First Observation of ELM Suppression in ASDEX Upgrade In a Shape Matching Experiment with DIII-D

by

R. Nazikian[1]

on behalf of W. Suttrop[2], A. Kirk[3], M. Cavedon[2], T.E. Evans[4], B. Grierson[1], A. Hyatt[4], M. Knolker[2], Y.Q. Liu[3], B. Lyons[4], R.M. McDermott[2], C. Paz-Soldan[4], D. Orlov[5], D.A. Ryan[3], E. Viezzer[2], Z. Wang[1], M. Willensdorfer[2], A. Wingen[6], and the AUG, DIII-D and EUROfusion MST-1 teams

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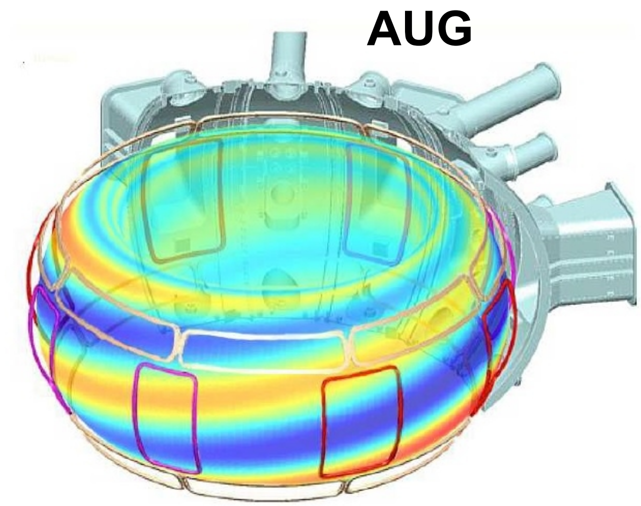

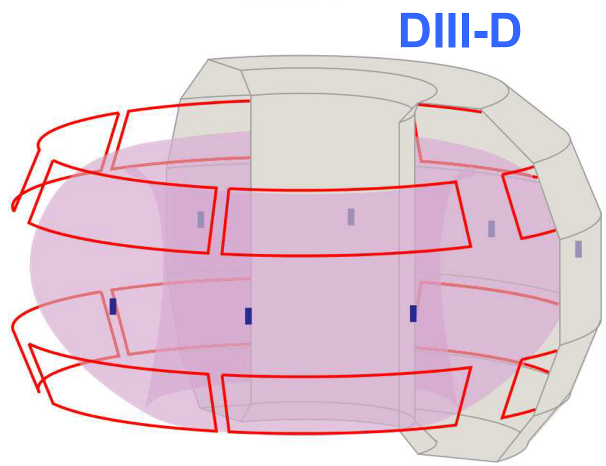

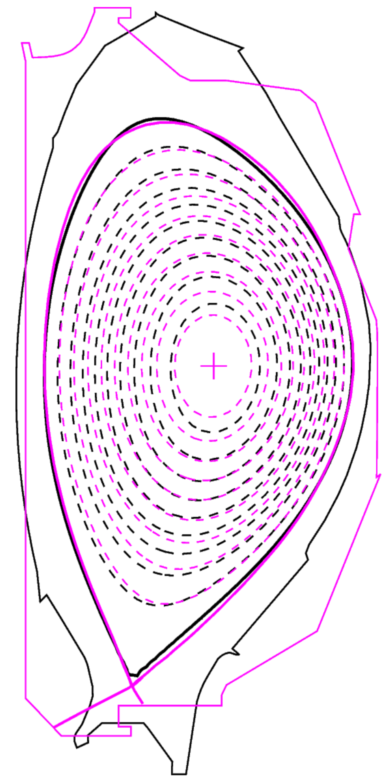

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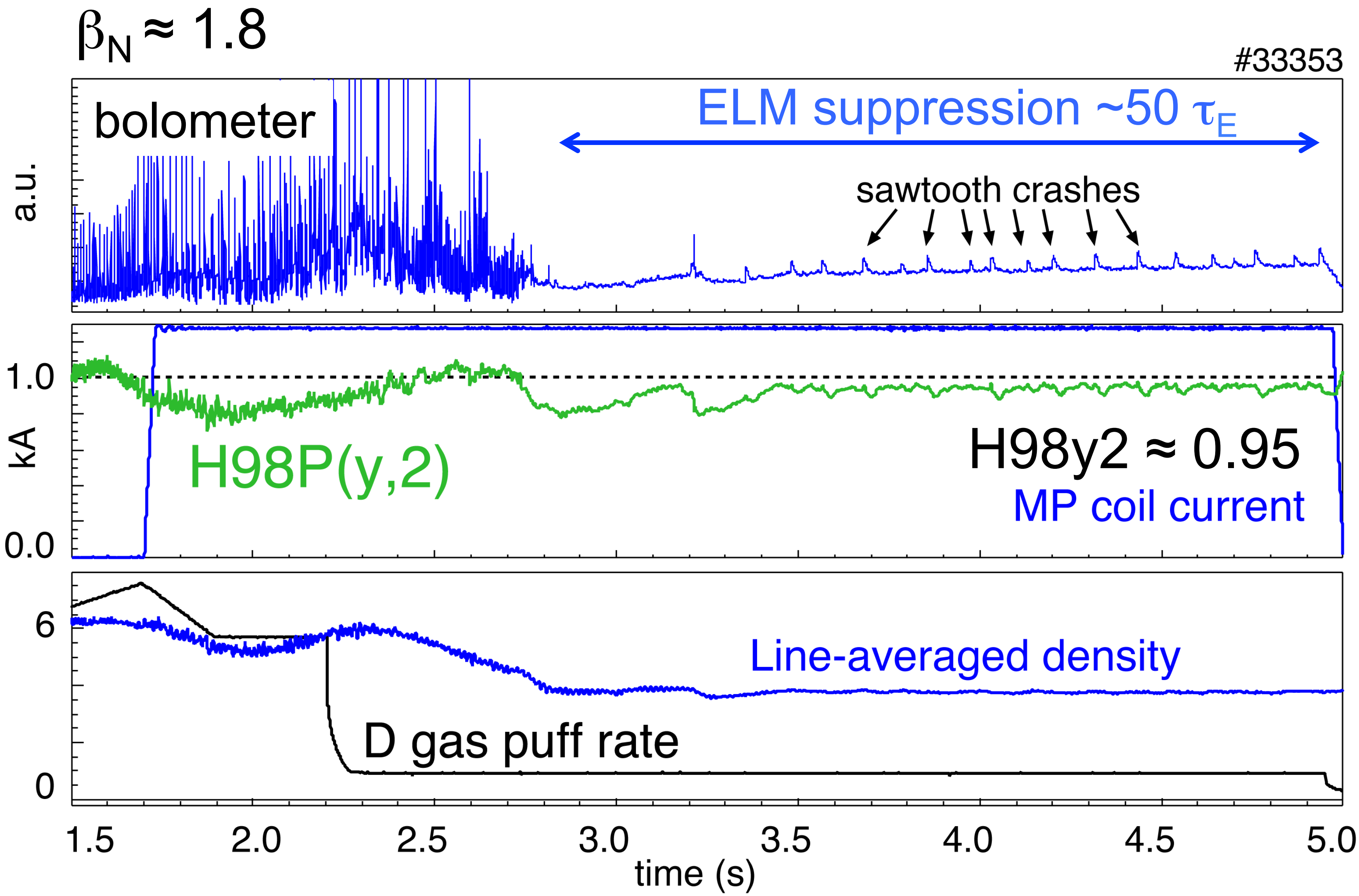
ASDEX Upgrade

IPP

CCFE CULHAM CENTRE FOR FUSION ENERGY

PPPL PRINCETON PLASMA PHYSICS LABORATORY

ELM Suppression Is Observed For First Time in ASDEX Upgrade at ITER Relevant Collisionality ($\nu_e^* \approx 0.25$)



Sustained ELM suppression for 50 τ_E

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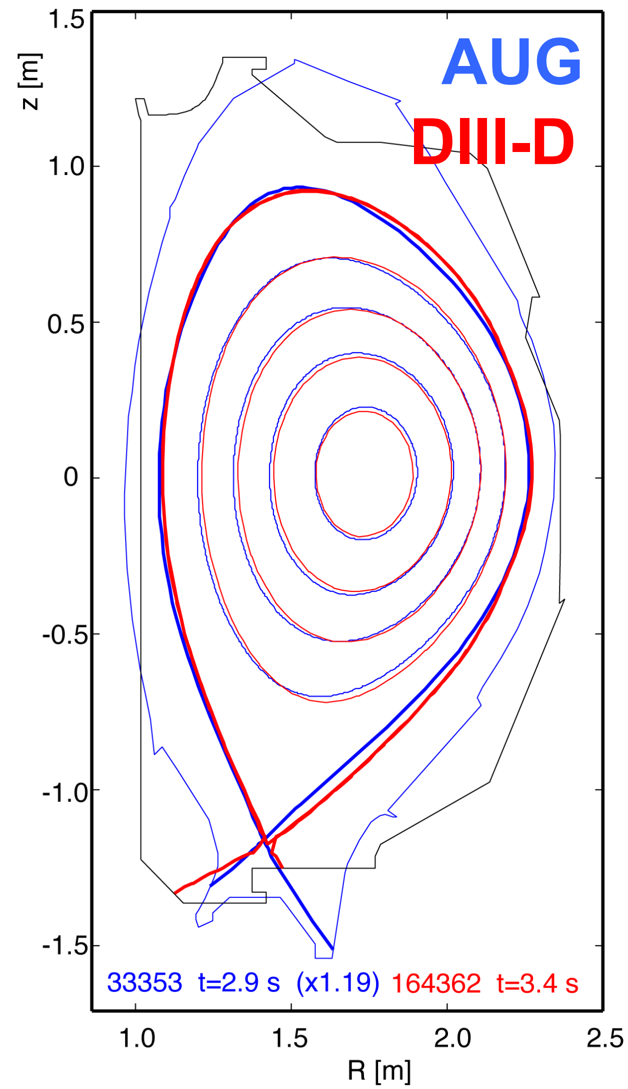
First Observation of ELM Suppression in ASDEX Upgrade In a Shape Matching Experiment with DIII-D

