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Enabling Adaptive Detachment Control: Novel Insights From Calibration-free X-point Phase Difference

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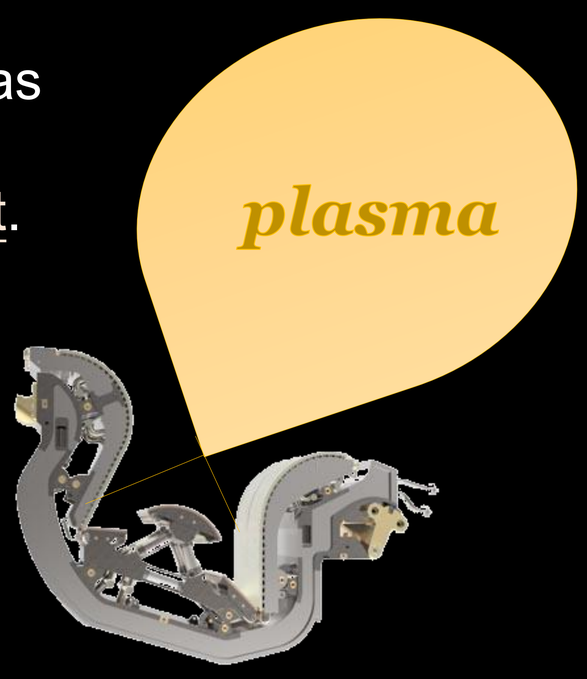
Motivation

➢High power load has to be alleviated via divertor detachment.



Direct measurement
↓
inoperative

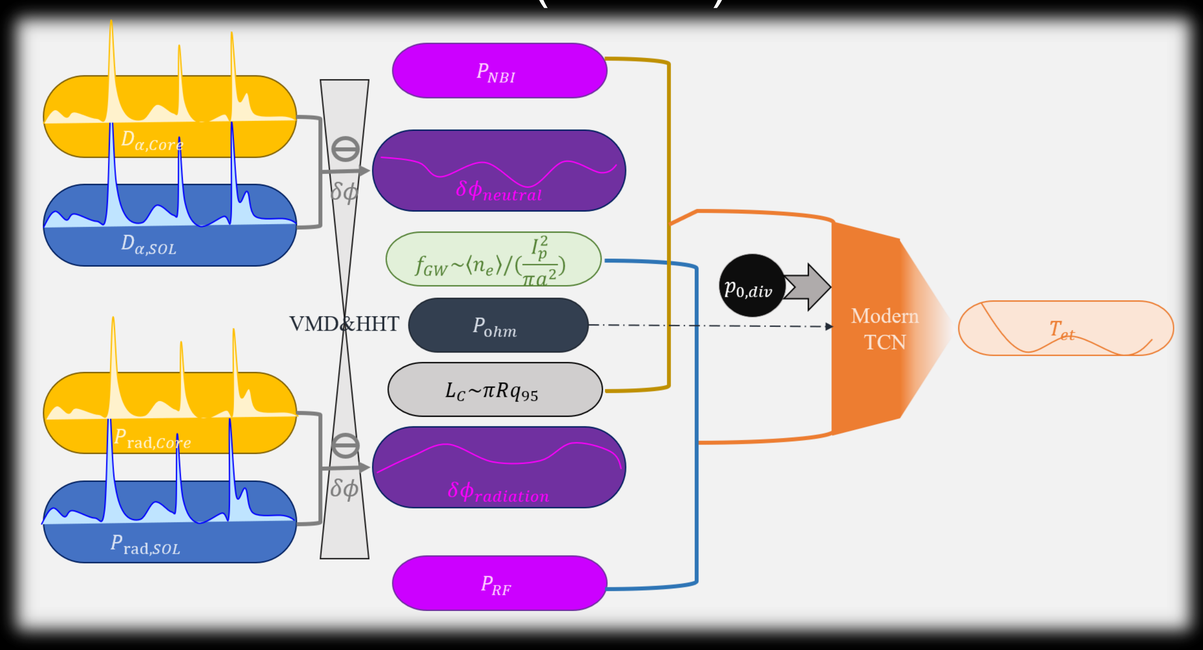
PID control
↓
delayed
sensitive to non-linearity

