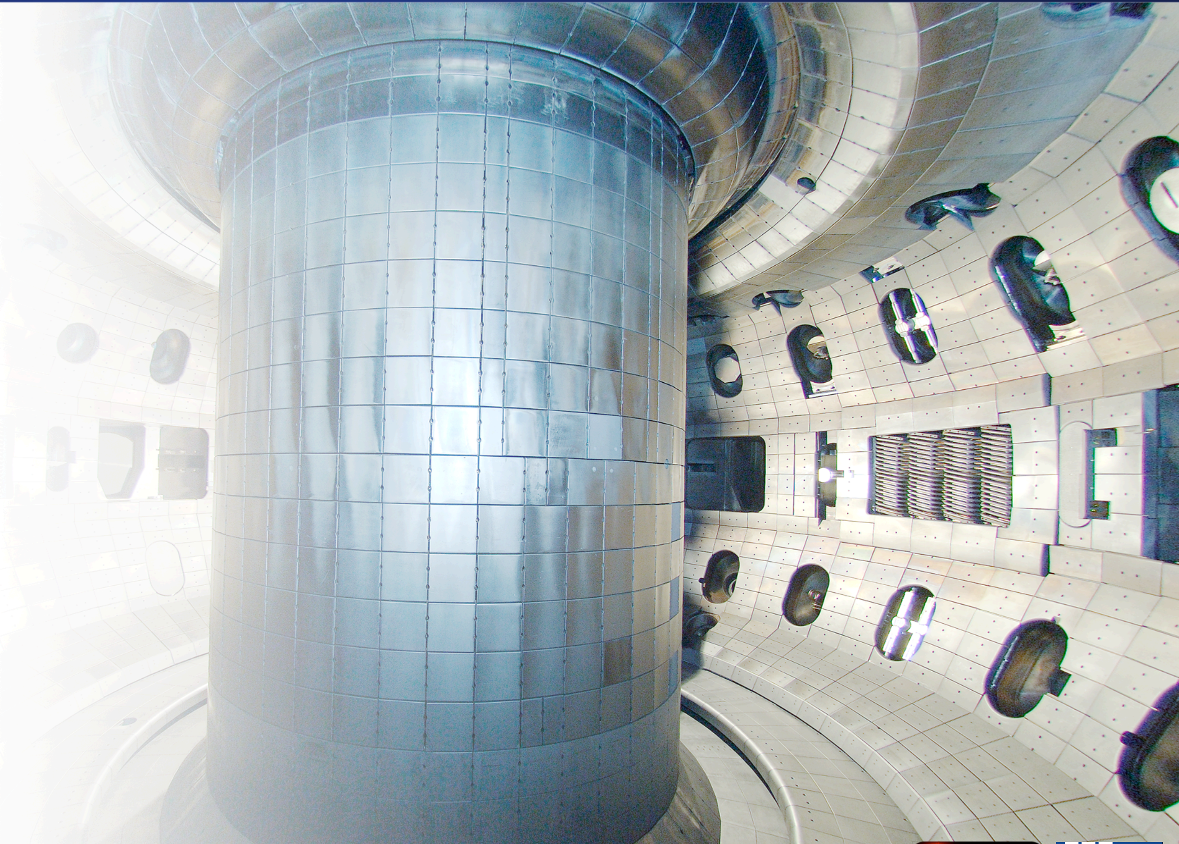
Overview of Recent DIII-D Experimental Results



M.E. Fenstermacher (LLNL)

Presented at the

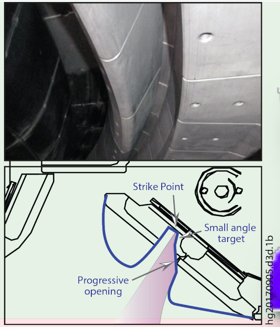
59th Annual APS Meeting
Division of Plasma Physics
Milwaukee, WI

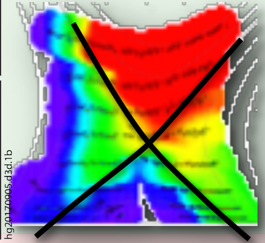
October 23–27, 2017

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, and under Contracts DE-FC02-04ER54698, DE-FG02-07ER54917, DE-FG02-05ER54809.
LLNL-PRES-705307

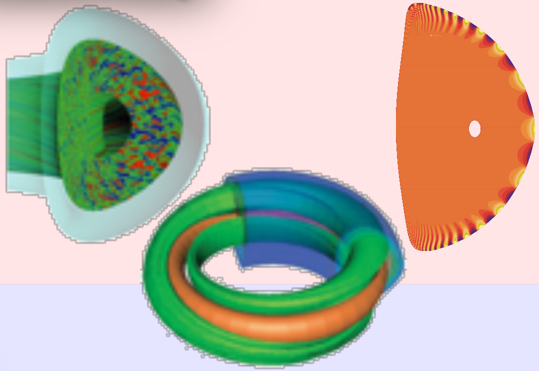
DIII-D Continues to Contribute to Fusion Energy Development by Focusing on Three Research Elements

Develop Relevant Boundary Solutions

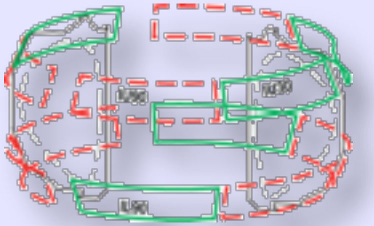


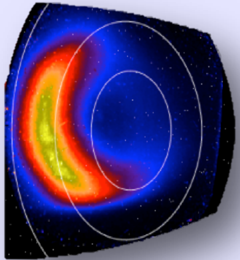


Strengthen the Basis for Fusion Science



Control Transients

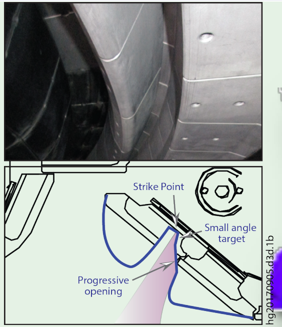


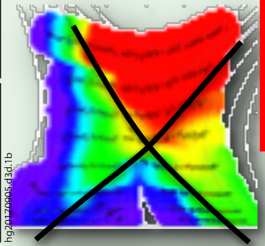


DIII-D Continues to Contribute to Fusion Energy Development by Focusing on Three Research Elements

Develop Relevant Boundary Solutions

- Divertor Geometry
- SOL and Divertor Flows
- Tungsten Migration





PMI, Divertor Solutions for Long Pulse

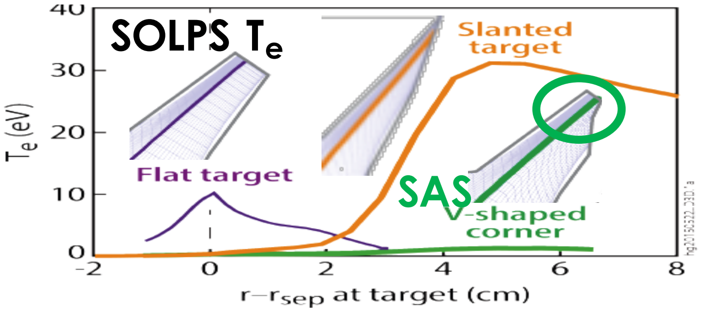
Strengthen the Basis for Fusion Science

Control Transients

DIII-D NATIONAL FUSION FACILITY

035-17/MEF/jy

New SAS Divertor Design Achieves Detachment Consistent with Initial Modeling



- **Detachment optimized with SP in corner of SAS structure consistent with simplified predict-first modeling**
  - Achieved low Te < 10 eV across SOL target

