Impurity, Heat and Momentum Transport in the First DIII-D/WEST Similarity Experiment

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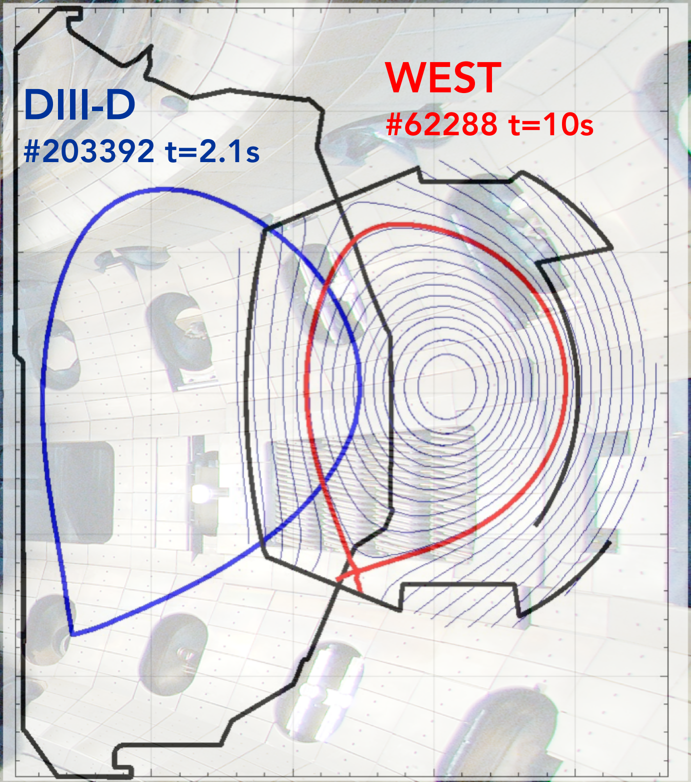
APS DPP 2025 • Long Beach, CA

November 17–21, 2025

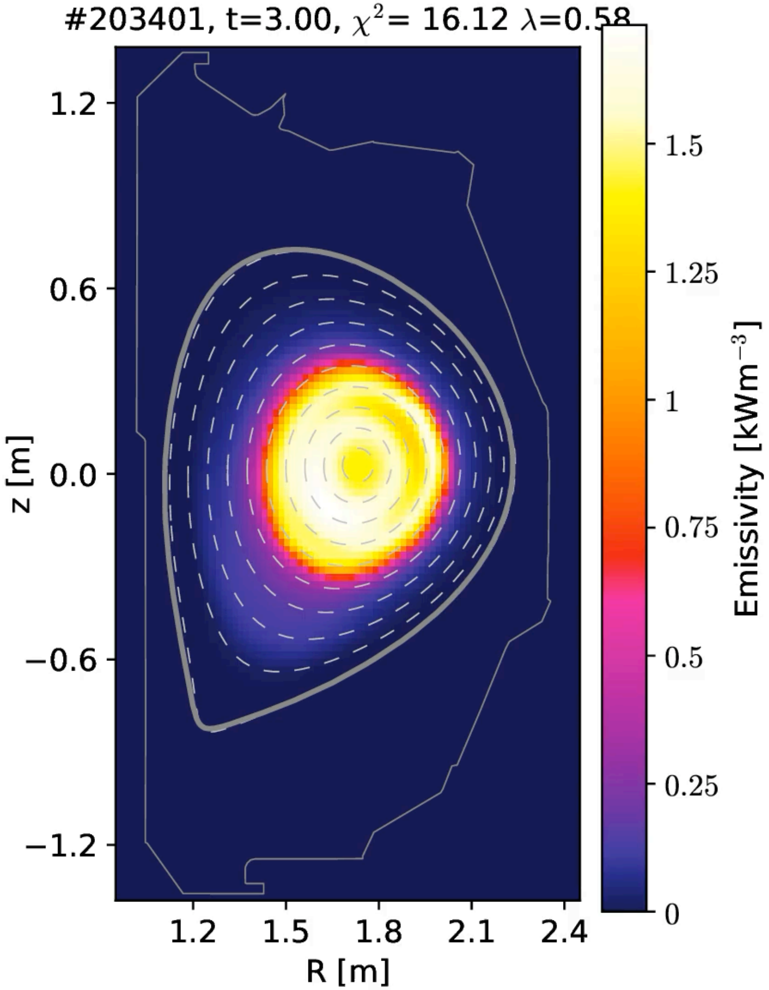


Supported by the U.S. DOE under DE-SC0014264 and DE-FC02-04ER54698.