Inversion monitoring
↓
calculating cost
untimely absolute calibration

➢ Non-intrusive
➢ Real-time
➢ Calibration-free

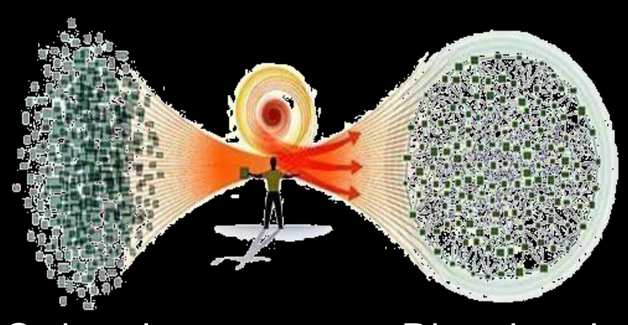
Algorithm

◆X-Point Ionization-Radiation Interface Structure (**X-IRIS**)



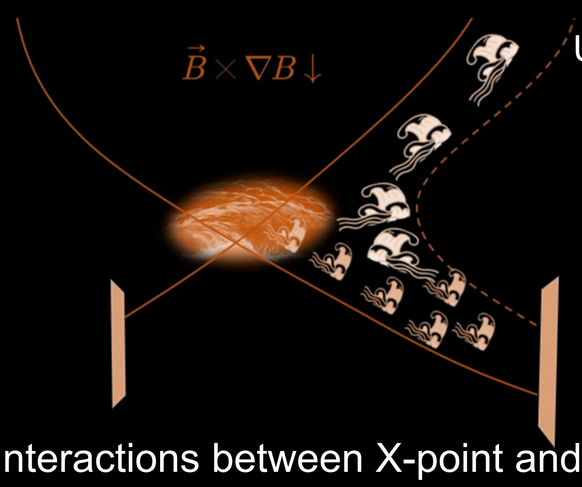
➢ **VMD:** K. Dragomiretskiy and D. Zosso, IEEE Trans. Signal Process. 62, 531 (2014).
➢ **ModernTCN:** D. Luo and X. Wang, ICLR(2024).

Theory



Ordered (gradient-driven)

Disordered (random distribution)