Guo, Fri AM

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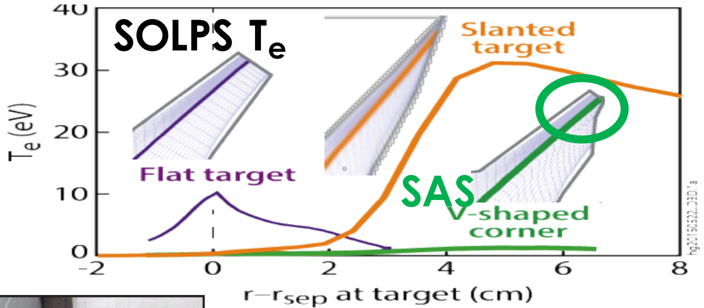

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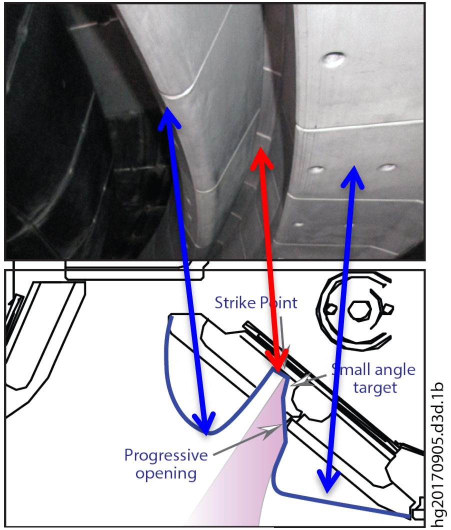

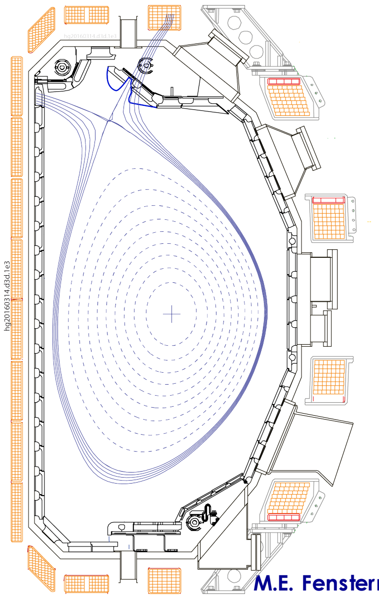

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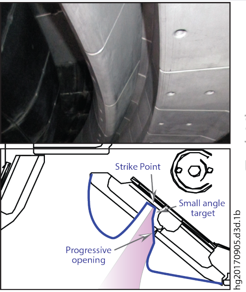

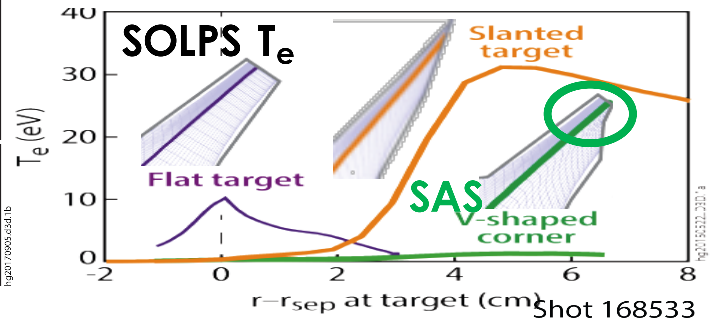

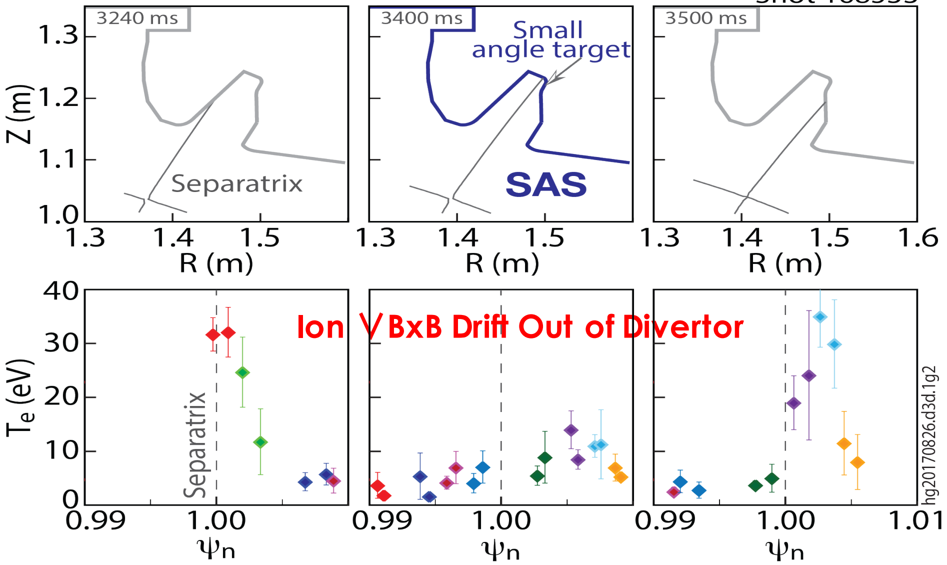

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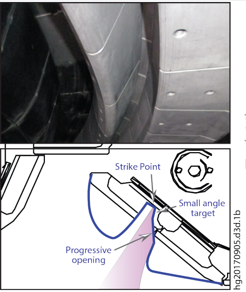
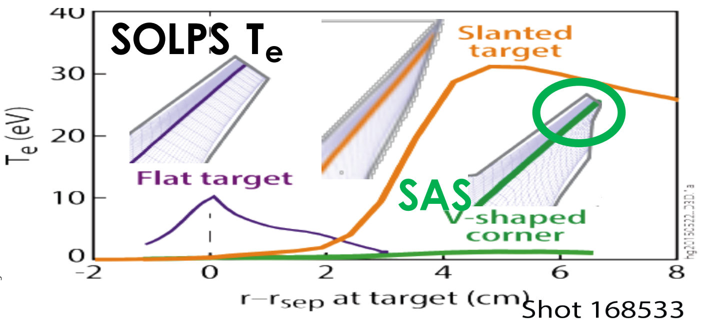
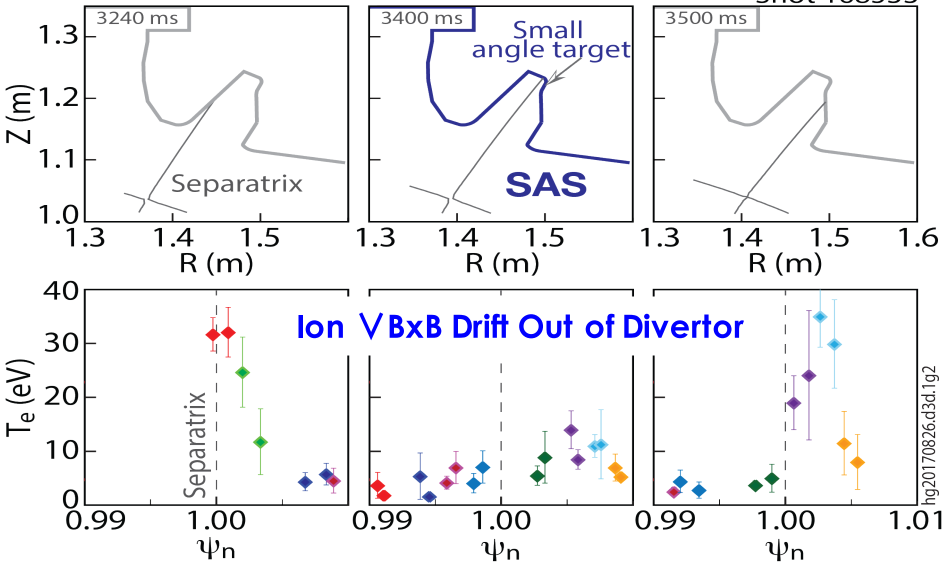