- **Characteristics of ELM suppression in ASDEX Upgrade, comparison to DIII-D**

- **The role of plasma shape in controlling access to ELM suppression**



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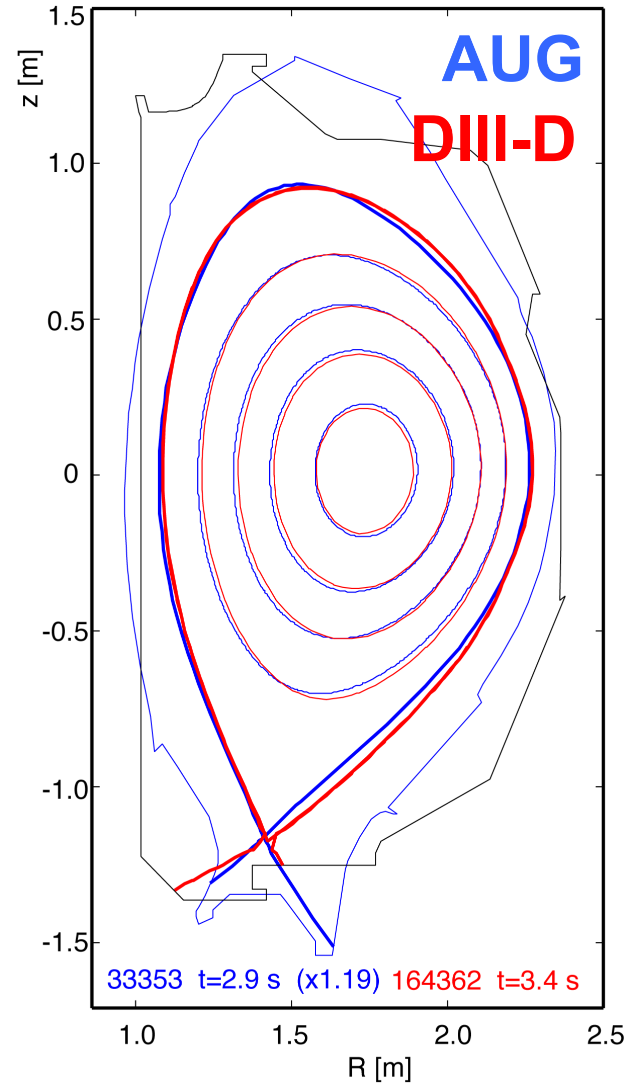
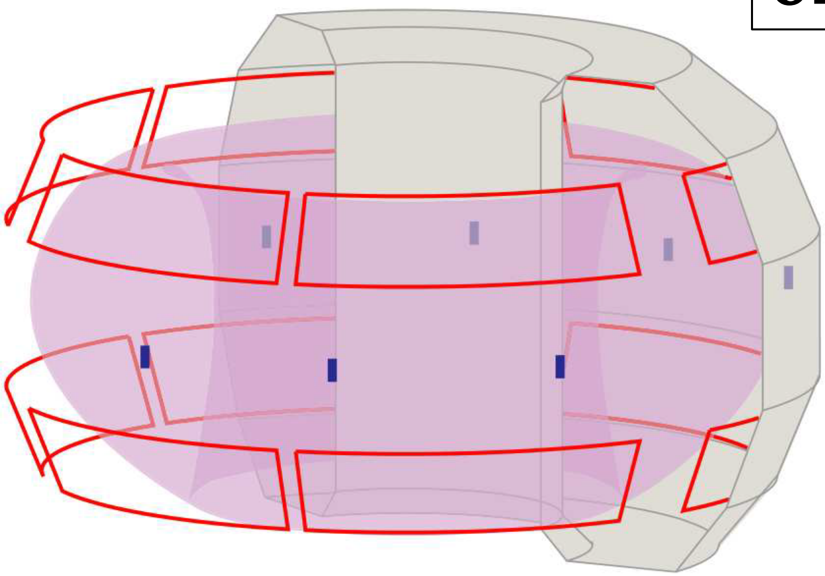
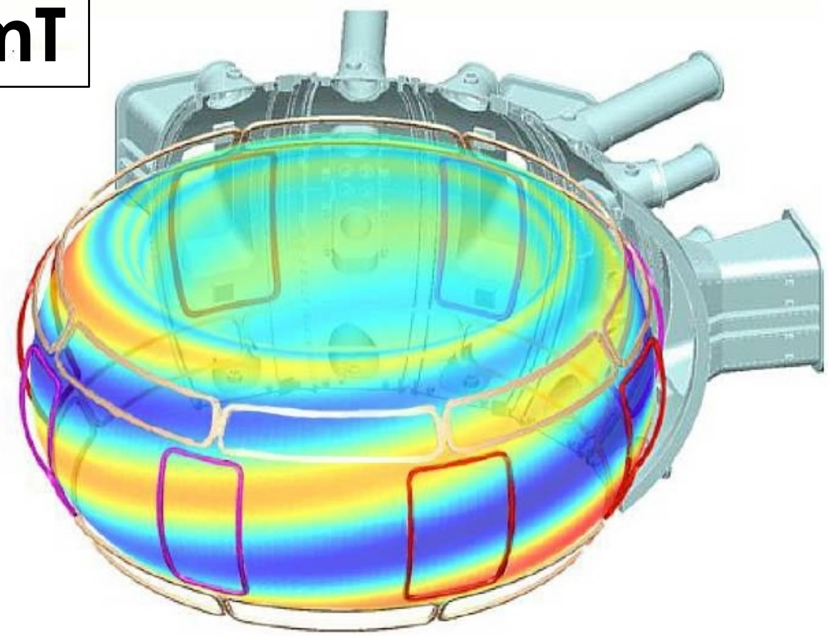


DIII-D and ASDEX In Vessel Coils

DIII-D: 2x6 MP coils



AUG: 2x8 MP coils



$\delta B \approx 0.5$ mT

DIII-D with n=2, 3, ELM suppression
AUG with n=2, 4, ELM mitigation

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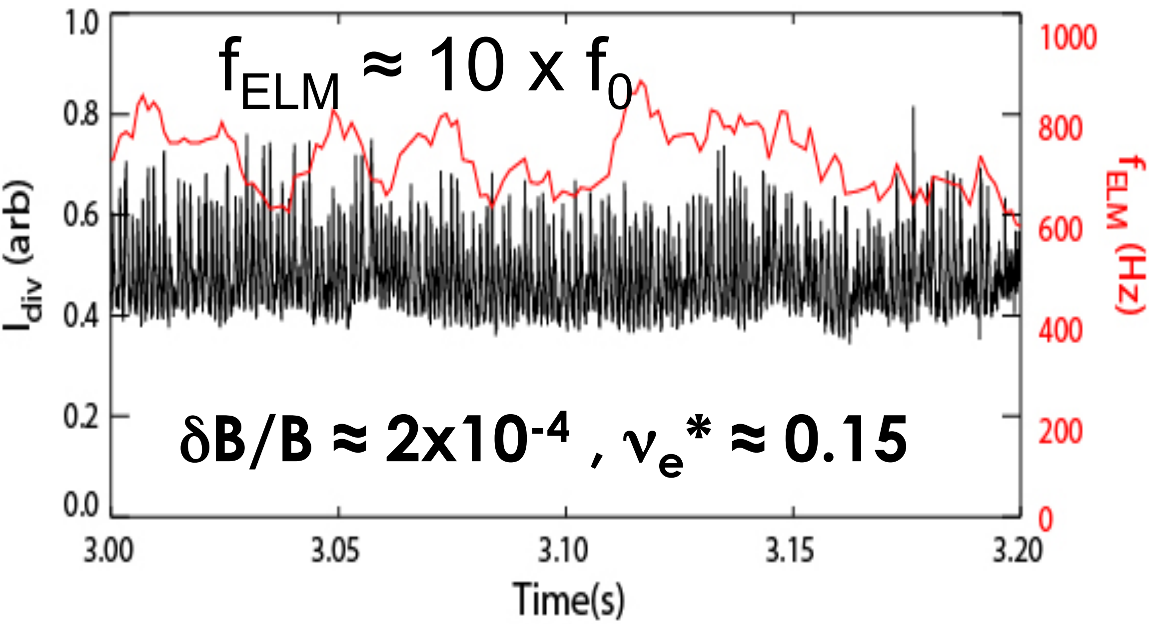
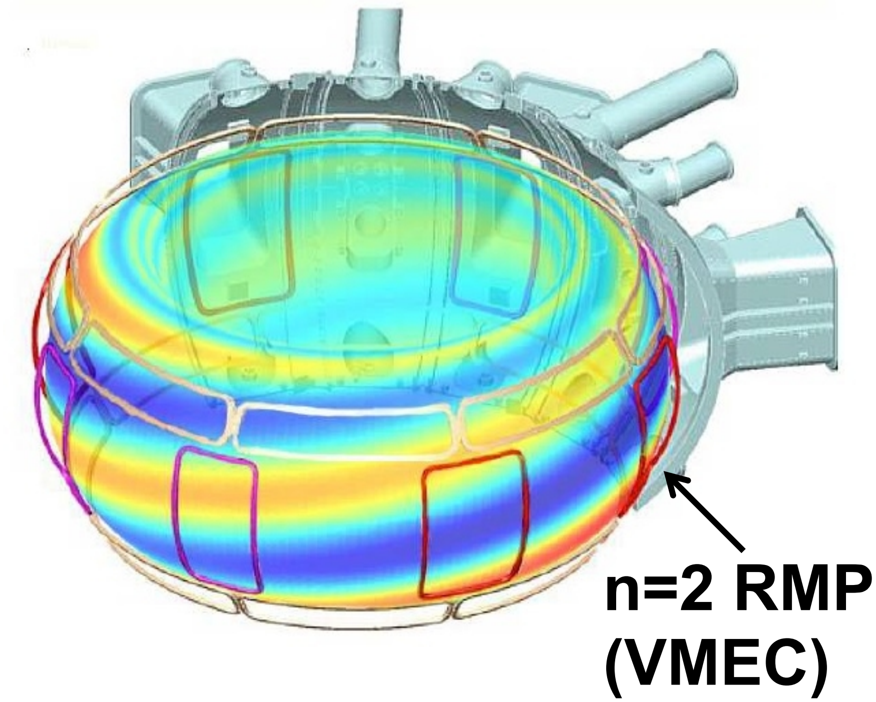
ELM Suppression Previously Not Been Observed in ASDEX Upgrade With Comparable Plasma Parameters to DIII-D

AUG: Strong (10x) ELM mitigation with n=2 RMP



Coupling to edge kink is essential



- **Lack of ELM suppression in ASDEX Upgrade is a concern for ITER**

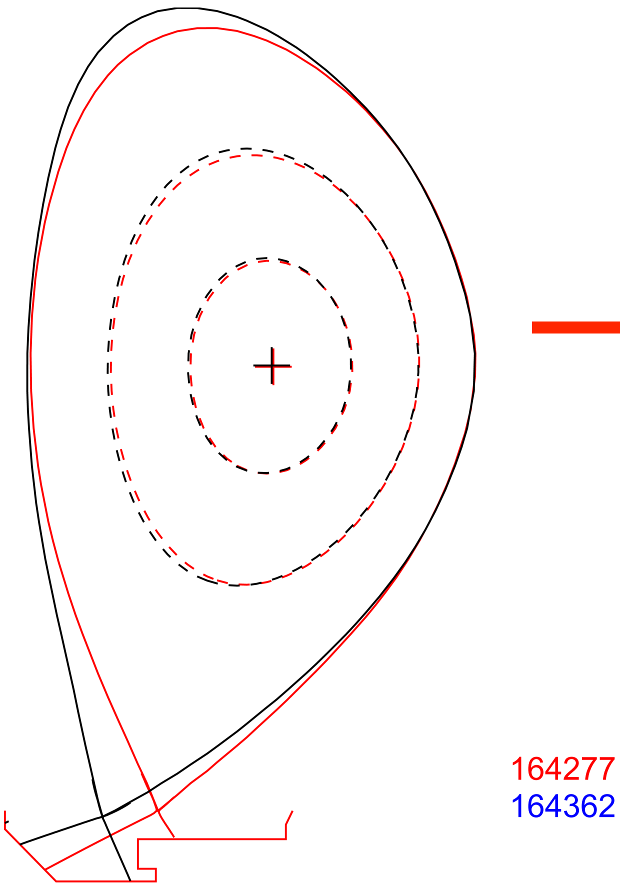
→ **Possible hidden variables?, impact on ELM coils design?**

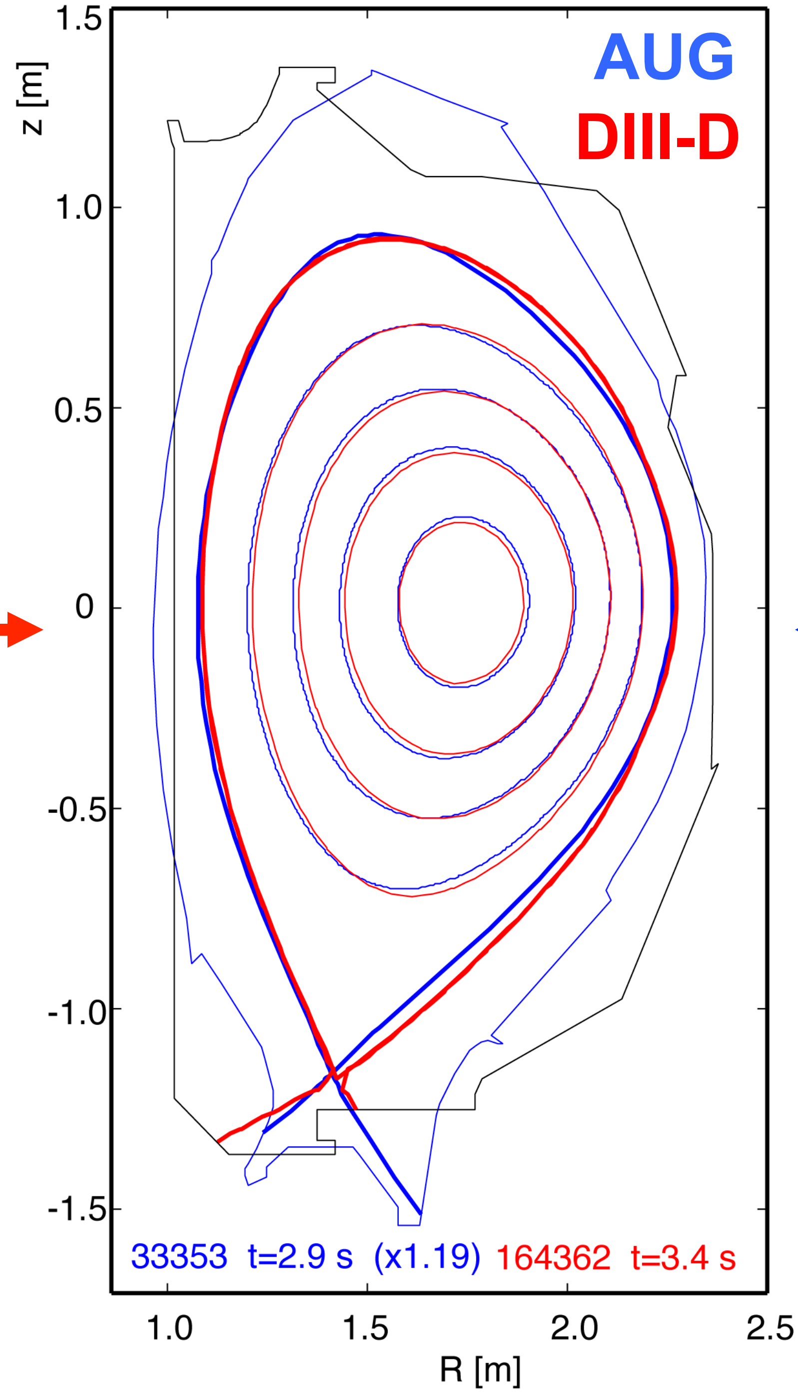
[Kirk, Suttrop NF 2015]

