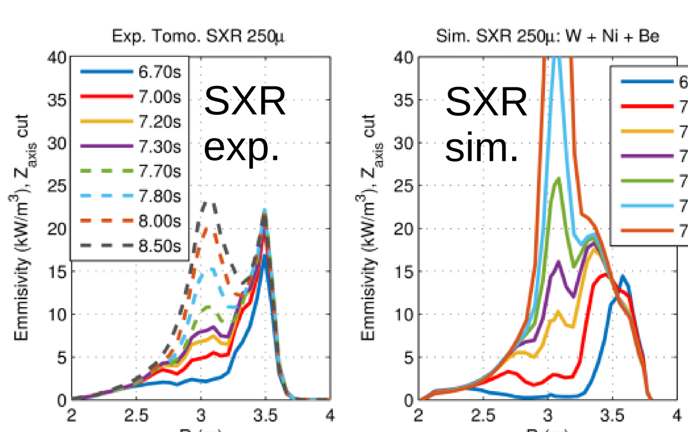
Black: Experiment

Colors: Predictive simulation



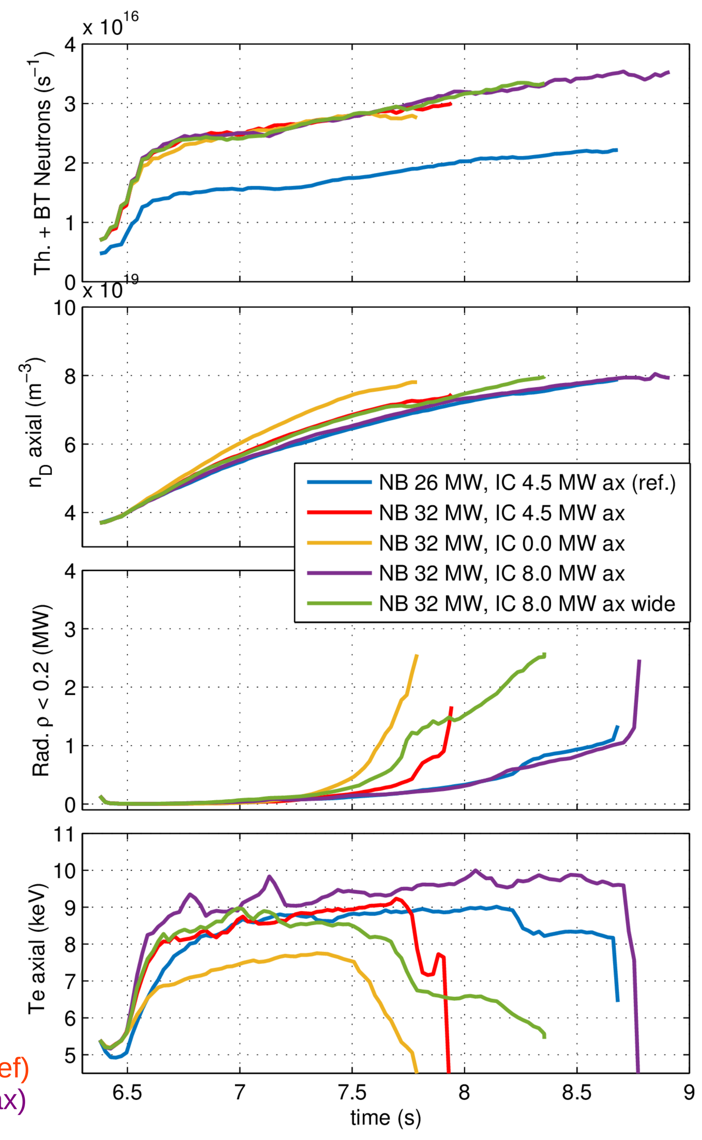
- **W on axis from 7.2s, in both simulation and expt.**
- **Radiative collapse in core**
  - **W dominates radiation**
  - **Ni dominates Zeff**