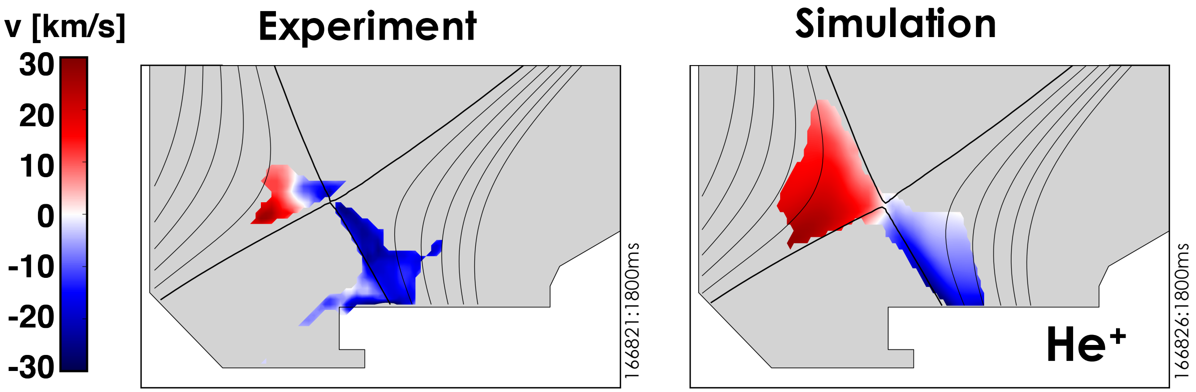
- **Detachment optimized with SP in corner of SAS structure consistent with simplified predict-first modeling**
  - Achieved low Te < 10 eV across SOL target

- **SAS upstream density at detachment lower with ion ∇BxB drift out of divertor (higher $P_{L\text{-}H}$ direction)**
  - Flat, low Te achieved down to ne = 4e19
  - With Grad-B into divertor, low Te requires significantly higher upstream density
    - Consistent with expected poloidal drift effects

Guo, Fri AM

Comparison of New 2D Ion Velocity Imaging and Fluid Modeling Contributes to Validation of Pressure Gradient and Other Forces Determining Parallel Velocity

- **Consistency of main ion flow profiles in UEDGE vs. experiment near target plate supports multi-term force balance model**
  - Region where He^{+} and electron-physics dominates
  - Enabled by absolutely calibrated 2D imaging of ion velocities



Samuell, Fri AM

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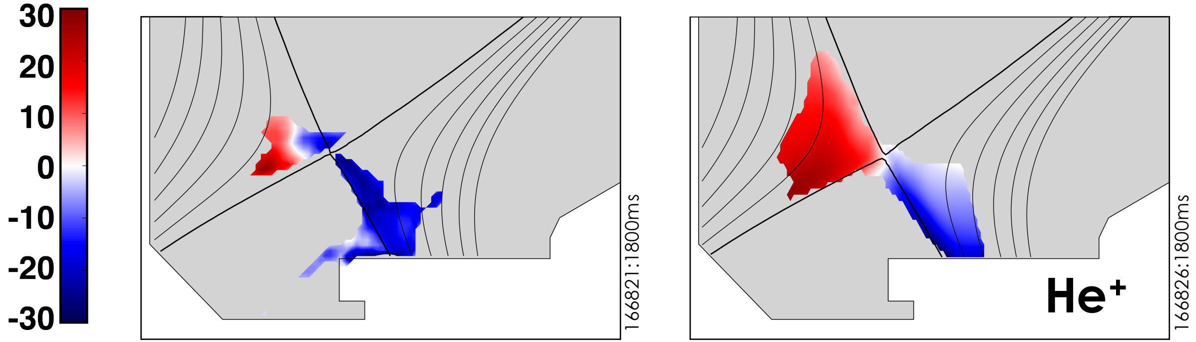
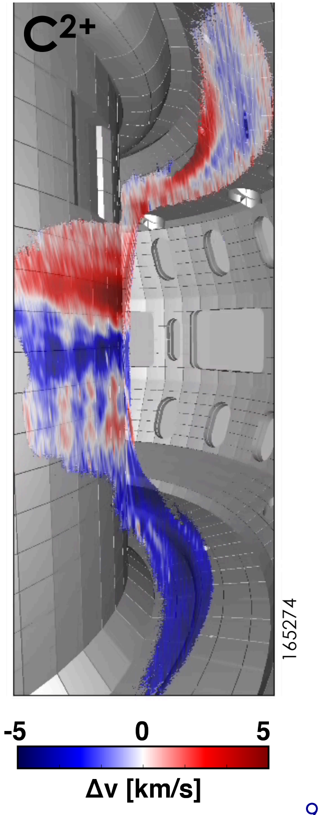


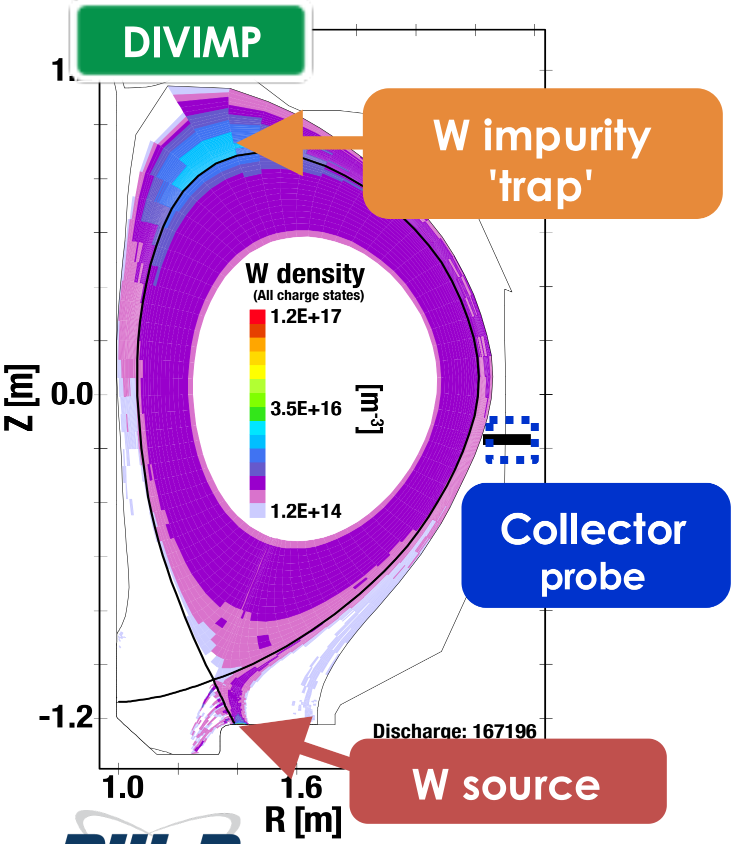
- **Confirmed EMC3-EIRENE fluid code prediction of temperature dominated pressure-gradient driven C^{2+} 3D flows**
  - First imaging of 3D flows around magnetic islands in a tokamak

3D flow perturbation



Samuell, Fri AM

Asymmetries in W Deposition Pattern on Midplane Collector Probe Consistent with Predicted High-Z Impurity Trap



Thomas, this session

- **Expect W Impurities trapped near 'crown'**
  - DIVIMP: Formation of potential well due to ITG force in near-SOL