At Last We Tried Matching Shape: Increase Shaping in AUG, Decrease Shaping in DIII-D, Meet Somewhere in the Middle

DIII-D, n=3

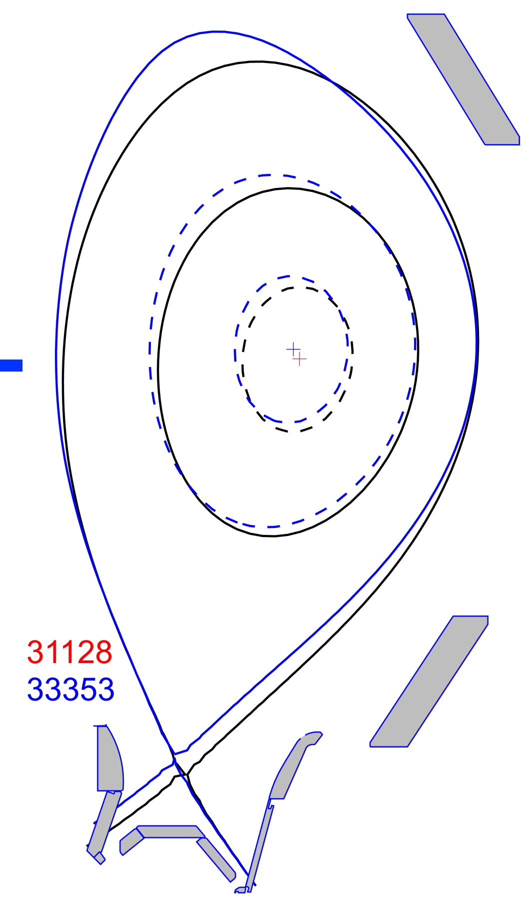
δ=0.5 → δ=0.3





AUG, n=2

δ=0.2 → δ=0.3



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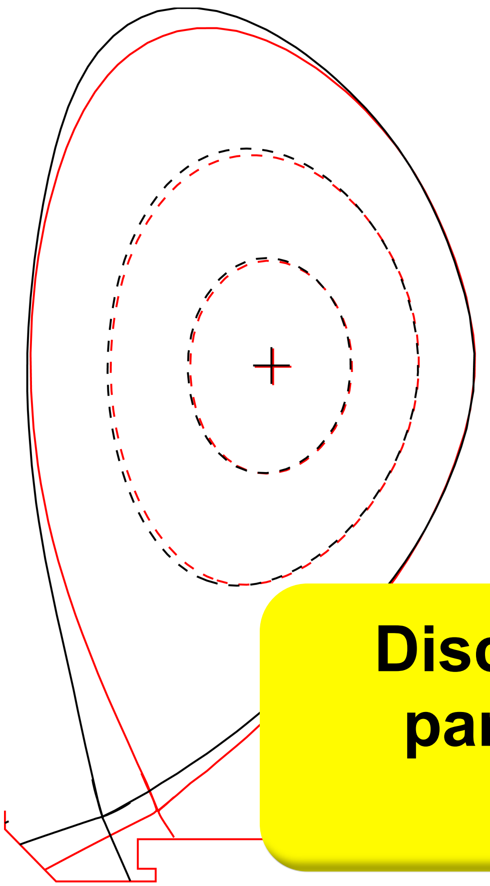
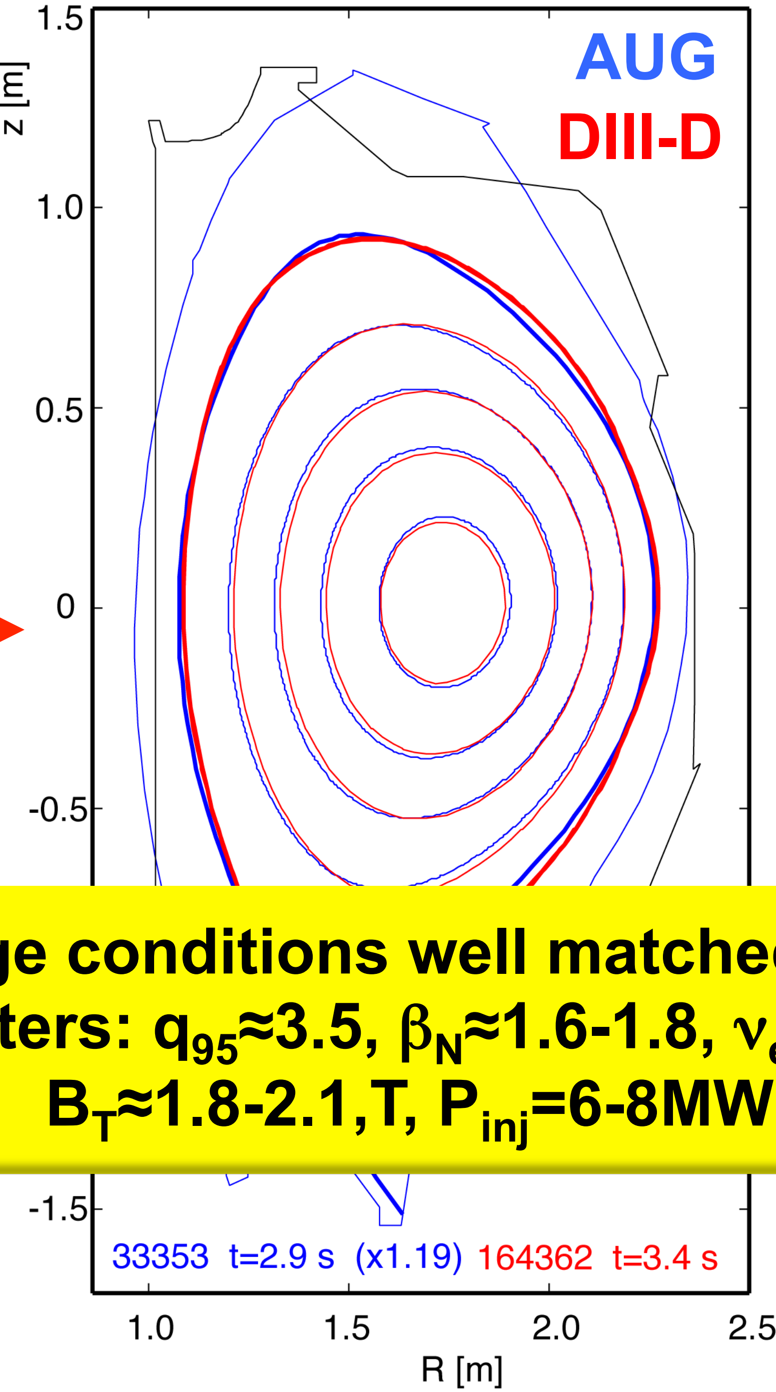
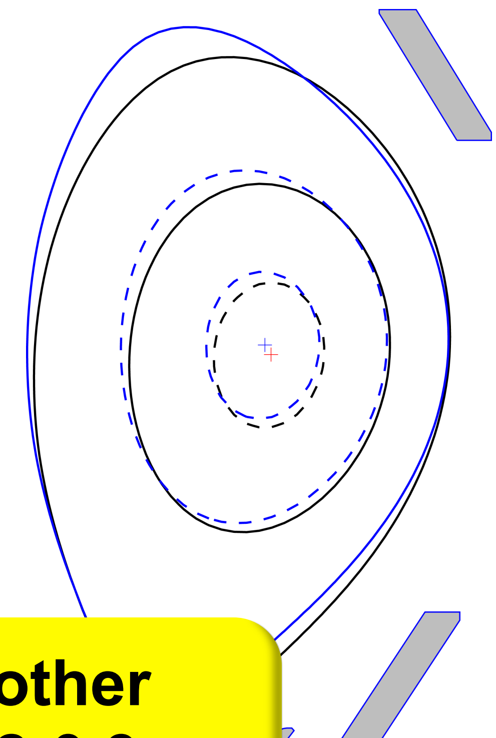
$\delta=0.5 \rightarrow \delta=0.3$