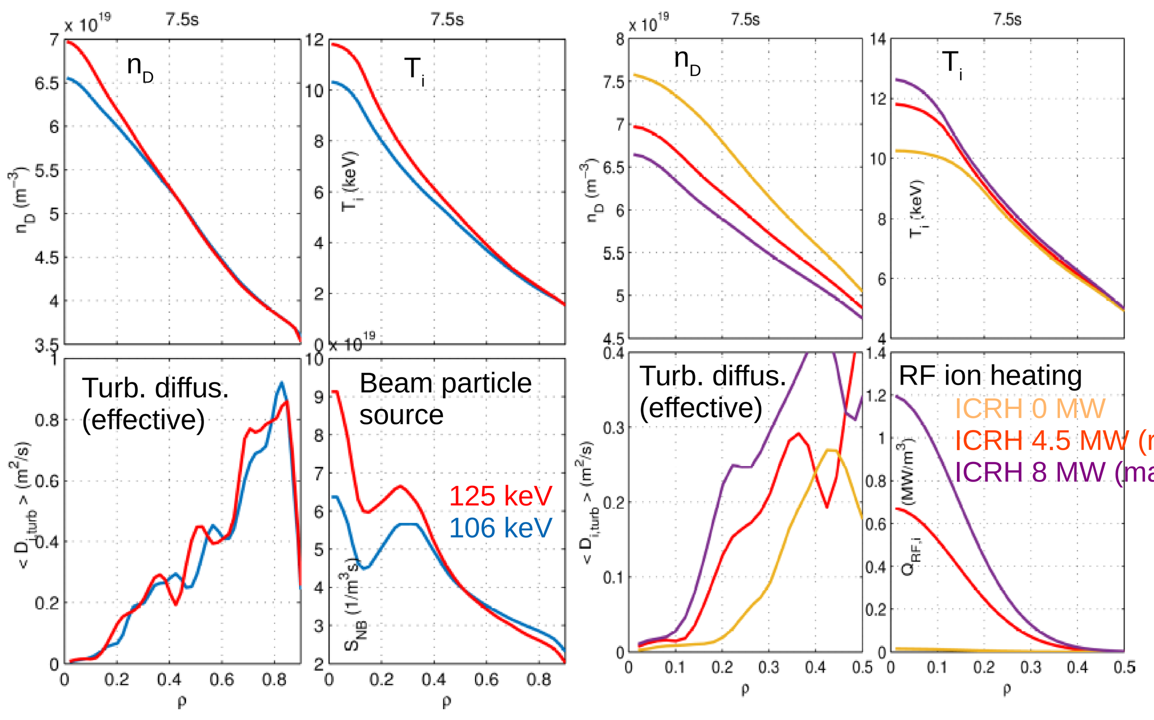
- **Accumulation process more controlled in expt.**
  - **Simulations *extremely* sensitive in accum. phase**
  - **May suggest a missing transport process**
  - **No ad-hoc transport used**
- **1,1 MHD arrives *after* accumulation begins**
  - Triggered by W? → loss of central bootstrap current
  - **Limits performance but mitigates accumulation**