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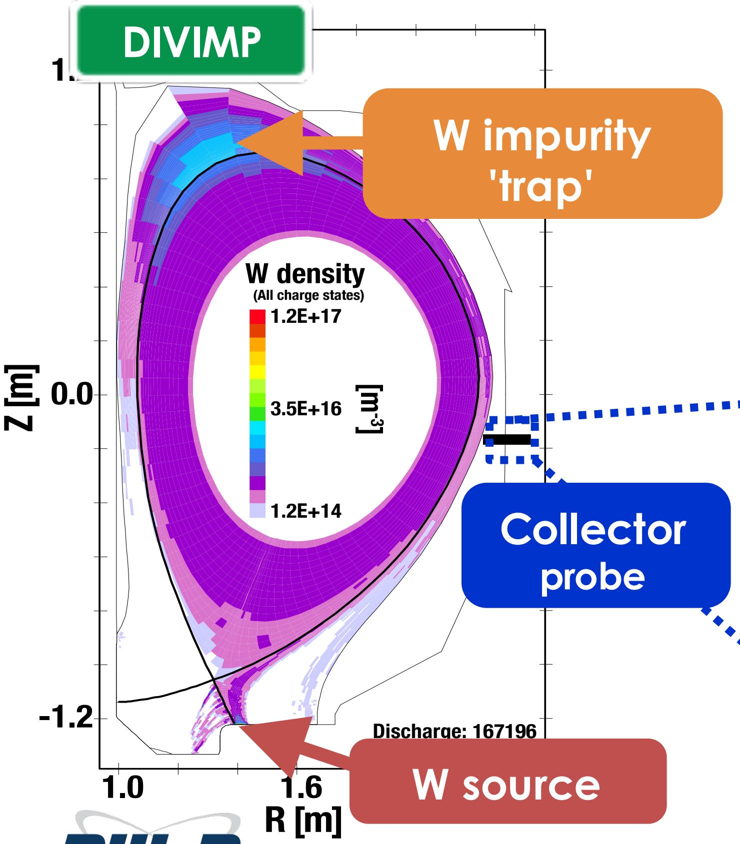
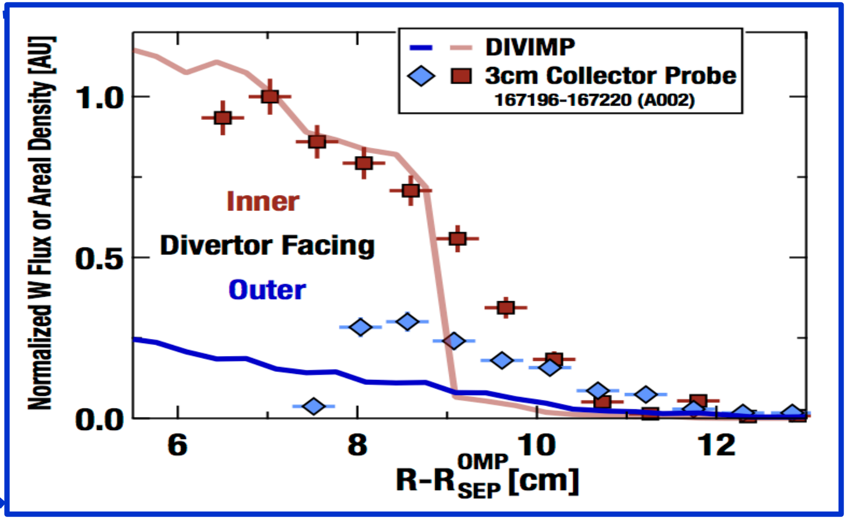


- **Expect W Impurities trapped near 'crown'**
  - DIVIMP: Formation of potential well due to ITG force in near-SOL
- **More W deposited on ISP-facing side of collector probe**
  - Features consistent w/ DIVIMP modeling



Thomas, this session

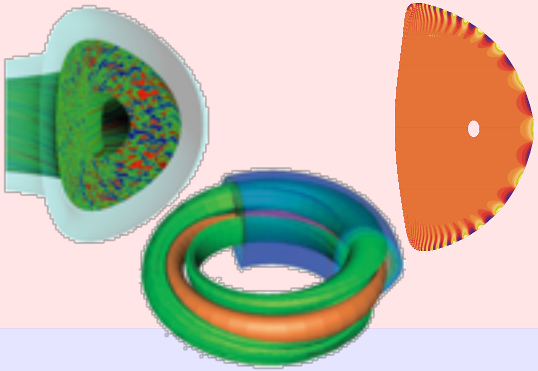
DIII-D Continues to Contribute to Fusion Energy Development by Focusing on Three Research Elements

Develop Relevant Boundary Solutions

Strengthen the Basis for Fusion Science

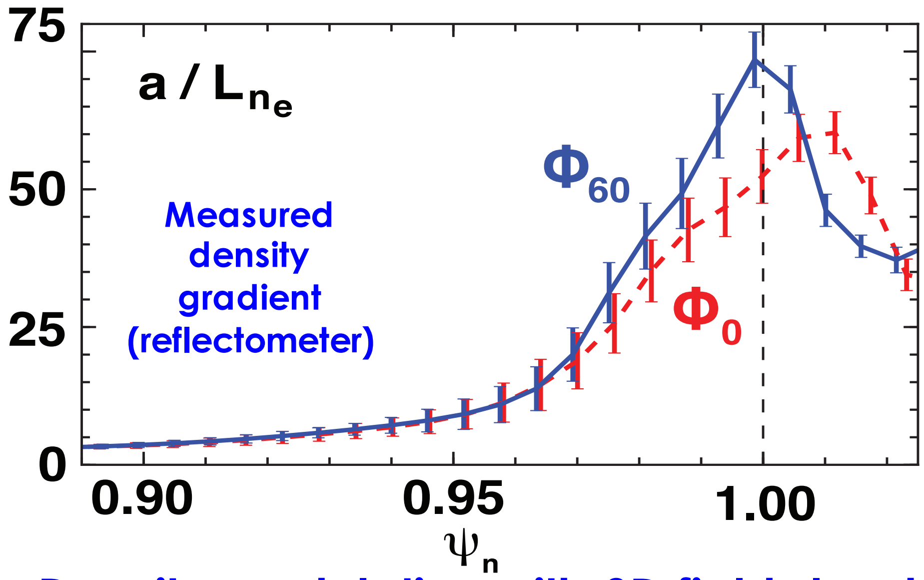
- 3D Effects
- Intrinsic Rotation
- Particle – Wave Coupling
- Current Drive Optimization

Optimizing Tokamak Plasma Performance



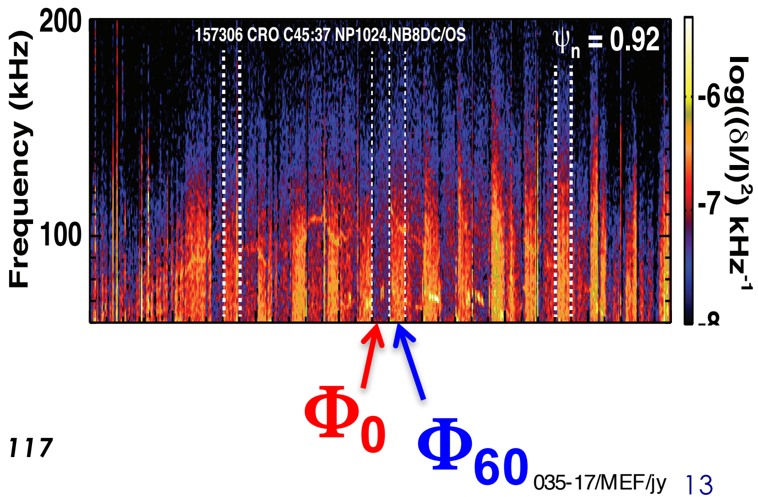
Control Transients

With RMP Fields Measurements and Modeling Show Density Changes within Flux Surfaces; Not Only Surface Displacement Effects



Measurements

- Density modulation with 3D fields leads to toroidal variation of a/L_{ne} and turbulence drive