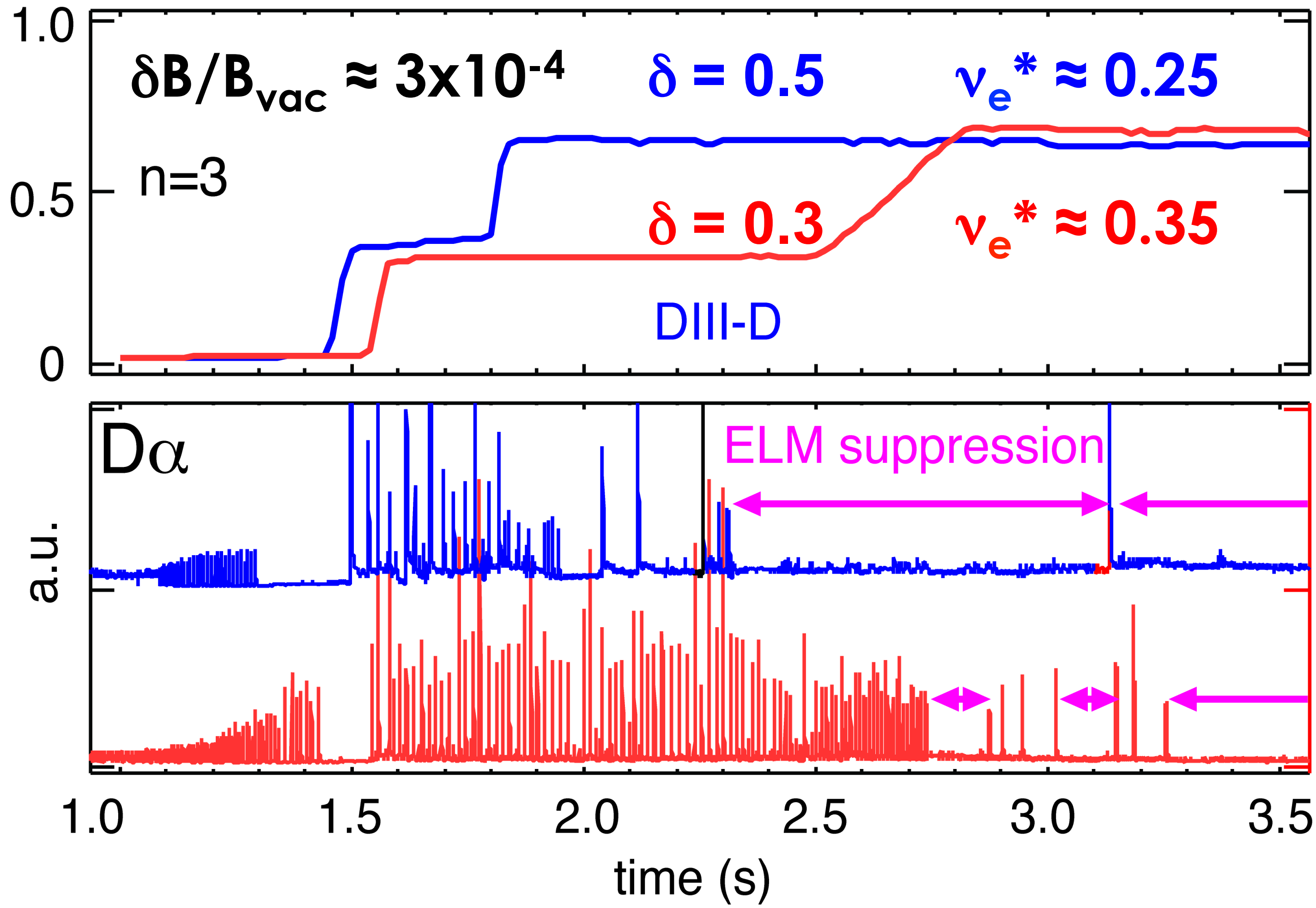
AUG, n=2

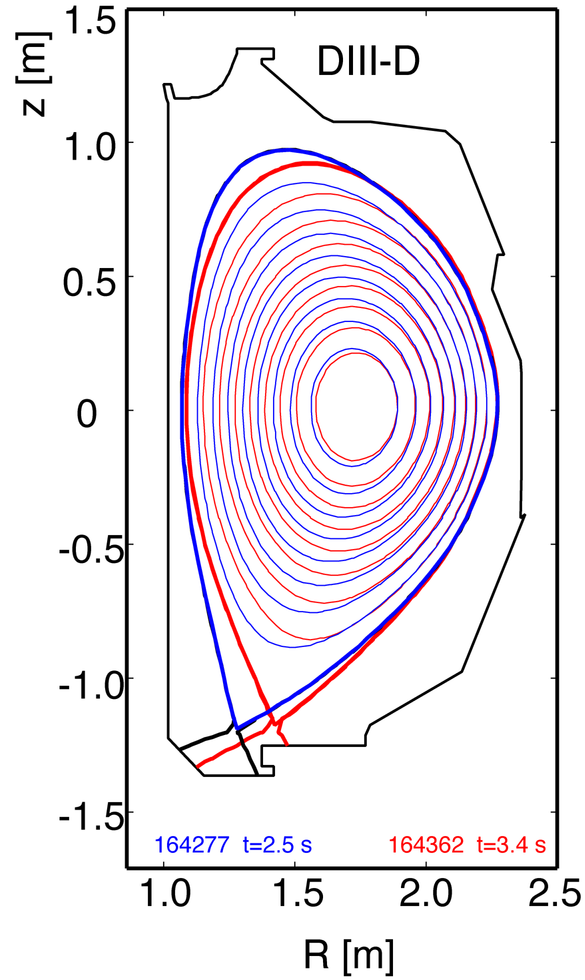
$\delta=0.2 \rightarrow \delta=0.3$



Discharge conditions well matched in other parameters: $q_{95}\approx3.5$, $\beta_N\approx1.6\text{-}1.8$, $\nu_e^*\approx0.2\text{-}0.3$ $B_T\approx1.8\text{-}2.1$,T, P_{inj}=6-8MW

Proof of Principle: DIII-D Demonstrates Access to ELM Suppression in the ASDEX Upgrade Matched Shape





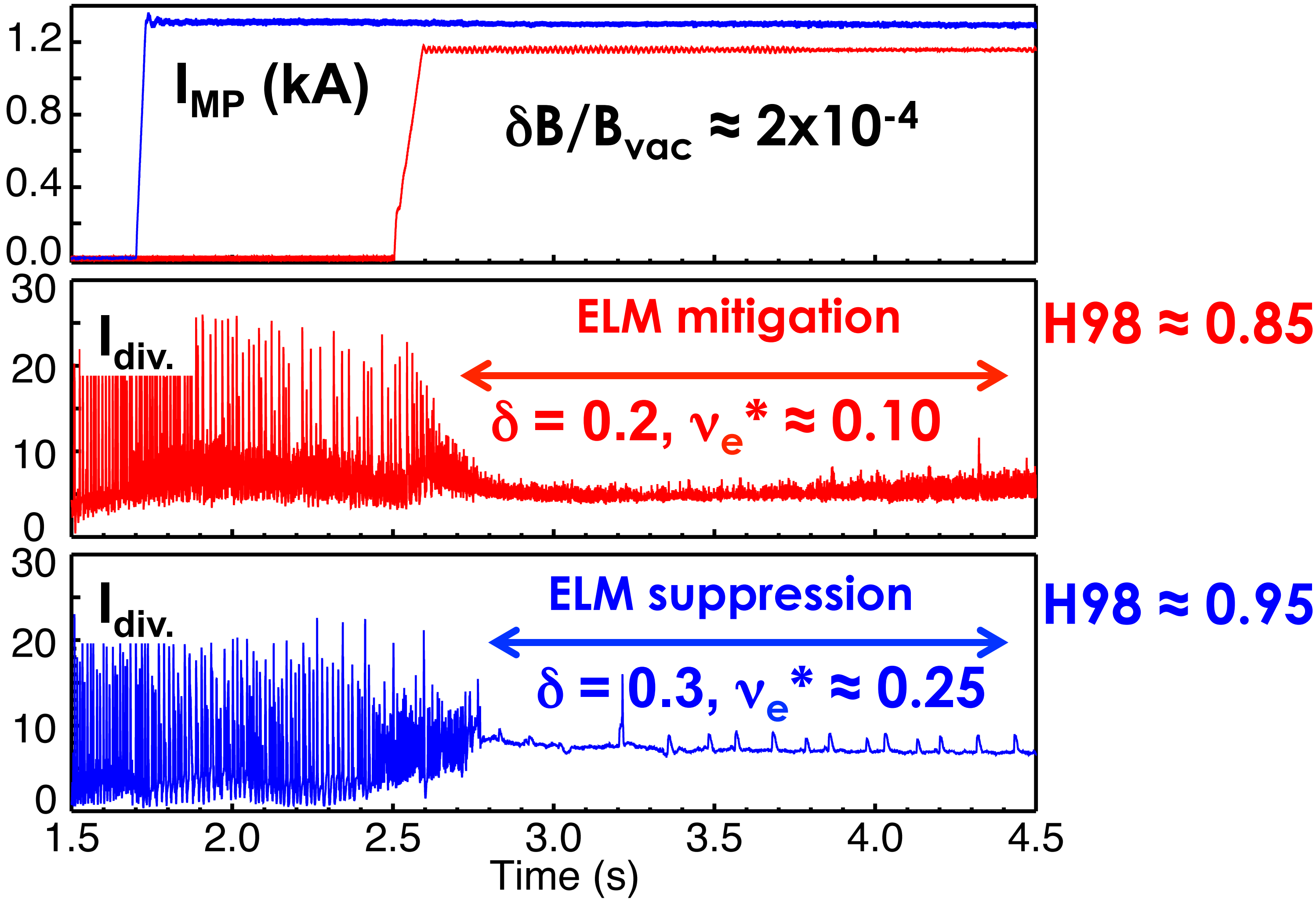
- **Increase in collisionality at low-δ due to large influx of carbon**

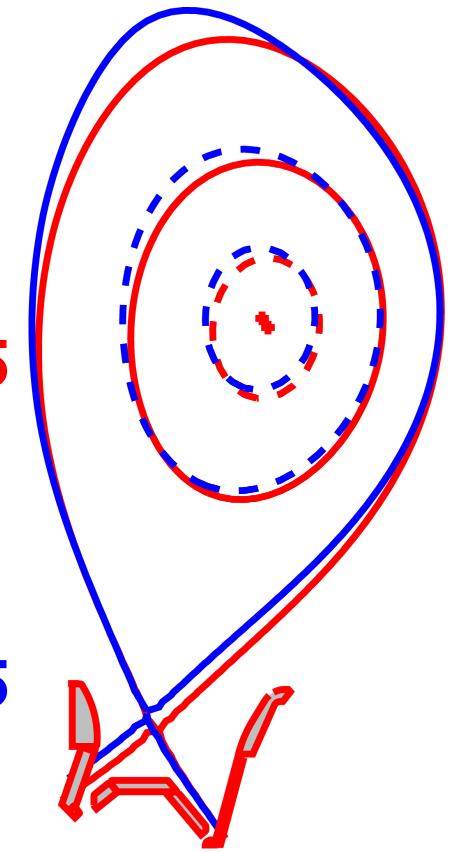
Success: ASDEX Upgrade Achieves ELM Suppression at Higher Triangularity With Improved Confinement

- **Higher-δ achieved ELM suppression with higher ν_e^* compared to mitigated case**

AUG, n=2

$\delta=0.2 \rightarrow \delta=0.3$





- **Low collisionality at same δB_{vac} is insufficient**

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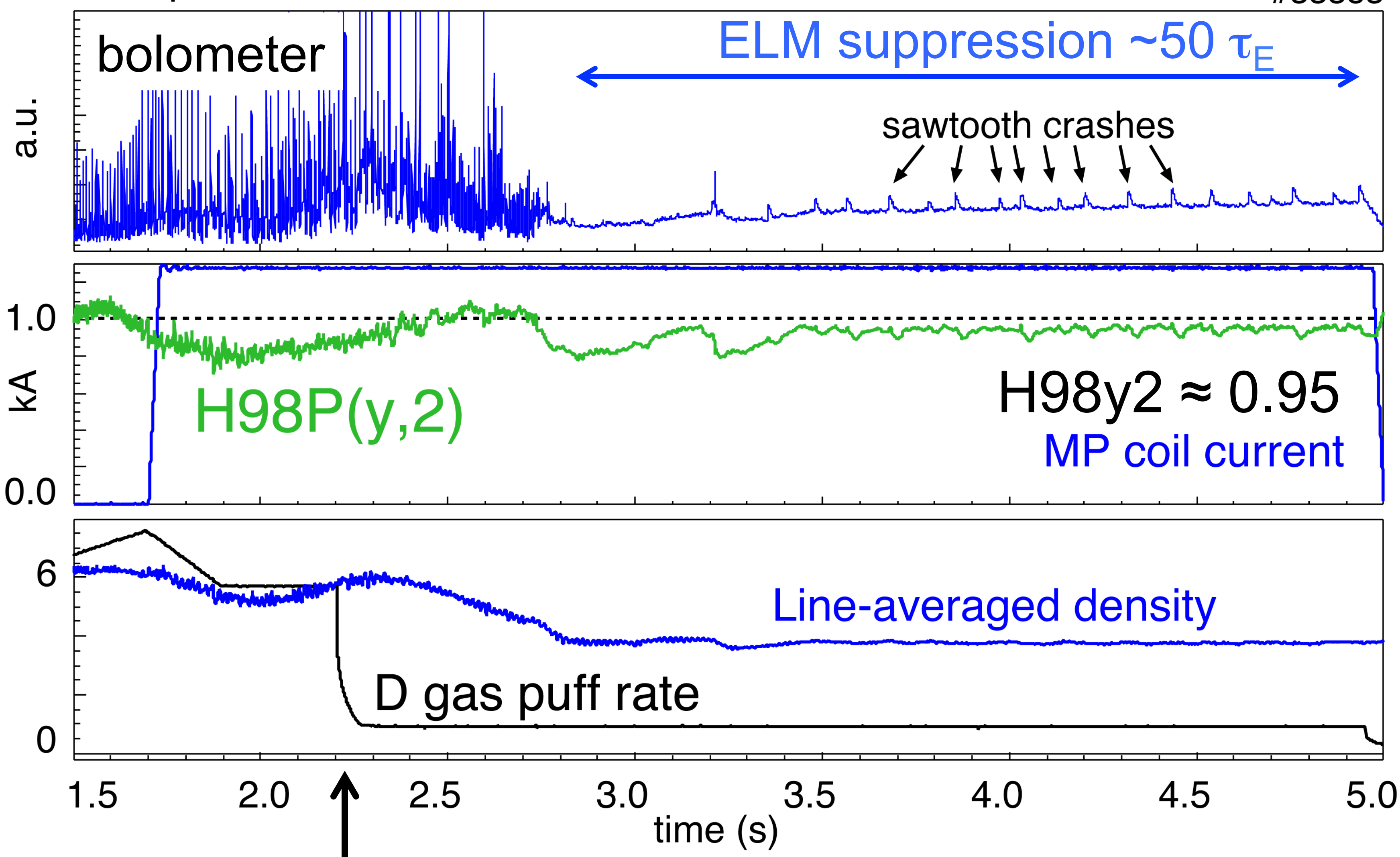
Increasing Triangularity in AUG Led To ELM Suppression After The Electron Density Fell Below a Threshold