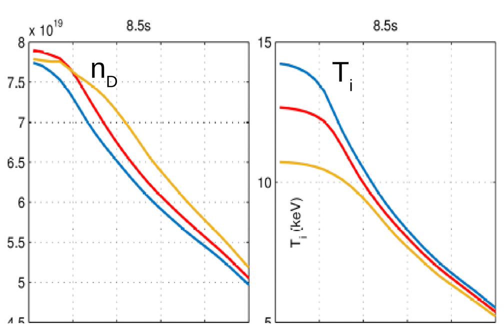
Optimisation of heating against W

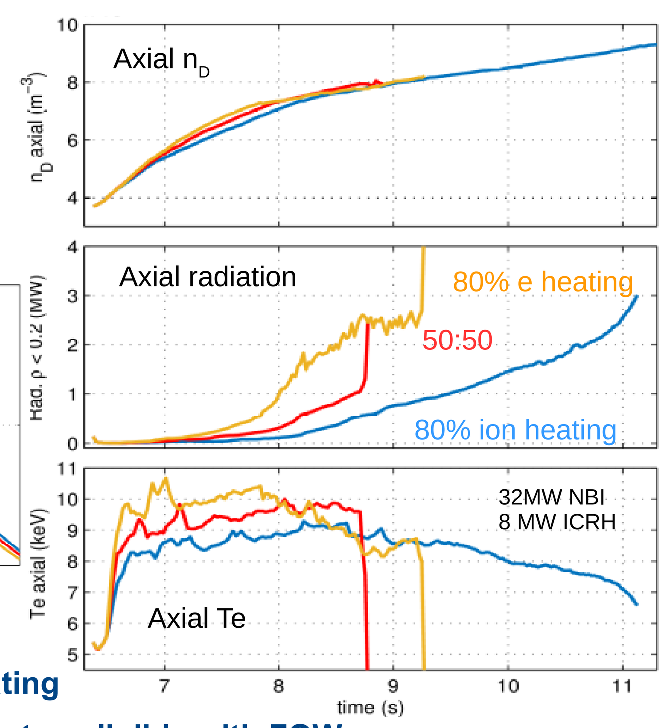
- **Increased NBI power will accelerate W accumulation [5]**
  - **Beam energies will be increased to reach maximum power**
  - **More central power, particle (density peaking), and torque deposition**
- **ICRH helps most in neoclassical dominated core, both increasing ∇T_i and decreasing ∇n_D**
  - **Increased turbulent diffusion reduces central density peaking localised axial ICRH most effective**
  - **Predictions consistent with JET observations [8,9]**
  - **4MW increase in ICRH compensates 6MW increase in NBI**

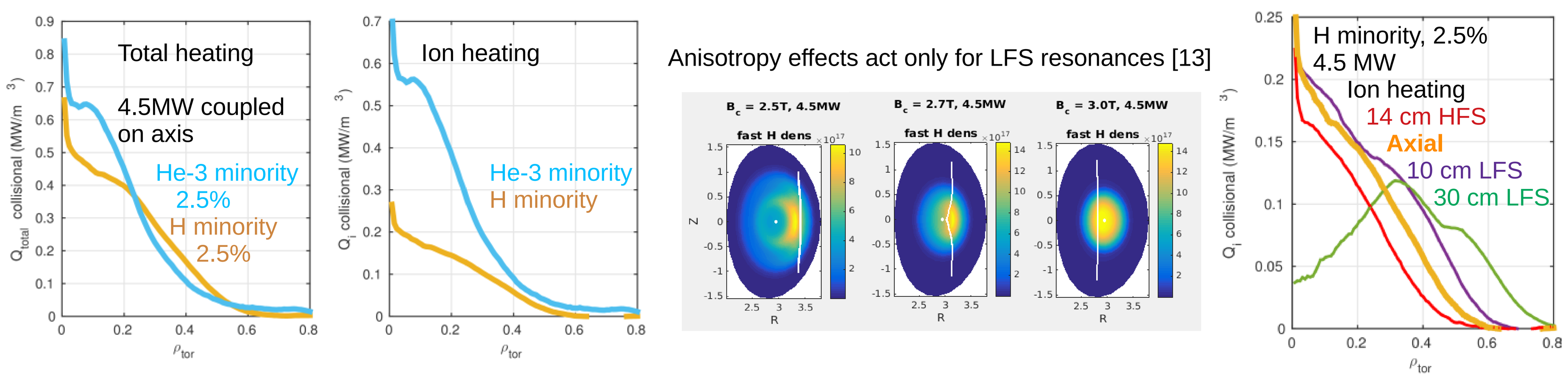




- **Ion heating schemes *predicted* as most effective on W**
  - **Ion heating both increases ∇Ti and decreases ∇n_D**
  - **Specific to JET hybrid scenario: Ti > Te, dominant neoclassical convection (large Mach no ~ 0.7)**
  - **Where Ti ~ Te coupled, or turb dominates, electron heating best [12] (e.g. ITER)**
- **Supporting high-fidelity ICRH model (SCENIC [10,11]) shows**
  - **He-3 minority scheme achieves larger power density and larger ion heating**
  - **Resonance within 10cm of axis is optimal; fast ion effects on W transport negligible with FOW**