Wilcox, Tues AM

R. S. Wilcox et. al., Phys. Rev. Lett. 117 (2016) 135001

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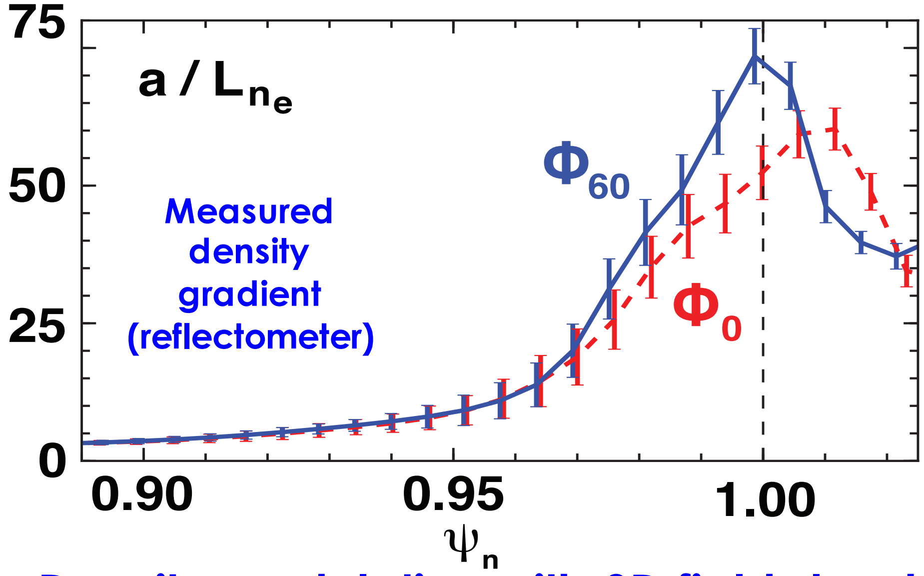
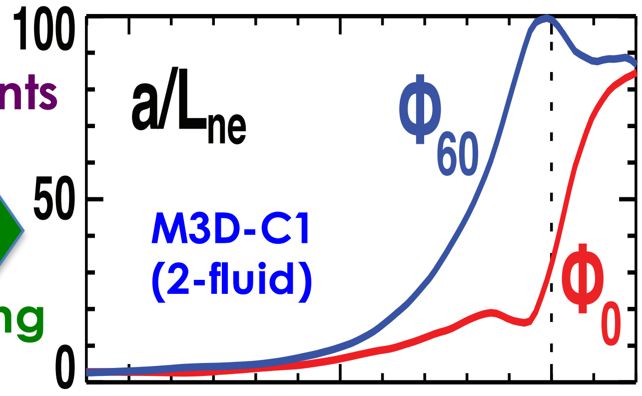
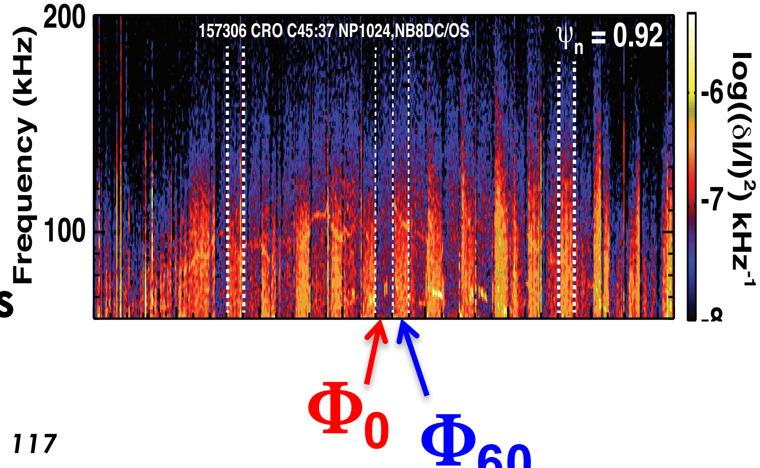


Measurements

Modeling





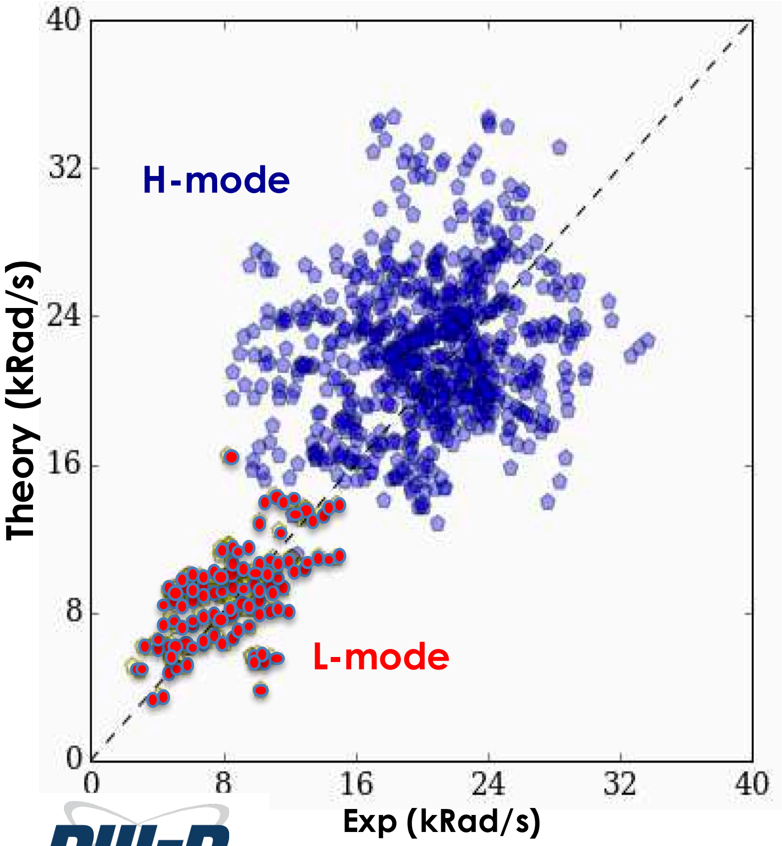
- Density modulation with 3D fields leads to toroidal variation of a/L_{ne} and turbulence drive
  - Linearized plasma response model predicts 3D deviation, but larger than measured

DIII-D NATIONAL FUSION FACILITY

Wilcox, Tues AM

R. S. Wilcox et. al., Phys. Rev. Lett. 117 (2016) 135001

Main-Ion Pedestal Top Intrinsic Rotation Model Prediction without Free Parameters Consistent w/ Experiments



- **Ctr-Ip passing ions stronger turbulent diffusion and higher loss rate than co-Ip ions**
  → ***Generates net co-Ip*** **rotation**

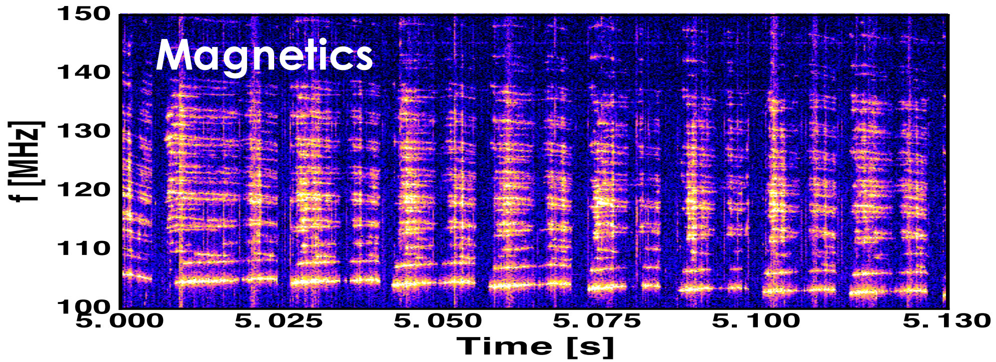
- **Predicted *value* and *direction* of pedestal top intrinsic rotation w/o free parameters consistent with observed intrinsic rotation**
  - **Database covers a wide range of parameters (L-mode, H-mode, ECH, NBI, USN, LSN, +/- Ip)**

- **Model recently extended to include finite NBI torque for predictive scenario modeling**

Ashourvan, Tues PM

Frontier Science: First Observations of Runaway Electrons Driving Whistler Waves

Post-deadline
APS invited



Whistler frequency bands show intermittency & whistler scattering

- **Validates model of Whistler behavior**
  - Follows predicted n_e B_T scaling
  - Multiple mode branches & spacing