UCF Determinant

$v_\theta\downarrow$

Radial Transport Enhanced

$\tau_{diff}\uparrow$

λ_q Broadened

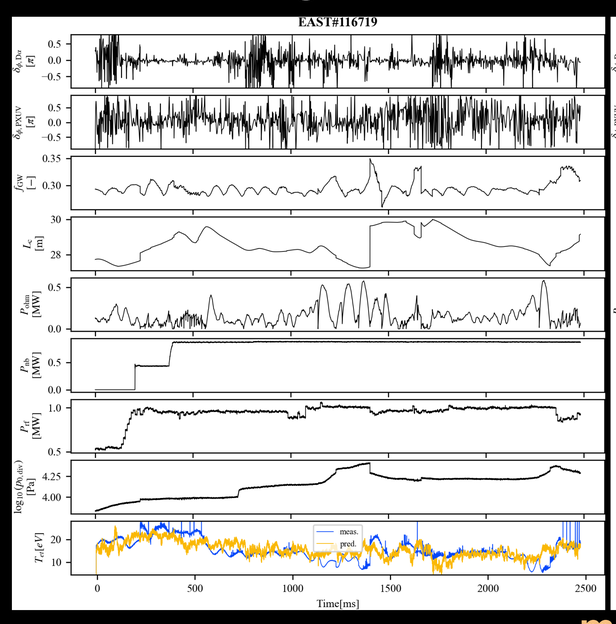
Stable Detachment

Interactions between X-point and the divertor

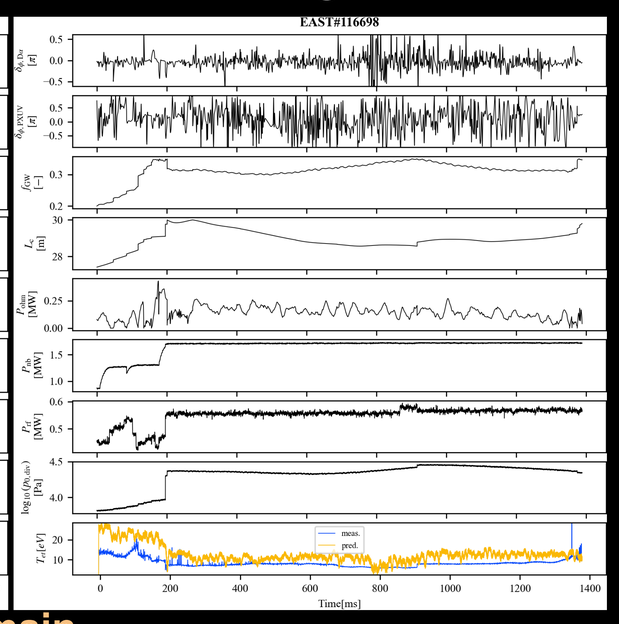
➢ C. Wüthrich et al., Nucl. Fusion 65, 016011 (2025).

Validation

RF-heating dominant



NBI-heating dominant

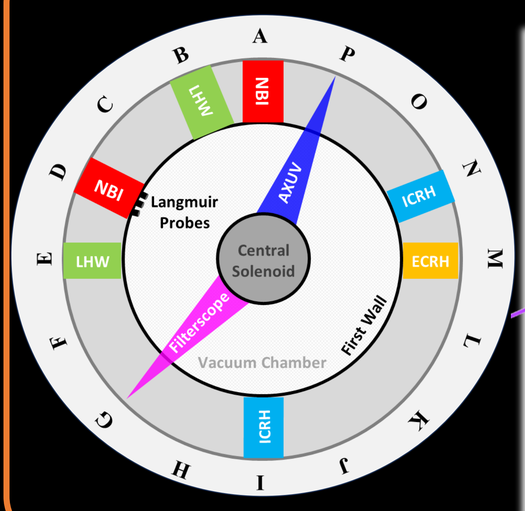


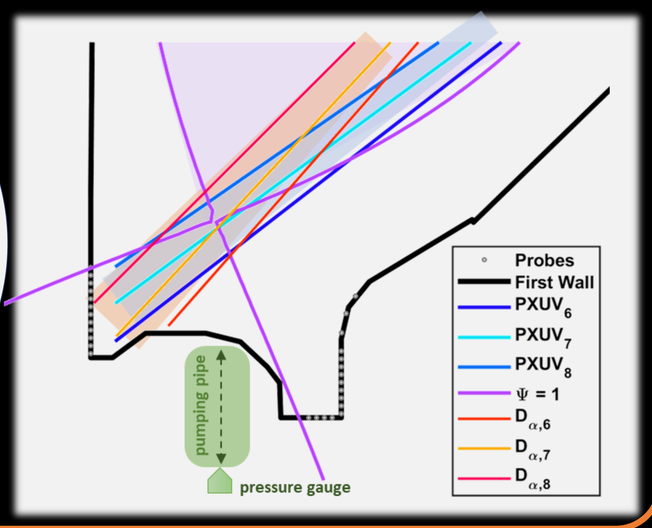
wave-particle interaction — **main mechanism** — collision and ionization

uneven energy absorption — instant global fueling

gradient-driven instabilities — **potential outcome** — instantaneous energy dissipation

Data Acquisition





Conclusions

- ✓ Towards **low q_{95}** burning plasmas, a physical-informed framework named **X-IRIS** has been proposed.
- ✓ X-IRIS pioneeringly utilizes the **entropy dynamics** of X-point turbulence to evaluate the energy dissipation in the divertor region.
- ✓ The **synergetic effect** of NBI and radio-frequency heating has been explored and concluded to the ratio between NBI and RF power.

Acknowledgement

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