Motivation & Outline
Plasma performance with high W radiation

- **Motivation**
  - Tungsten (W) is the primary high-Z material for FPPs
  - Understanding plasma performance in W environment is essential
  - DIII-D and WEST devices complement each other
    - *WEST : long-pulse, full W wall*
    - *DIII-D : C-wall + Laser Blow-Off (LBO) for controlled W injections*
- **This Talk :**
  - **DIII-D** similarity experiment with high, WEST-like, **W radiation**
  - Originally aimed at discussing **MHD** effects on **W impurity**
  - Observed strong **thermal/momentum transport** changes with **high f_{rad}**
  - with consequences for impurity transport, and **W peaking**

MHD W pump-out observed with SXR in DIII-D



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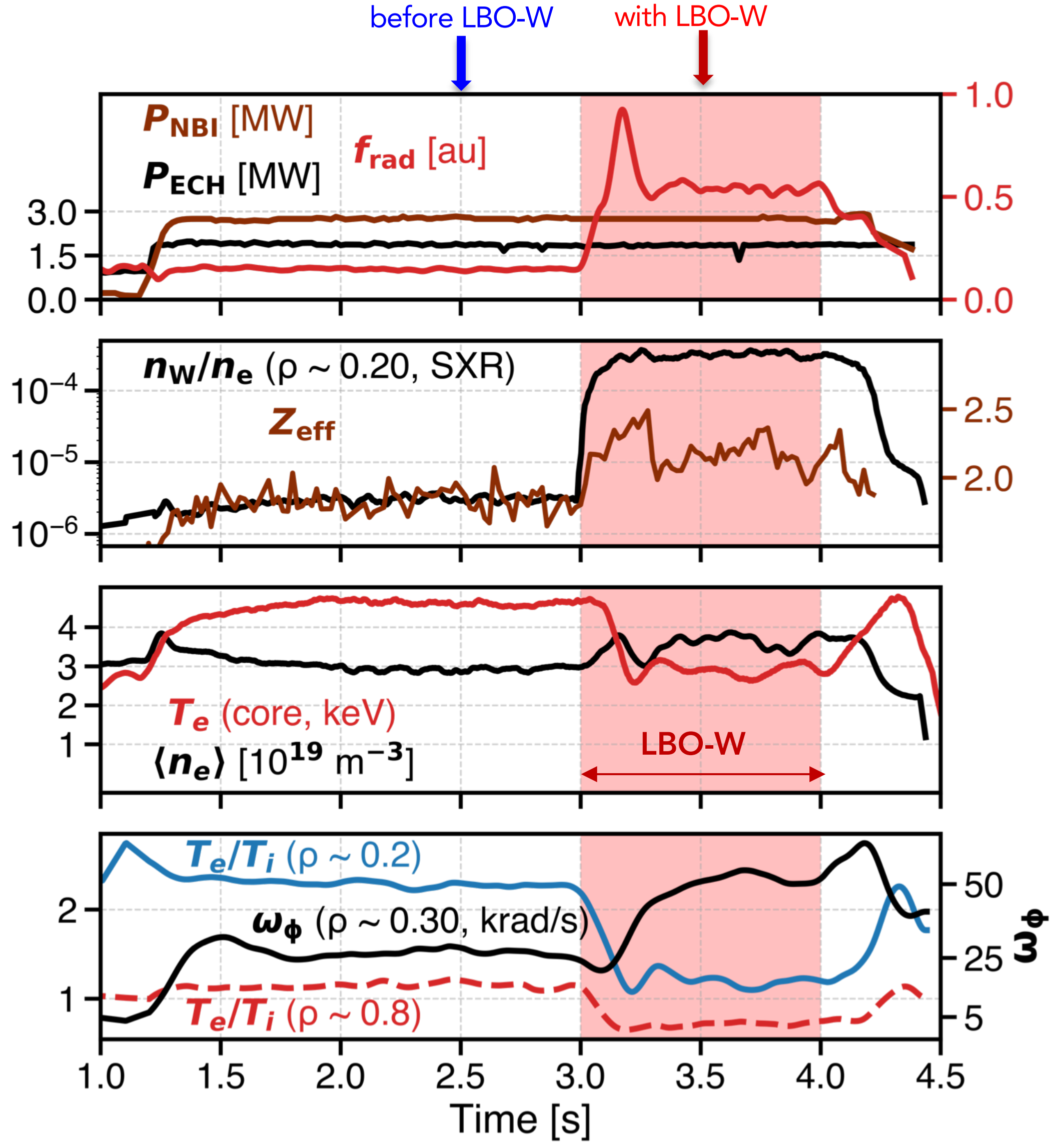
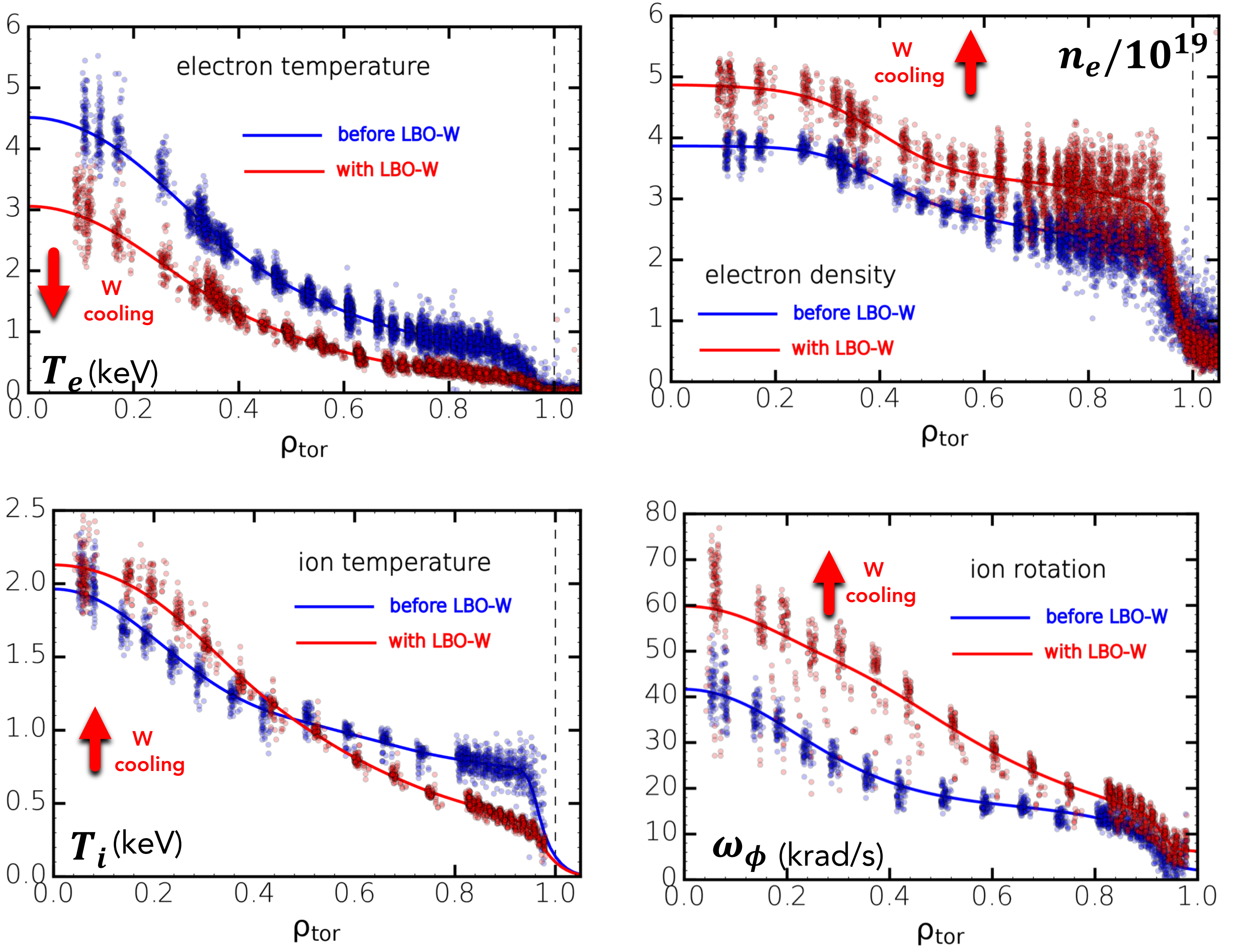
Laser Blow-Off (LBO) induced high W radiative cooling in DIII-D/WEST similarity experiment