Spong, Fri AM

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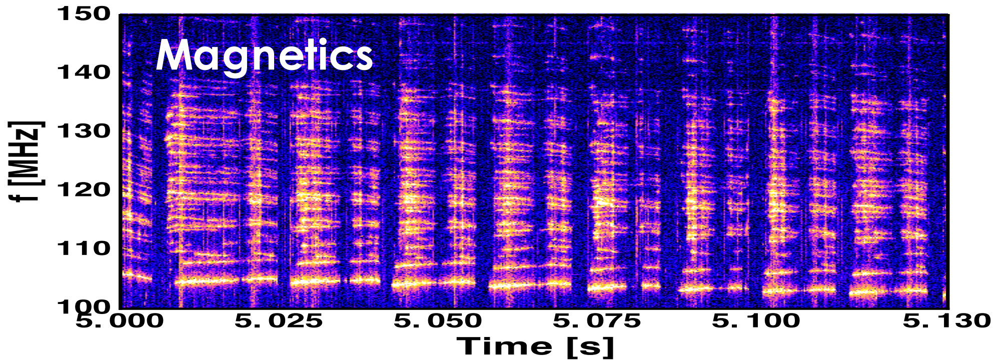

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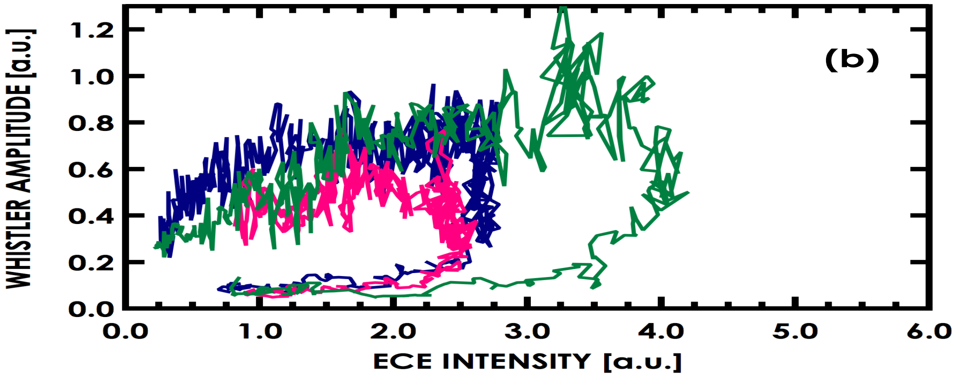

Predator-prey limit cycles between whistler wave amplitude and electron cyclotron emission

- **Validates model of Whistler behavior**
  - Follows predicted n_e B_T scaling
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  - Limit cycle as Whistler scatters REs , waves damp, REs restored

035-17/MEF/jy

Spong, Fri AM

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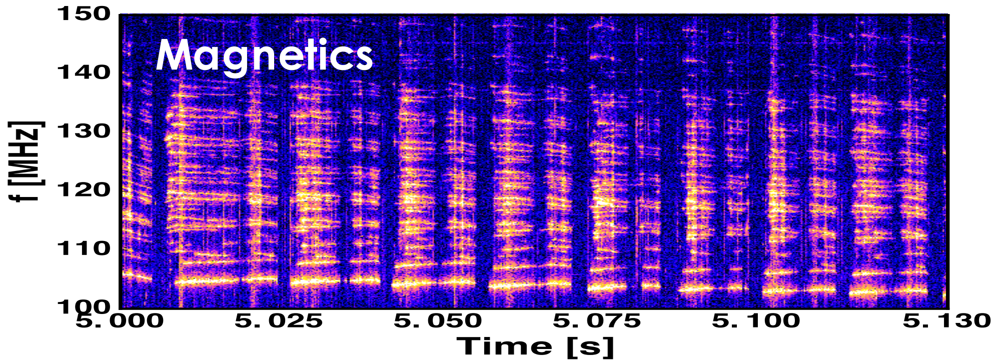

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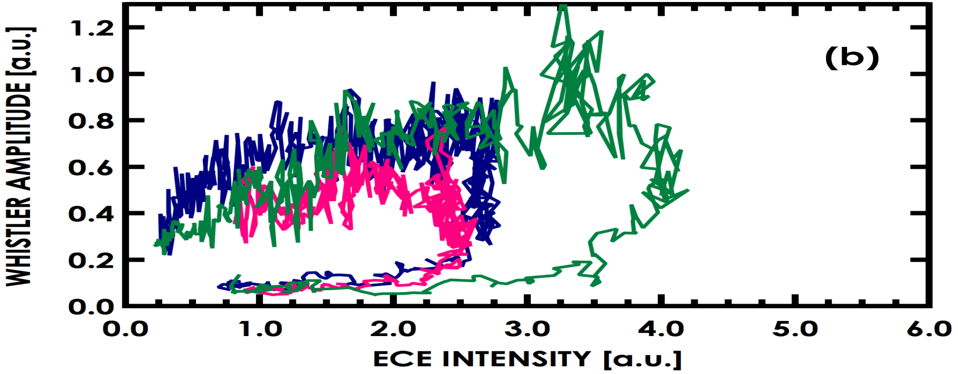

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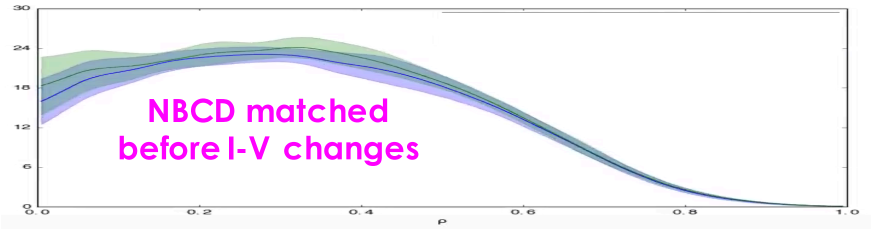
DIII-D 2018 Frontier Science Campaign: Announcement UFA Tonight (Mon), Discussion Tomorrow (Tues) ~ Noon

Buttery, Mon 7 PM

Spong, Fri AM

Improved Energetic Ion Confinement at Reduced Energy Gives Increased Neutral Beam Current Drive



- **Classical expectation: NBCD increases with voltage**
  - **Expt: setup three shots with comparable NBCD before beam I-V changes**

Pace, Weds NOON

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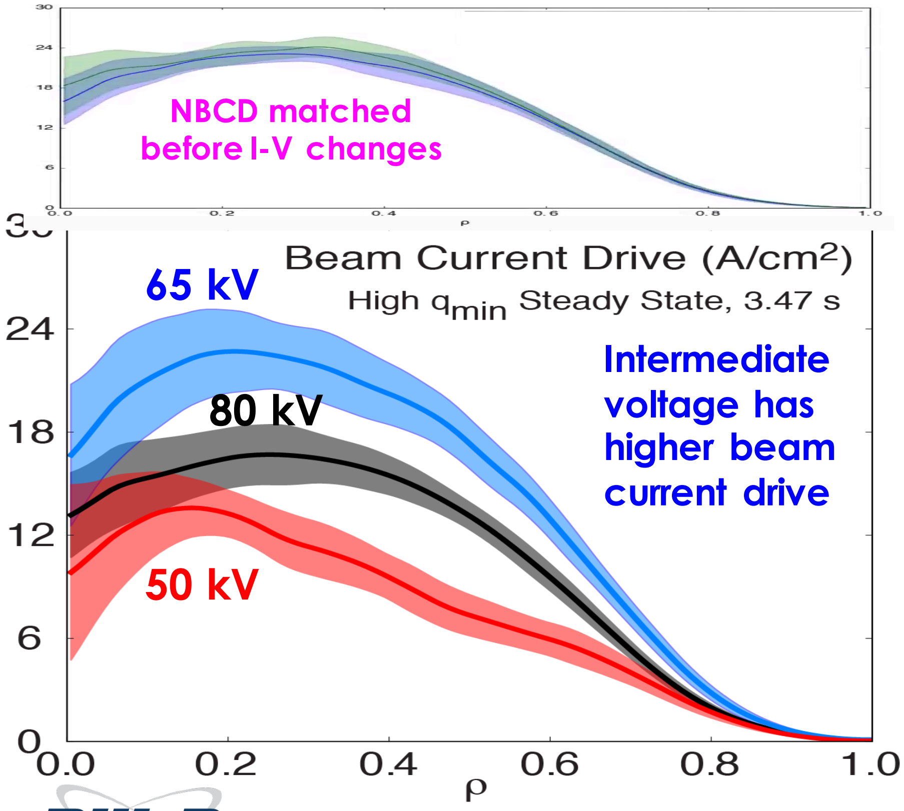