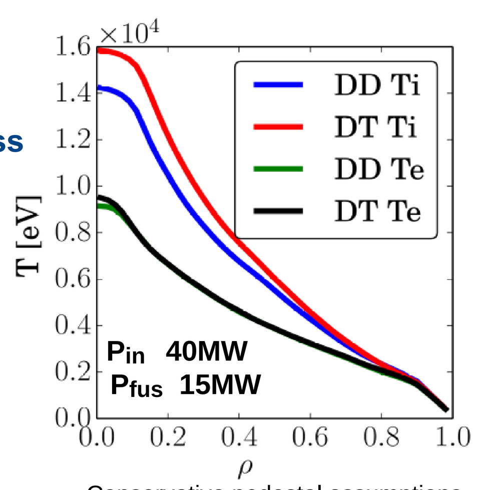




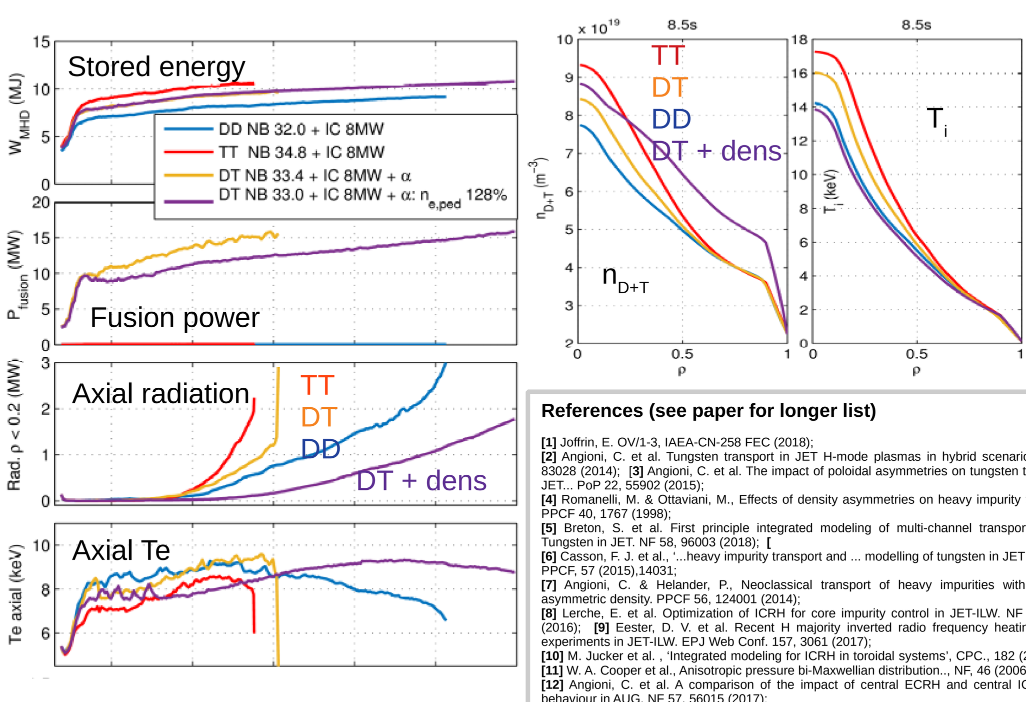


Predictions for DT

- **Tritium plasmas have better confinement but earlier W accumulation**
  - **Inclusion of ETG scales pins Te; i-e collisional energy exchange reduces with mass**
  - **Increased Ti / Te and ITG stabilisation; specific to plasmas with Ti > Te [14]**
  - **Improved confinement in DT also gives larger density peaking**
- **Mitigate with increased density (less central NBI particle deposition)**
  - **Some cost in performance - requires optimisation / integration**
  - **Access via Increased triangularity / plasma current / pedestal isotope scaling**



Conservative pedestal assumptions (no scaling with power or isotope)



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Summary

- **First-principle models integrated into a powerful multi-channel predictive tool for core plasma**
- **Reproduces observed W accumulation after several confinement times**
- **Guides scenario development to optimise W control in JET hybrid**

JET CCFE ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE cea DIFFER IPP GENERAL ATOMICS

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