- **DIII-D experiment achieved with WEST matched parameters :**
  - *triangularity* δ , *elongation* κ , q_{95}
  - and normalized core parameters (*toroidal beta, ion larmor radius, collisionality, electron to ion temperature ratio* T_e/T_i*, Mach numbers*). ***X Litaudon BO04 – MFE ITER Session***
- **LBO-W injection yielded**
  - W concentration $\boldsymbol{n_W/n_e \sim 3\times10^{-4}}$
  - Radiated power fraction $\boldsymbol{f_{rad} = P_{rad}/P_{in} > 0.5}$
- **W radiative cooling in DIII-D enabled observation of :**
  - electron temperature drop ($\boldsymbol{T_e}$⬇) and density rise ($\boldsymbol{n_e}$⬆)
  - increased toroidal rotation velocity, $\boldsymbol{\omega_\phi}$⬆
  - reduction in $T_e/T_i < 1$ in the edge



W radiative cooling drives ion-temperature peaking and increased plasma rotation

- **Key DIII-D observations with W cooling :**
  - T_e decreases and n_e increases across the radius
  - **ion-temperature peaking develops**
    - *+ ~10% on-axis, reduced pedestal* T_i
  - **toroidal rotation** increases by **up to a factor-of-two**
- **Profiles modeling confirms these trends**
  - TGLF/NEO match measured responses
  - points to changes in **background turbulence**
- **Implications for WEST**
  - Insights into T_i , W peaking and plasma rotation (more difficult to assess on WEST)