$\nu^*_{e,ped} \approx 0.25$, $\beta_N \approx 1.8$



D2 gas valve turned off

[Suttrop PPCF submitted]

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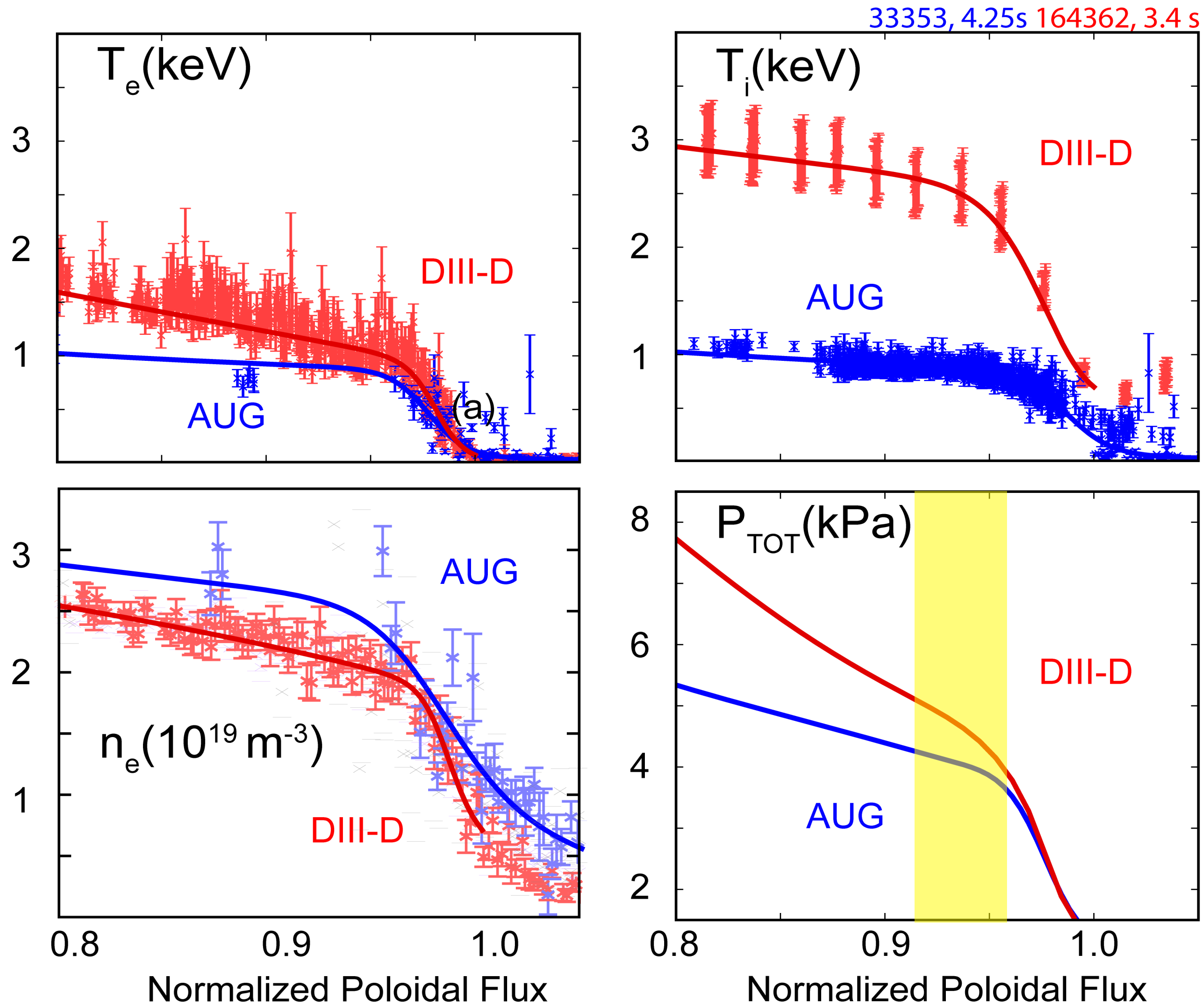
The Pedestal Density Threshold For ELM Suppression Is Very Similar For AUG and DIII-D Matched Plasmas

- **Large difference in T_i due to difference in plasma dilution**

→ AUG has W wall, some Boron Z_{eff}=1.5

→ DIII-D has C wall Z_{eff} = 4.5 (n_D≈1/3 n_e) in these experiments



H98y2 ≈ 0.95

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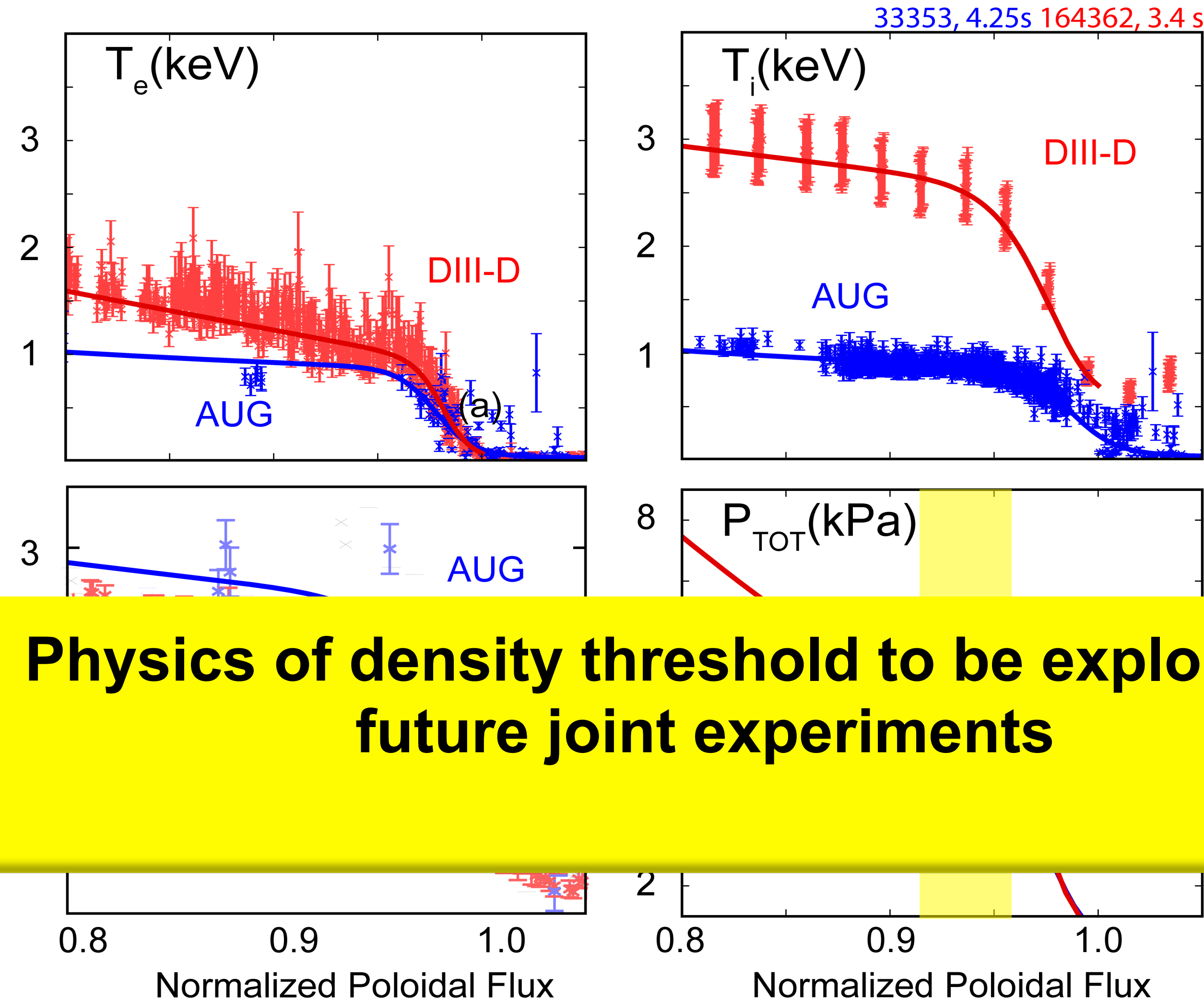
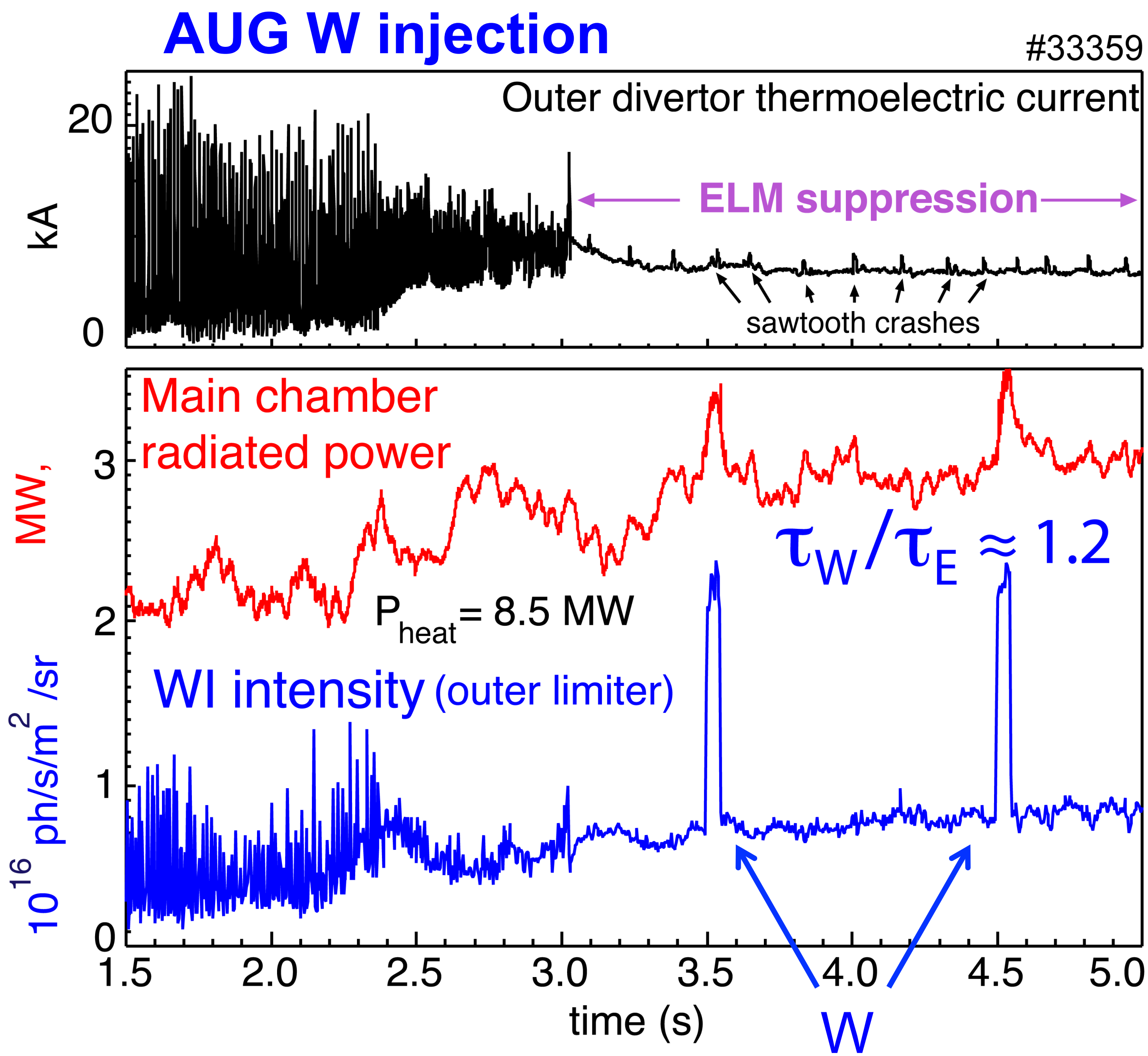