- **Classical expectation: NBCD increases with voltage**
  - Expt: setup three shots with comparable NBCD before beam I-V changes
- **Nominal beam current drive (80 kV) improves at intermediate (65 kV) and suffers at low (50 kV) voltage**
- **Calculated NBCD from balance of improved confinement (inferred from neutrons) vs reduced ion velocity (AE's off)**
  - Suggests optimum injection voltage for maximum current drive

Pace, Weds NOON

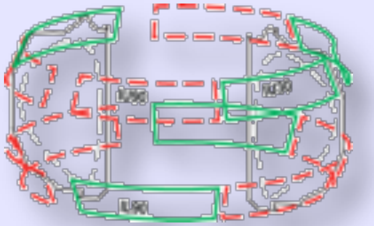
DIII-D Continues to Contribute to Fusion Energy Development by Focusing on Three Research Elements

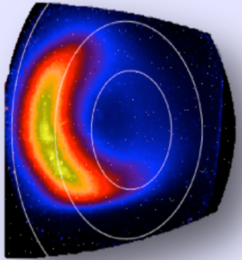
Develop Relevant Boundary Solutions

Strengthen the Basis for Fusion Science

Control Transients

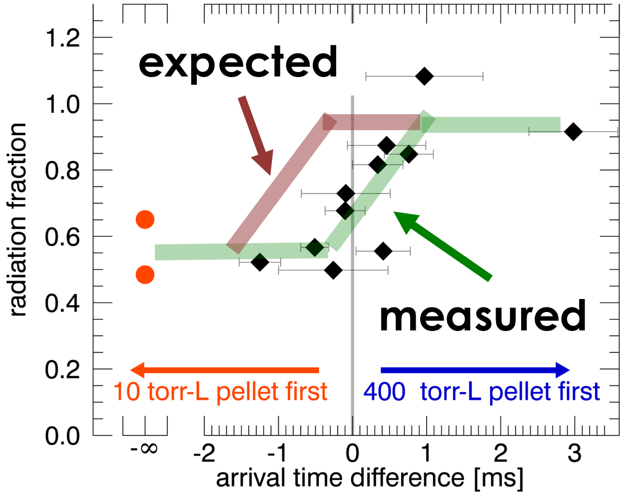
- Disruption mitigation
- ELMs & 3D





Critical transients issues for the design and operation of ITER

ITER-relevant Disruption Mitigation: Changes in Impurity Transport and Assimilation Can Impact SPI Performance

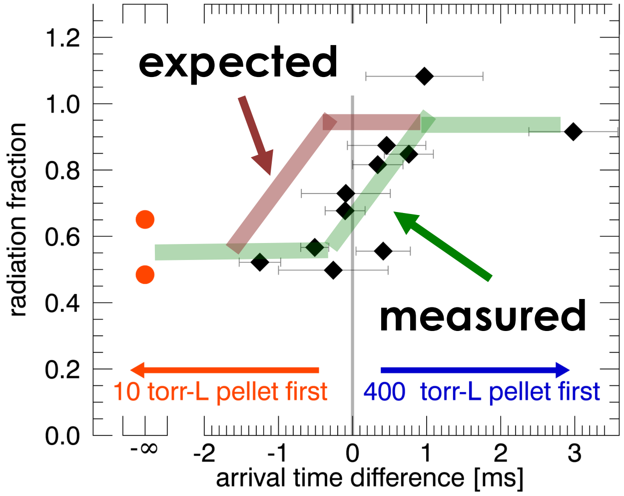


Multiple shattered pellets injected for the first time

- ITER will inject multiple pellets for disruption mitigation
- Effect of multiple pellets appears to not sum directly

Herfindal, ITER session, Shiraki poster Tues AM

ITER-relevant Disruption Mitigation: Changes in Impurity Transport and Assimilation Can Impact SPI Performance



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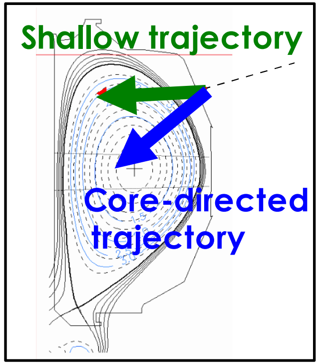
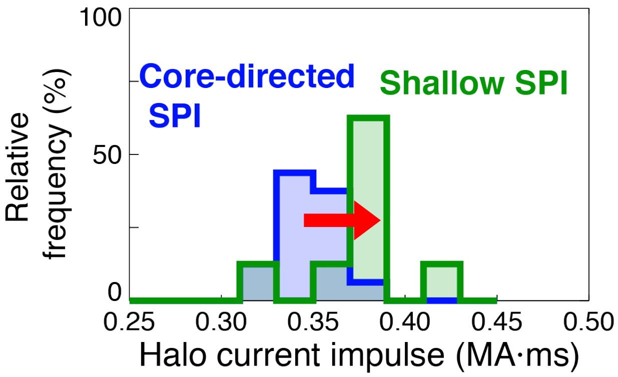
ITER-like shallow pellet trajectory reduces SPI performance

- Performance comparable to similar MGI
- Implies ballistic transport important for SPI





Herfindal, ITER session,
Shiraki poster Tues AM

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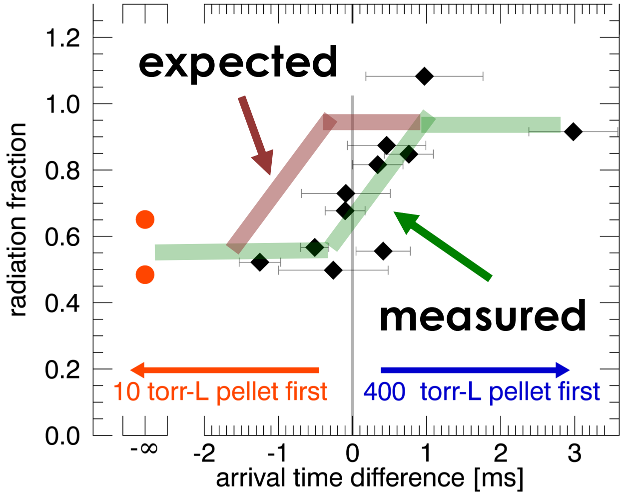

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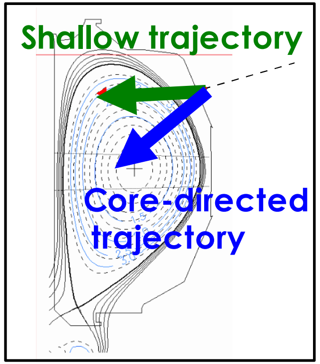

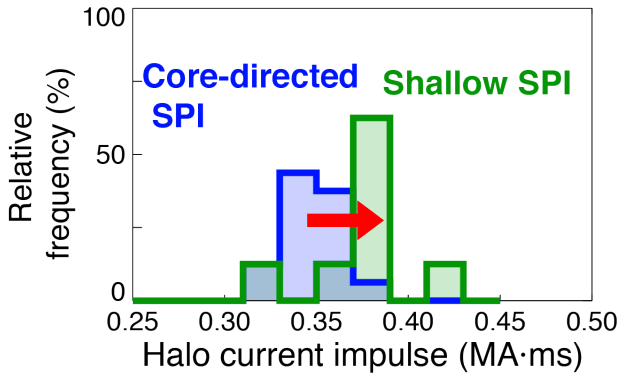

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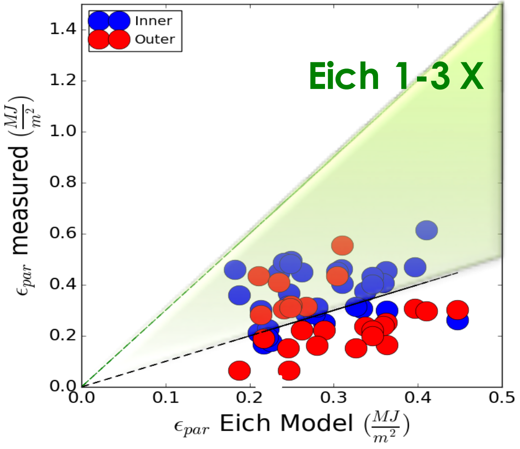
Herfindal, ITER session, Shiraki poster Tues AM