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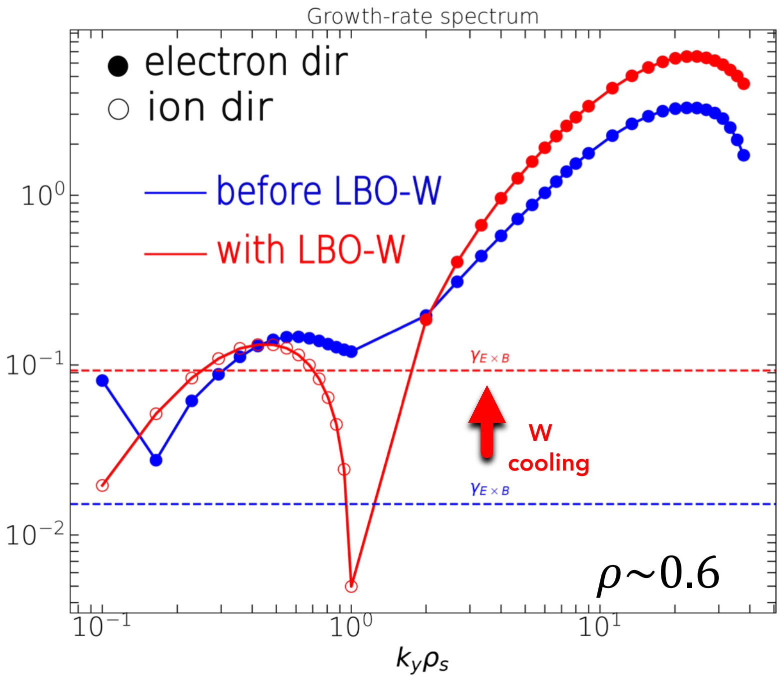
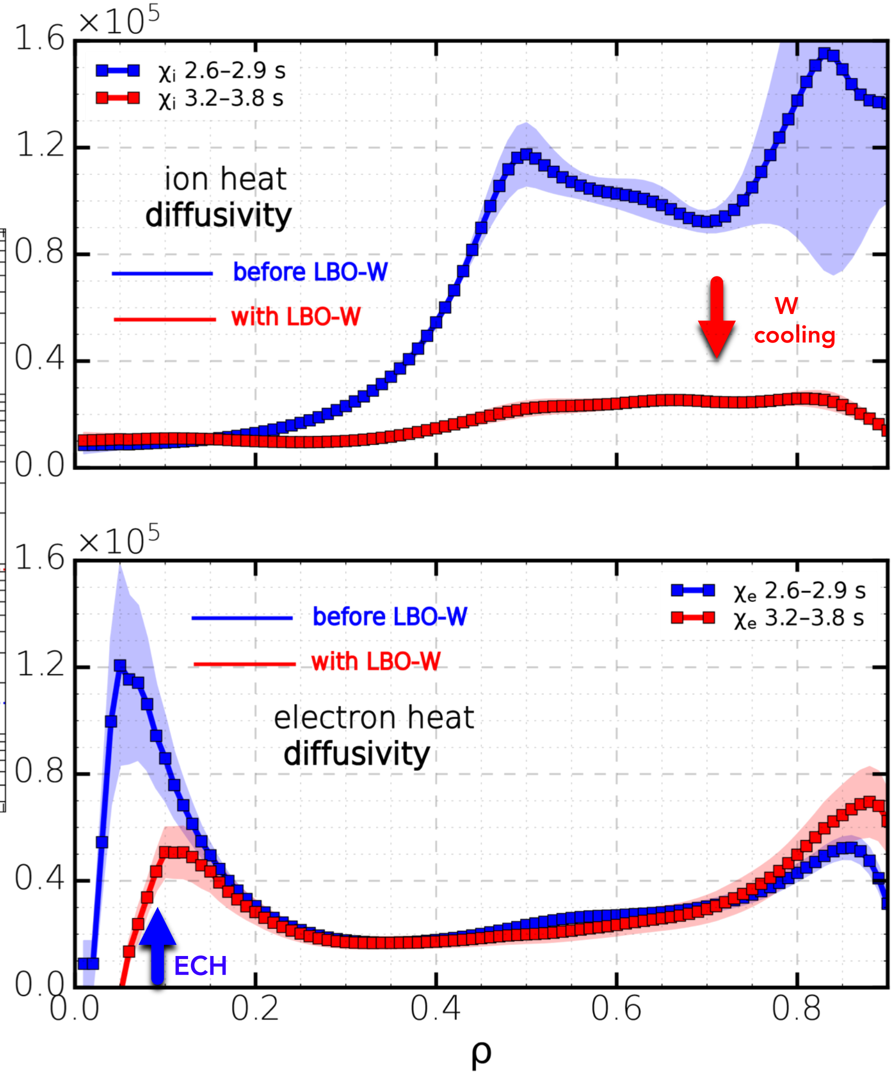
Turbulence transition and stabilization with radiative W cooling drive the observed changes.