H98y2 ≈ 0.95

Physics of density threshold to be explored in future joint experiments

Effective Exhaust of Tungsten in AUG ELM Suppressed Plasmas; $\tau_W/\tau_E \approx 1.2$, Similar to ELMy H-mode Level



- **Comparable to DIII-D fluorine exhaust; τ_f/τ_E≈2**

[Grierson PoP 2015]

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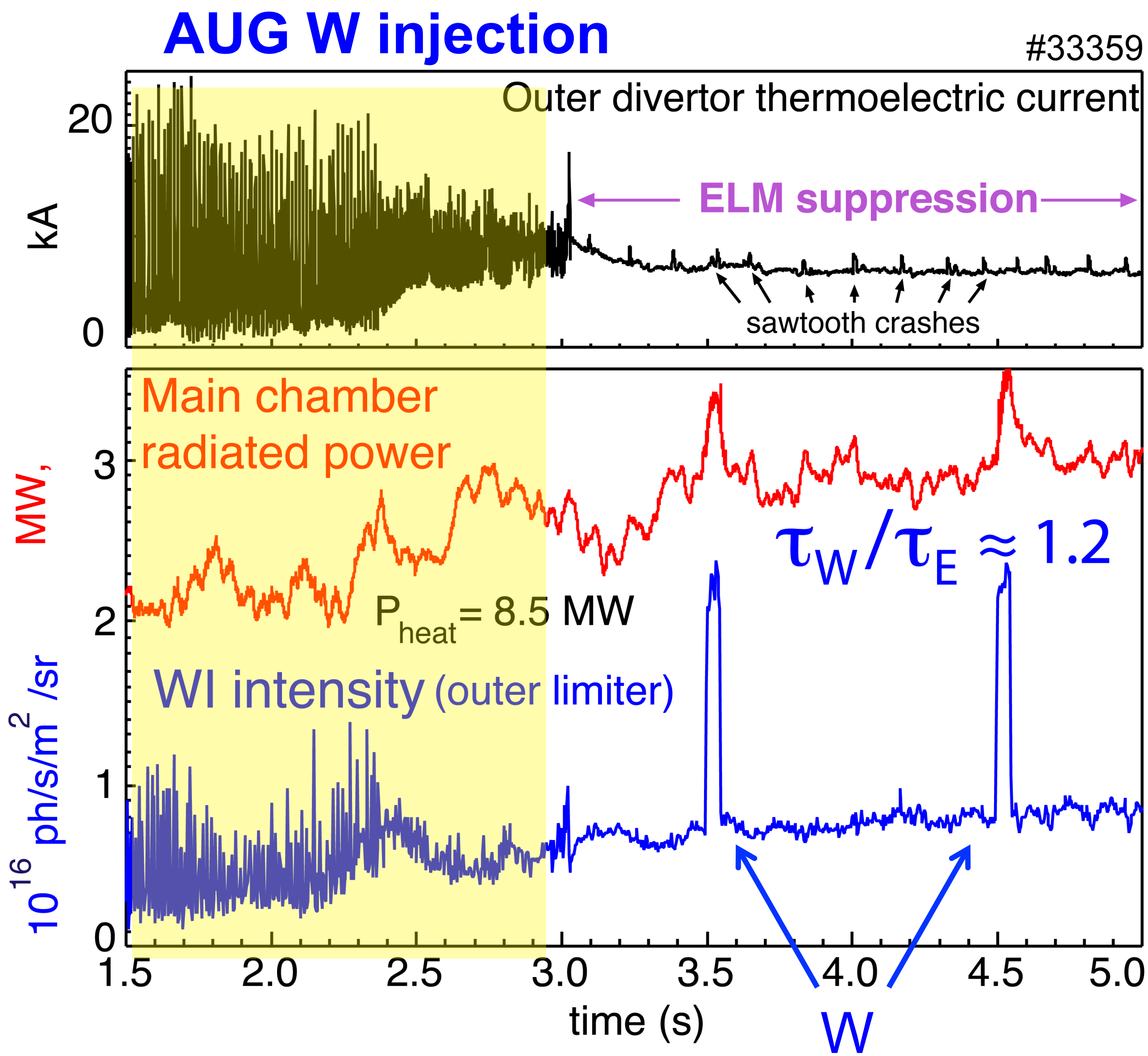


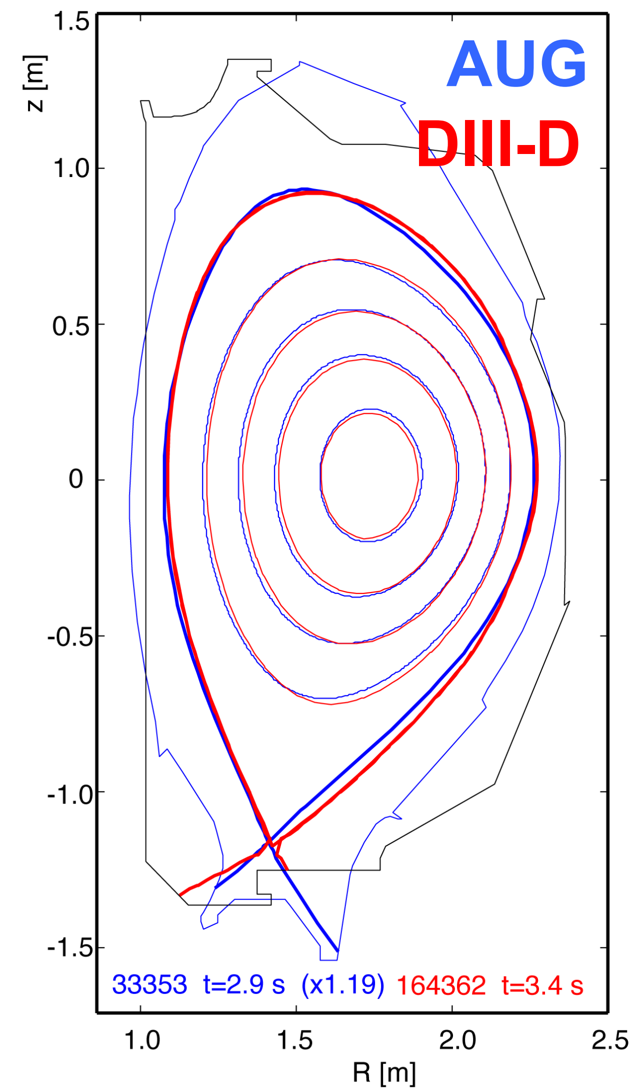
- **Magnetic Perturbations also effective in preventing W accumulation in ELMing phase**

ASDEX Upgrade

First Observation of ELM Suppression in ASDEX Upgrade In a Shape Matching Experiment with DIII-D

- Characteristics of ELM suppression in ASDEX Upgrade, comparison to DIII-D

- **The role of plasma shape in controlling access to ELM suppression**



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Stronger Shaping Can Enhance Access To ELM Suppression By Increasing Stable Edge Kink Response

Step 1: Stronger shaping can increase pedestal pressure and beta at low edge collisionality

→ Effect of triangularity, Shafranov shift, transport stiffness

↓

Step 2: Higher pedestal pressure at low collisionality amplifies the the stable edge kink response to magnetic perturbation (MP)

↓

Hypothesis: Higher stable edge kink response improves access to ELM suppression

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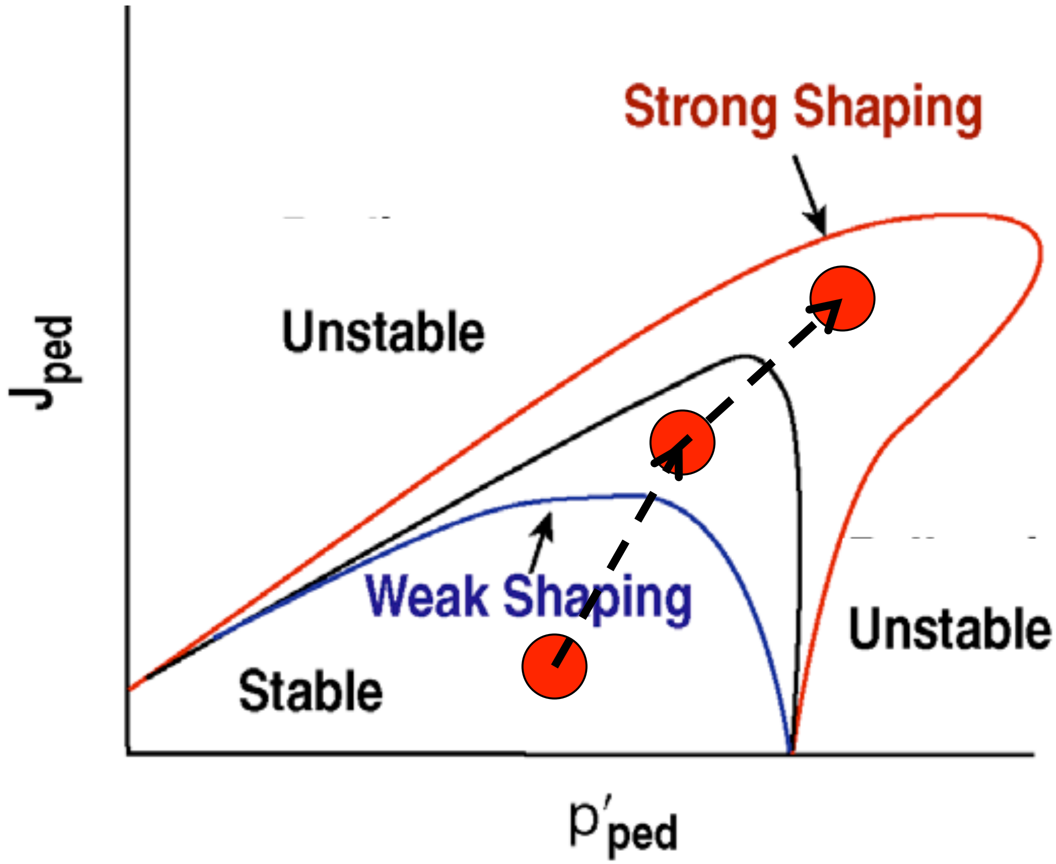
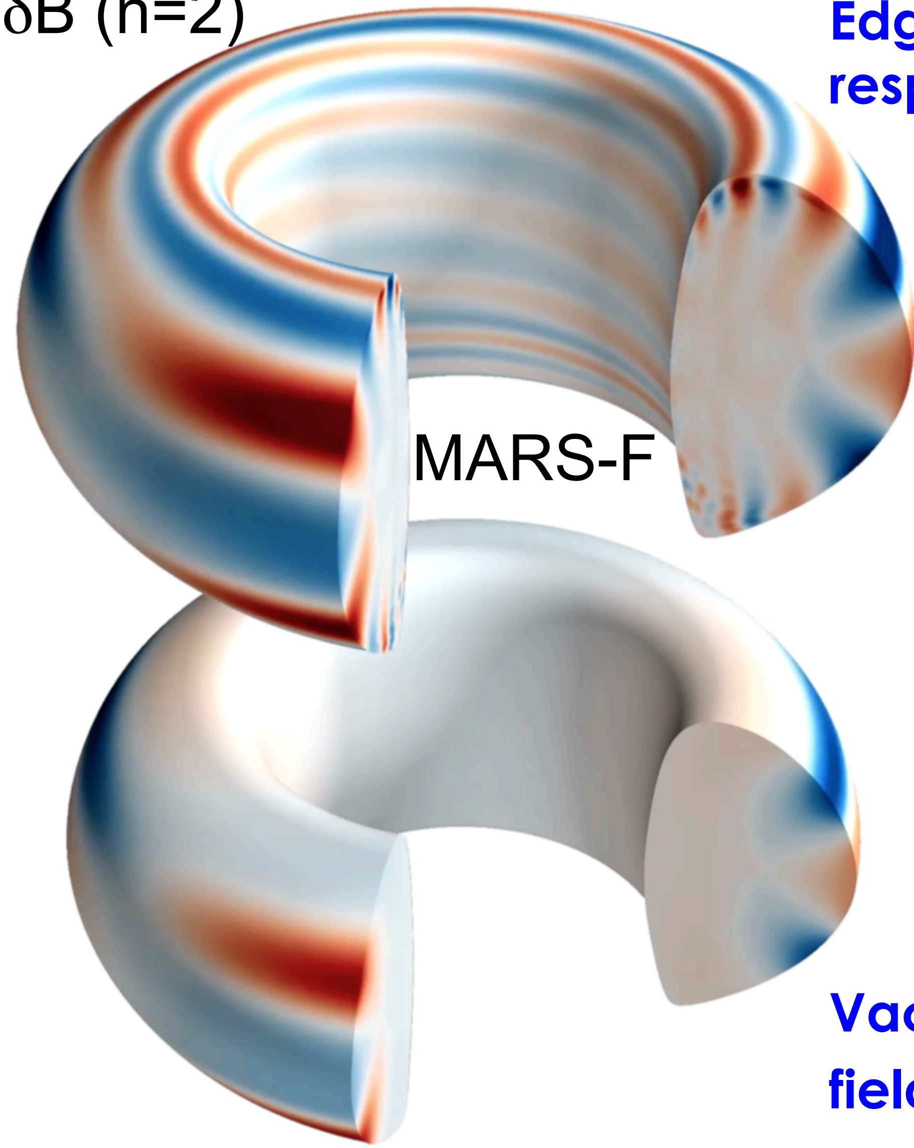
Step 1: Increased Shaping Can Enhance Pedestal Pressure and Beta at Low Collisionality in Stable Region