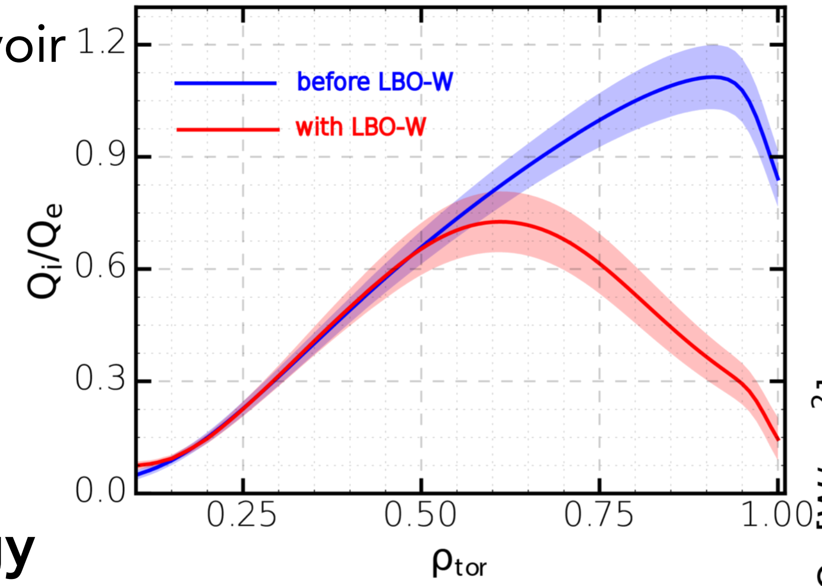
- **Mechanism behind the changes**
  - T_e/T_i, Z_{eff}, ν_{ee} shift mixed **TEM/ITG to → ITG**
  - overall **turbulence level decreases**
- **Toroidal rotation increase**
  - enhances $E{\times}B$ **shear**
  - quenching remaining ITG
- χ_i **strongly drops towards the edge, no core changes**
- χ_e **drops only around ECH**
  - even rises towards very edge

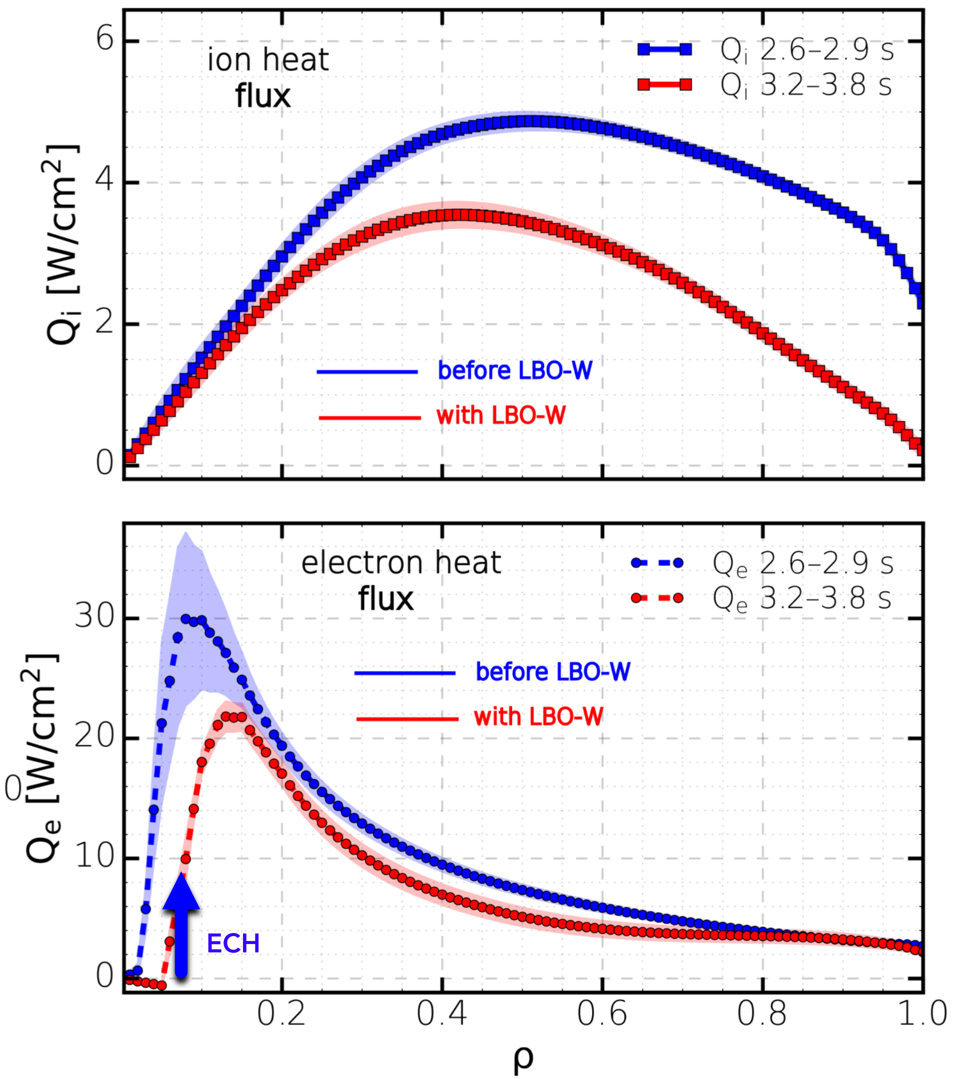




T_i peaking with W cooling arises from turbulence reduction, and i→e heat exchange in the edge

- **Core Q_i unchanged by W cooling**
- **Edge Q_i/Q_e drops strongly**
  - edge ions are energy reservoir for electrons ($T_e < T_i$)
- **Flattened T_i pedestal + unchanged core Q_i**
  - → produces T_i peaking
  - lower χ_i reinforces peaking
- **Both the reversal of energy transfer and reduced turbulence contribute**





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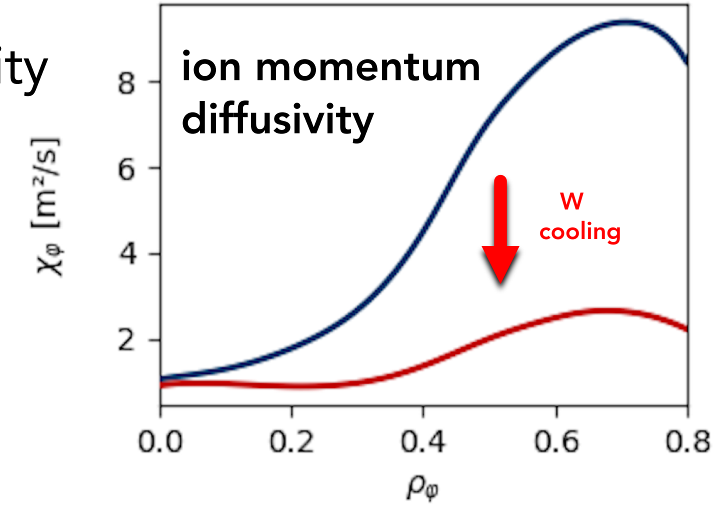
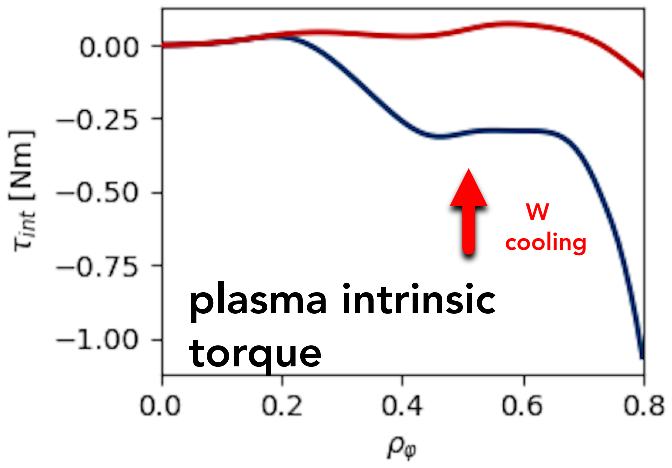
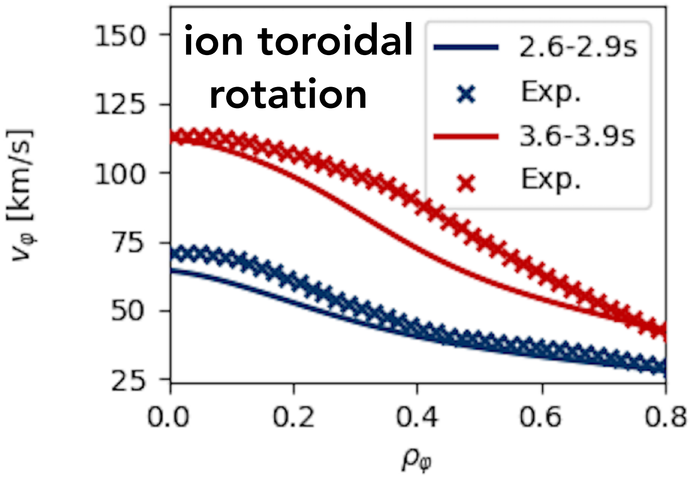
Radiative W cooling stabilizes turbulence and restores toroidal plasma rotation

- **Turbulence reduction from W**
  - Reduces ion momentum diffusivity χ_ϕ
  - Lower χ_ϕ allows rotation to rebuild
- **Intrinsic torque τ_{int}**
  - is **less negative with W cooling**
  - further supports rotation recovery
  - **NBI torque input unchanged** between the two phases
- **Relevance to WEST**
  - similar turbulence-driven changes expected: **harder to diagnose directly on WEST**







Before LBO-W

with LBO-W

Reduced-rotation model (*Zimmermann PoP 2024*) well reproduces the observed rotation recovery using experimental profiles.