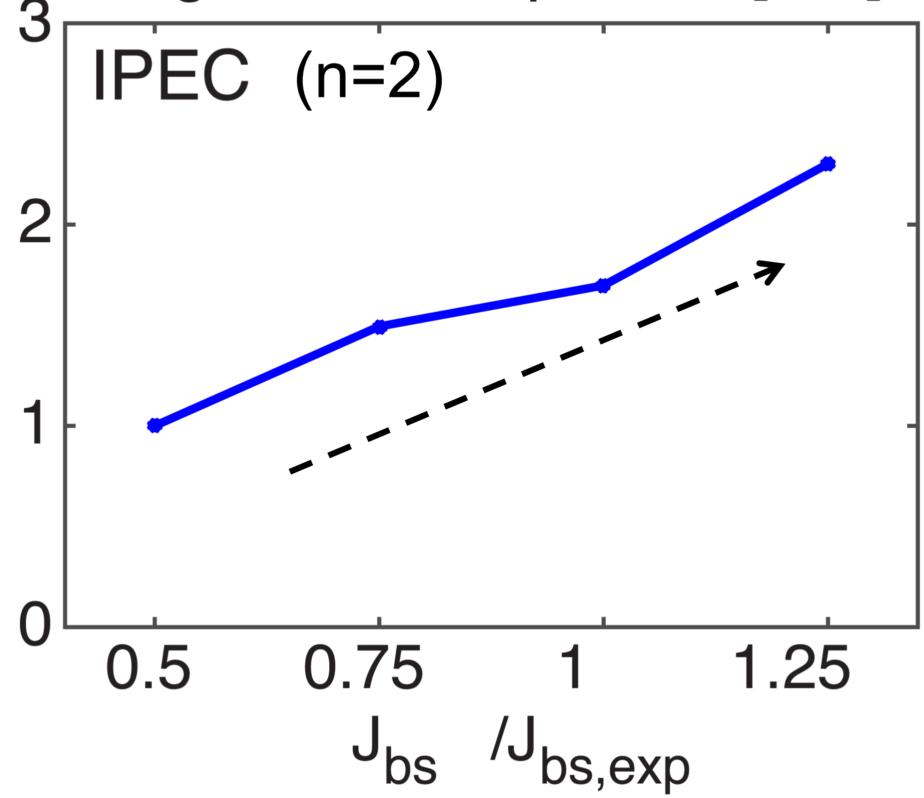
- **Increased δ, shafranov shift allows access to higher pedestal pressure**



[Snyder NF 2007]

Step 2: Increase In Pedestal Pressure at Low Collisionality Enhances Stable Edge Kink Response to MP





[Paz-Soldan NF 2016]

Low-n kink amplification comes from increase in edge bootstrap current

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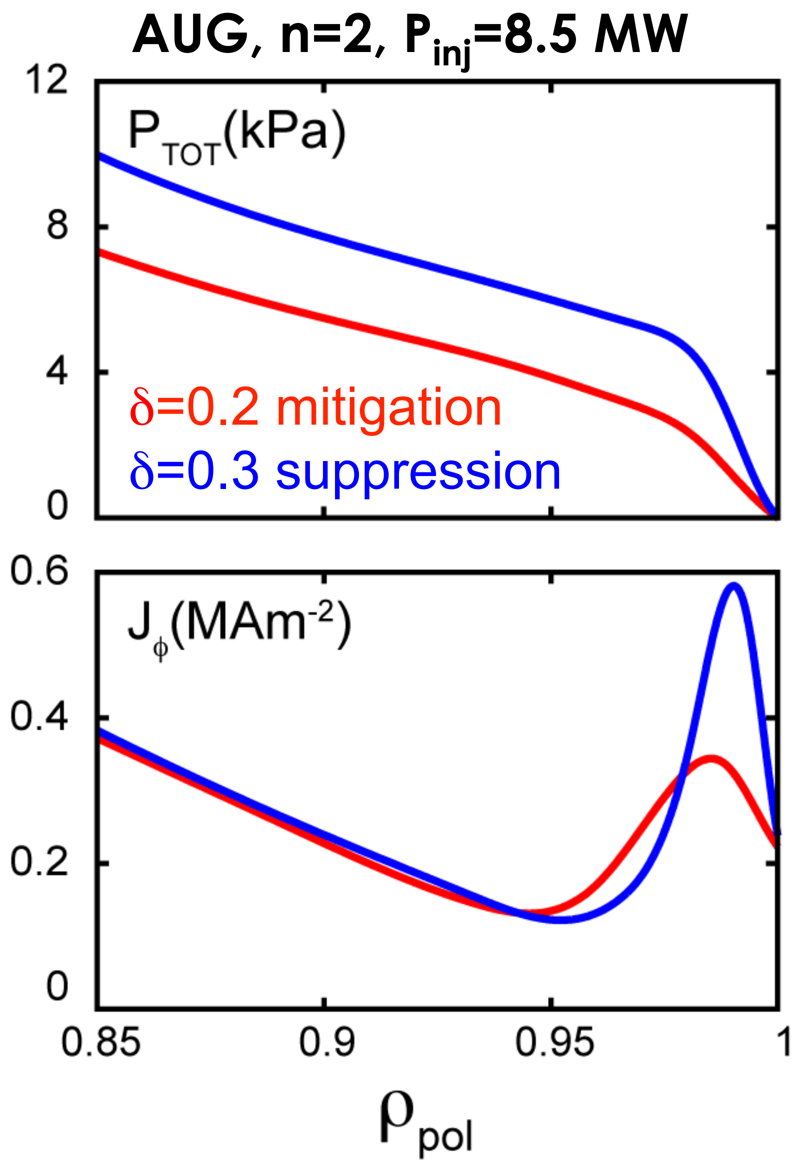
Pedestal Pressure and Edge Current Are Higher in ELM Suppressed Plasma At Higher δ Than in ELM Mitigated Case



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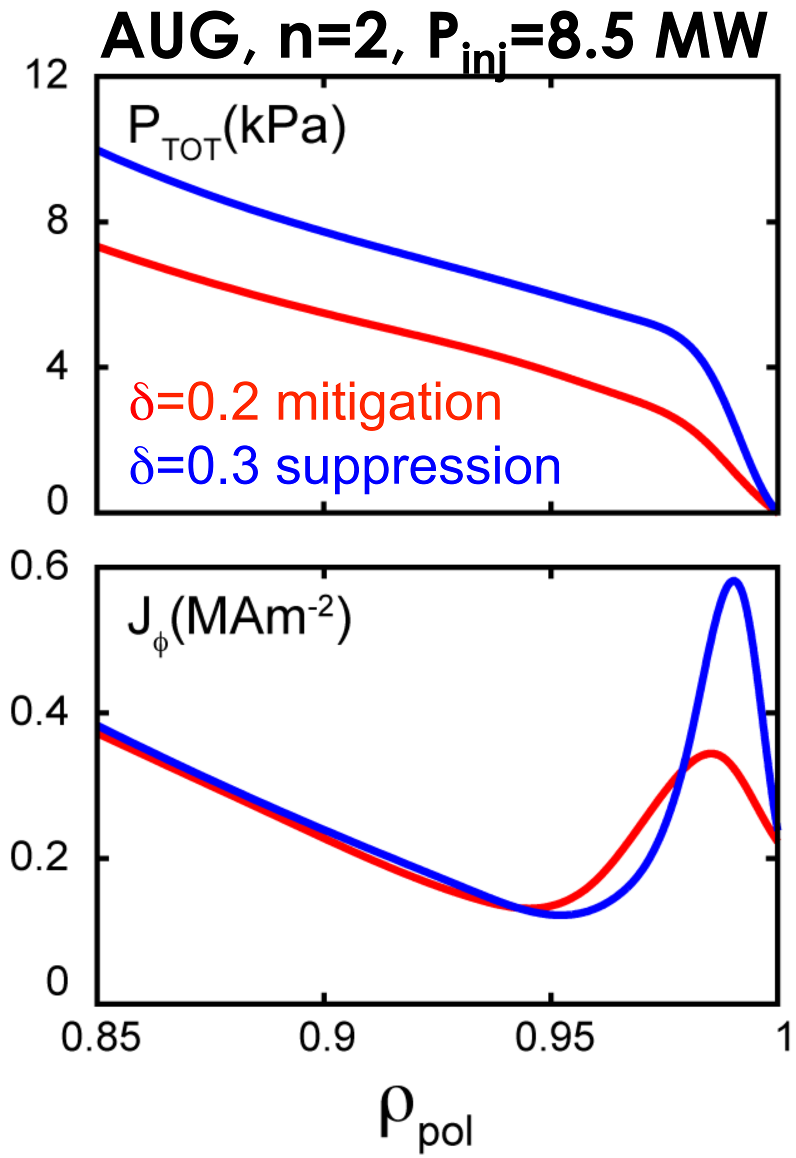
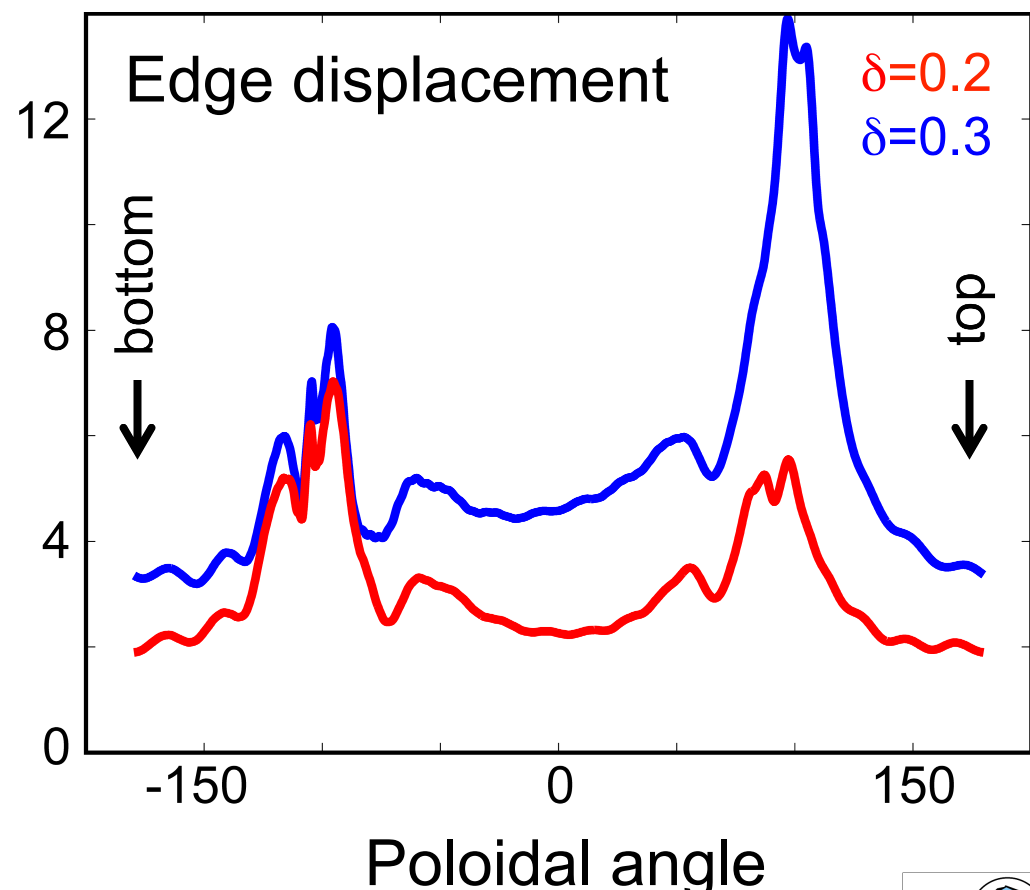
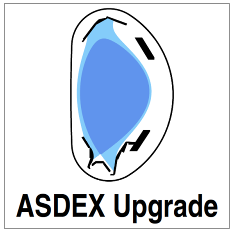
Leads To Stronger Stable Edge Kink Response: [Y. Liu APS Invited 2016]