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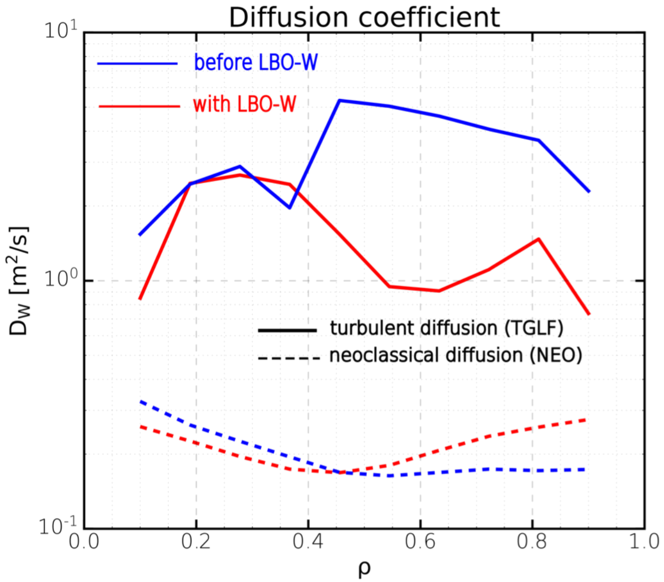
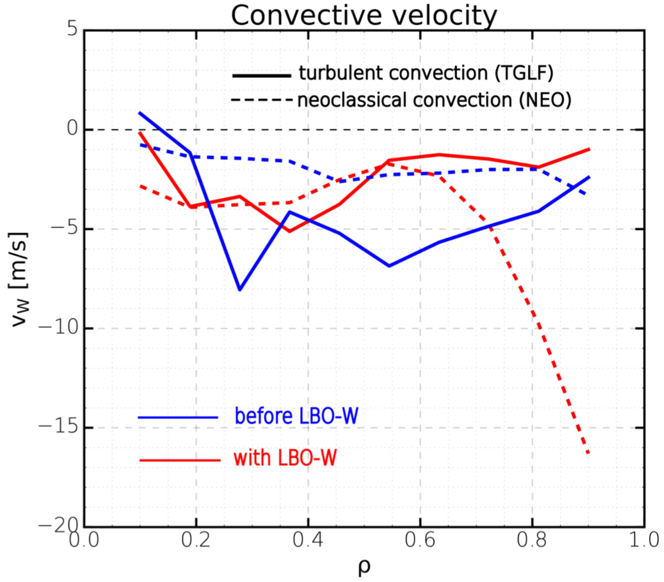
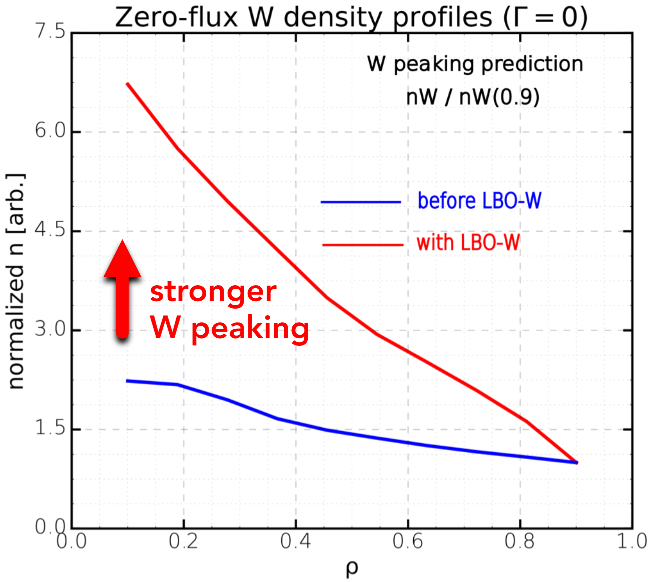
Radiative cooling enhances the inward neoclassical pinch → increased W peaking !

- **Turbulent transport decreases:**
  - Lower turbulent D and v in the W-cooled phase
- **Neoclassical inward pinch increases**
  - Stronger v_{neo} with cooling
  - almost across entire radius
- **Combined effect → more peaked W**
  - cooling suppresses turbulence, enhances neoclassical pinch, **bootstrapping the cycle.**
- **Relevance to WEST & W-walled DIII-D**
  - impurity accumulation **bigger concern** with **high** f_{rad}.







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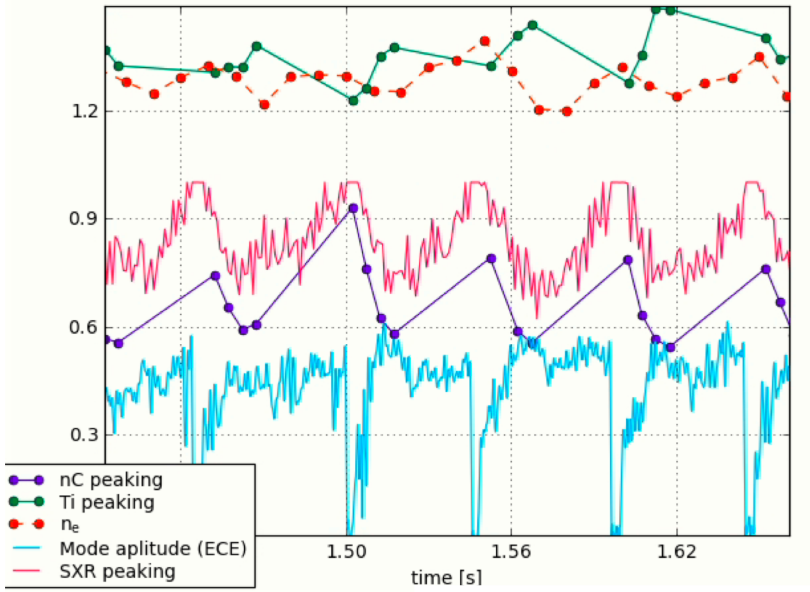
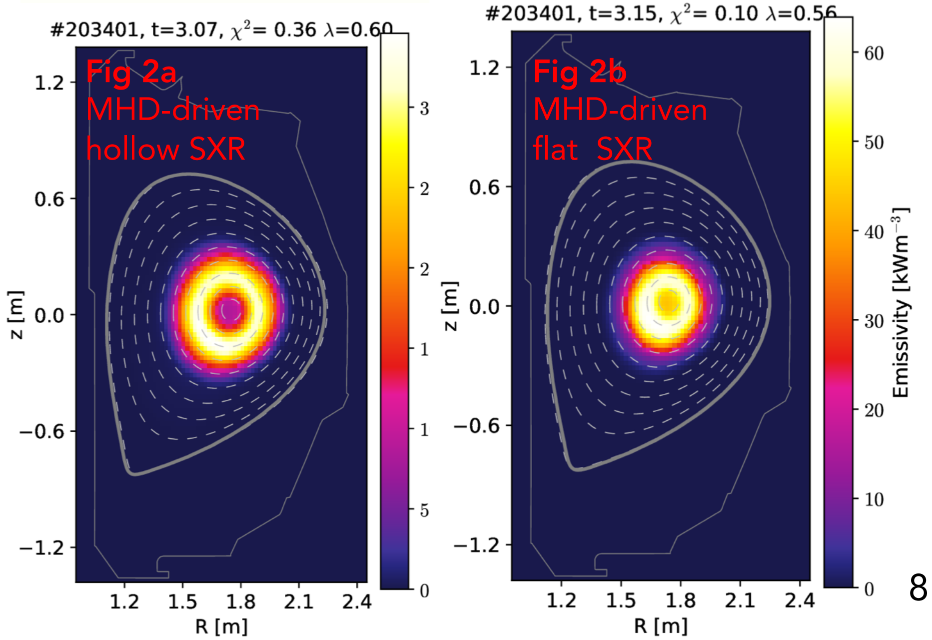
Impurity peaking modulated by MHD activity, possibly through T_i-screening effects

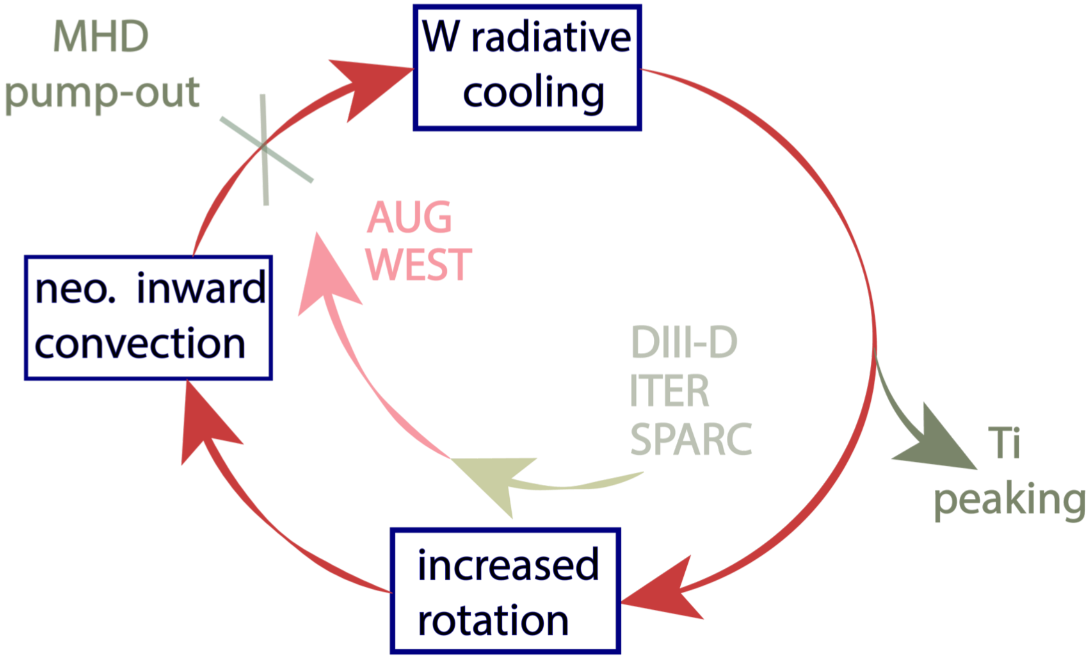
- **Benign MHD mode present through the discharge**
  - mode frequency doubles during cooling phase
- **Impurity peaking oscillates in phase with the MHD amplitude**
- MHD oscillations **modulate T_i and n_e profiles** → modulate neoclassical convection
- **Higher T_i and flatter n_e enhance outward neoclassical convection** (T_i -screening) → reduces W peaking (**Fig 2a**)





Conclusions

- **LBO was used to simulate W environment in DIII-D/WEST similarity plasma**
  - with $n_W/n_e \sim 3\times10^{-4}$, $f_{rad} > 0.5$ (matching WEST)
- **Radiative cooling by W**
  - increases toroidal rotation
  - shifts, stabilizes turbulence via lower $\boldsymbol{T_e/T_i}$ and enhanced $\boldsymbol{E\times B}$ **shear**
  - indirectly enhances ion heat confinement (T_i peaking)
- **Impurity transport**
  - modulated by MHD pump-out via $\boldsymbol{T_i}$ **screening**
  - is mainly turbulent in the no-W phase
  - acquire stronger **inward neo. pinch with high cooling**



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A Biwole, RSI & NF, in prep
S K Kim, PRL, in review
X Litaudon BO04 – MFE ITER

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