MARS-F extended MHD calculation indicates large increase in kink amplitude



Validation is required experimentally

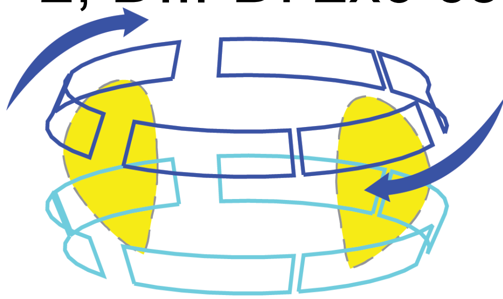


Magnetic Field Phase Scan Can Be Used to Optimize Stable Edge Kink Response

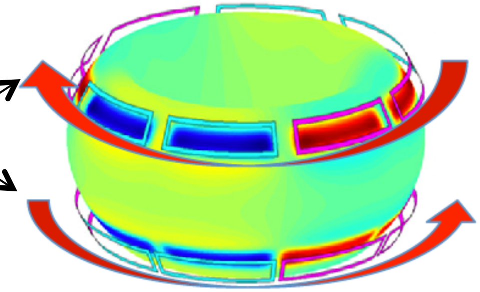
n=2, DIII-D: 2x6 coils

n=2, AUG: 2x8 coils

n=2



$\Delta\phi_{UL}$



n=2

$\Delta\phi_{UL}$ = 90°

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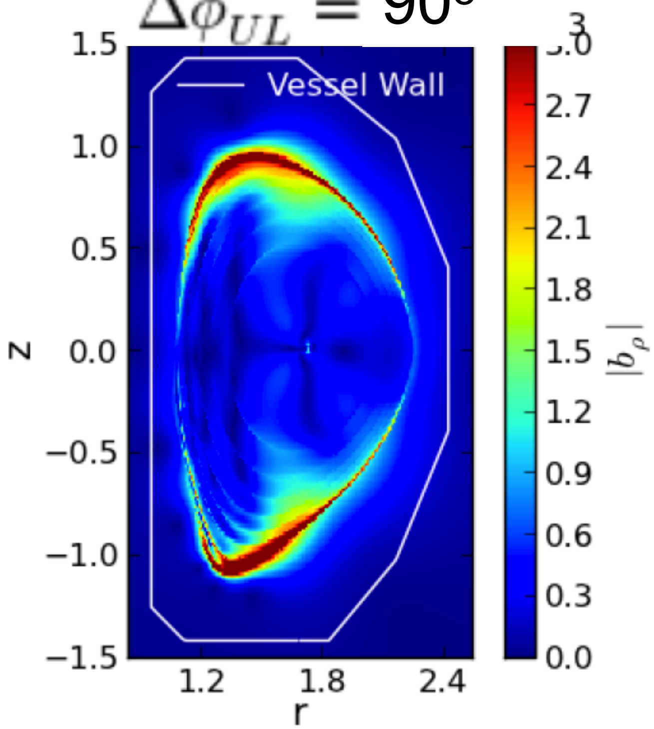
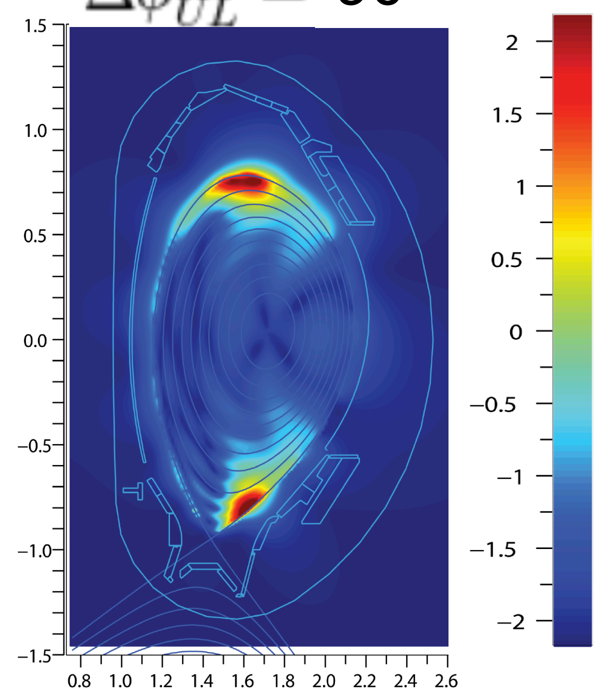
IPEC



δB



VMEC

- **Phasing scan varies poloidal spectrum, leads to tuning and detuning from edge kink mode**

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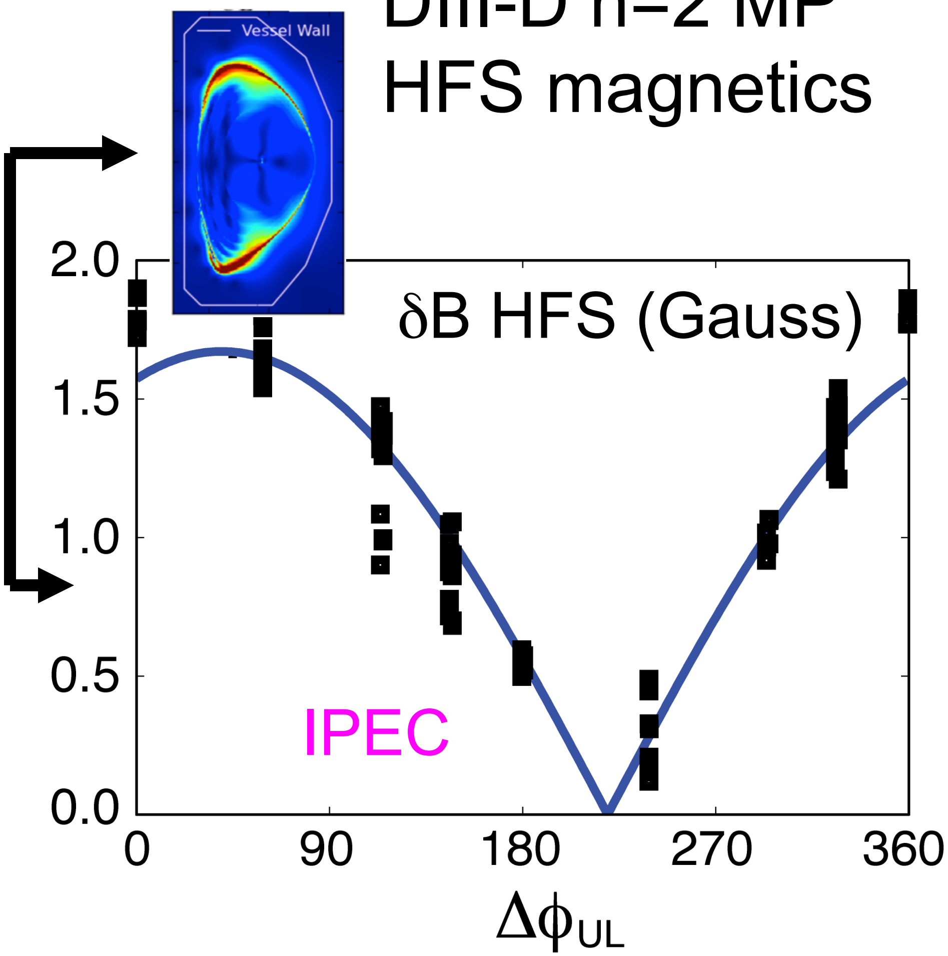
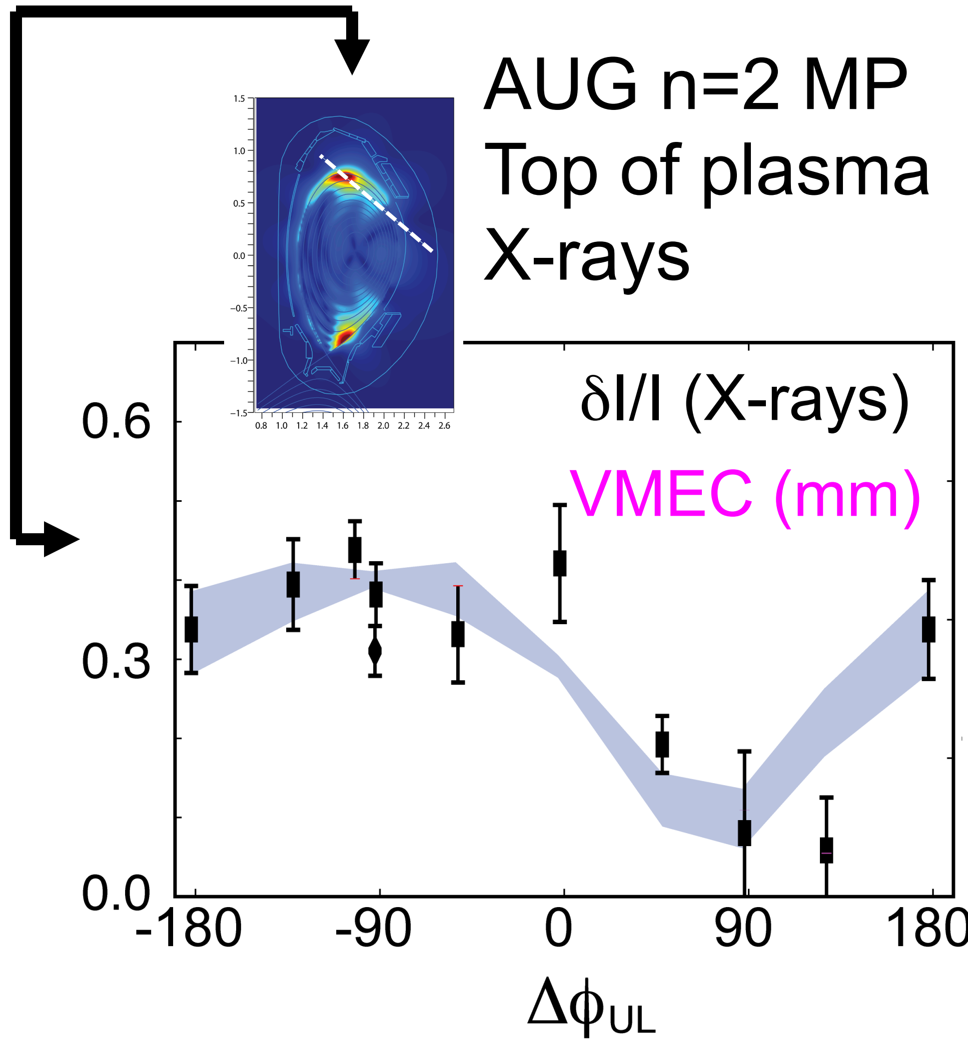
Rapid Progress in the Validation of the Stable Edge Kink Response From Multiple Sensors

DIII-D n=2 MP
HFS magnetics



C. Paz-Soldan, PRL 2015

AUG n=2 MP
Top of plasma
X-rays



M. Willensdorfer, EX/P6-25
PPCF 2016

These and new methods will be used to validate shaping effect on kink response

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Shape Matching Experiment Leads To First Observation of ELM Suppression in ASDEX Upgrade

- ELM suppression observed in AUG for 50 τ_E at ITER relevant ν_e* with effective exhaust of tungsten $\tau_W/\tau_E \approx 1.2$

- Similar features of ELM suppression in AUG and DIII-D shape matched plasmas despite impurity differences

- Access to ELM suppression at higher-δ in AUG confirms importance of stable edge kink response

- Extension to AUG is good news for ITER, opens new directions for studies in tungsten and carbon machines

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