GRI Reveals Energy Dependent Growth of REs

Paz-Soldan, Weds AM

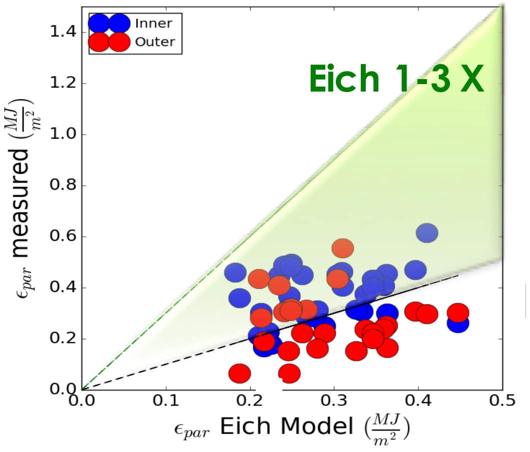
ELM Parallel Energy Densities Normalized to Eich Model Suggest Dependences on P_{heat}/P_{L-H} and Highest Growth Rate Mode



- **Measured ε_{par} never exceeds upper boundary of Eich model (from JET, AUG and MAST data)** $\varepsilon_{//} = 3\, p_{e,ped}\, a_{pol}\, B_T/B_p$

Knolker, this session

ELM Parallel Energy Densities Normalized to Eich Model Suggest Dependences on $P_{heat}/P_{L\text{-}H}$ and Highest Growth Rate Mode



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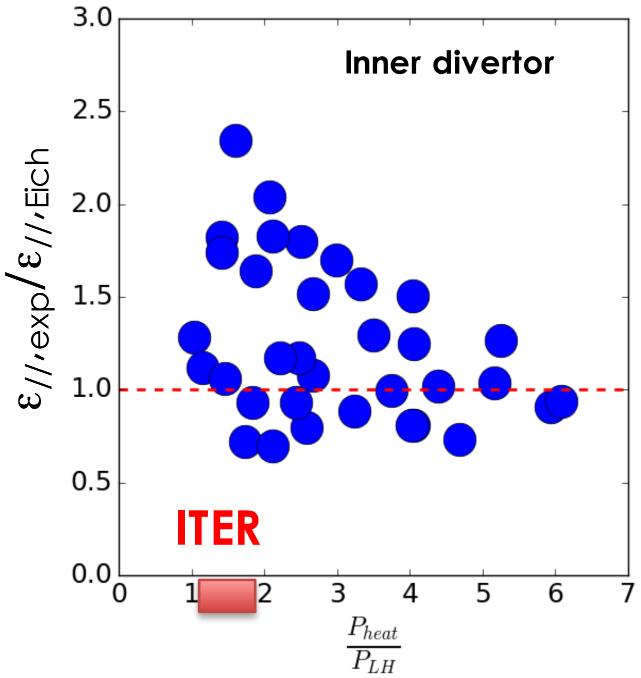
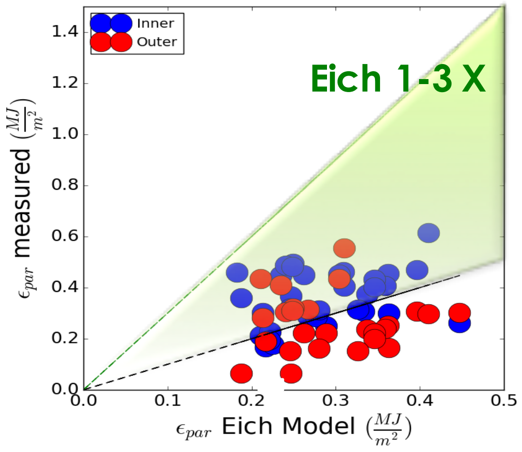


- **Scatter of $\varepsilon_{//,exp}/\varepsilon_{//,Eich}$ larger close to L-H power threshold**

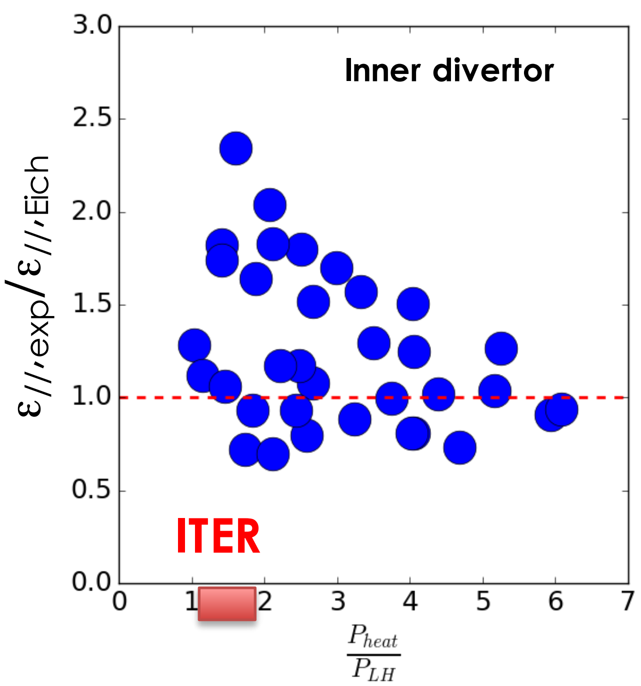
Knolker, this session

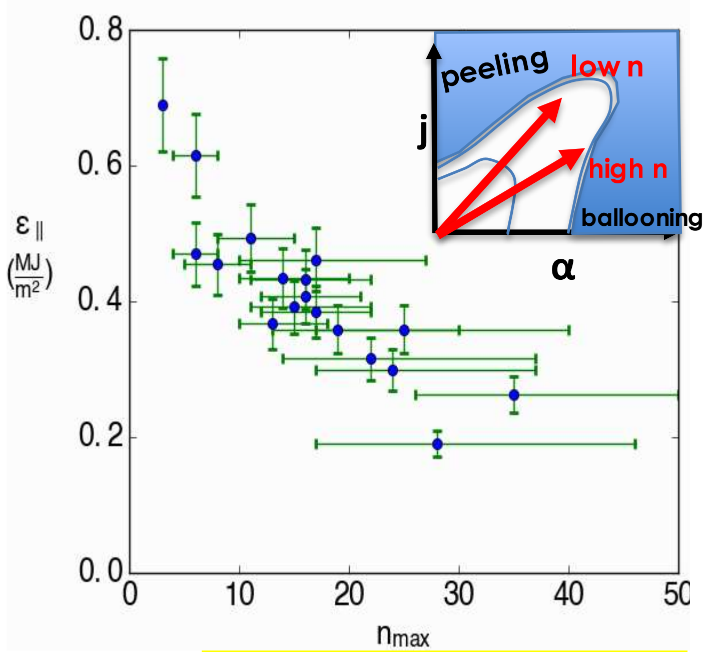
ELM Parallel Energy Densities Normalized to Eich Model Suggest Dependences on $P_{heat}/P_{L\text{-}H}$ and Highest Growth Rate Mode



- Measured ε_{par} never exceeds upper boundary of Eich model (from JET, AUG and MAST data) $\varepsilon_{//} = 3\ p_{e,ped}\ a_{pol}\ B_T/B_p$

- ELMs with larger $\varepsilon_{//}$ dominated by low-n peeling modes





- Scatter of $\varepsilon_{//,exp}/\varepsilon_{//,Eich}$ larger close to L-H power threshold

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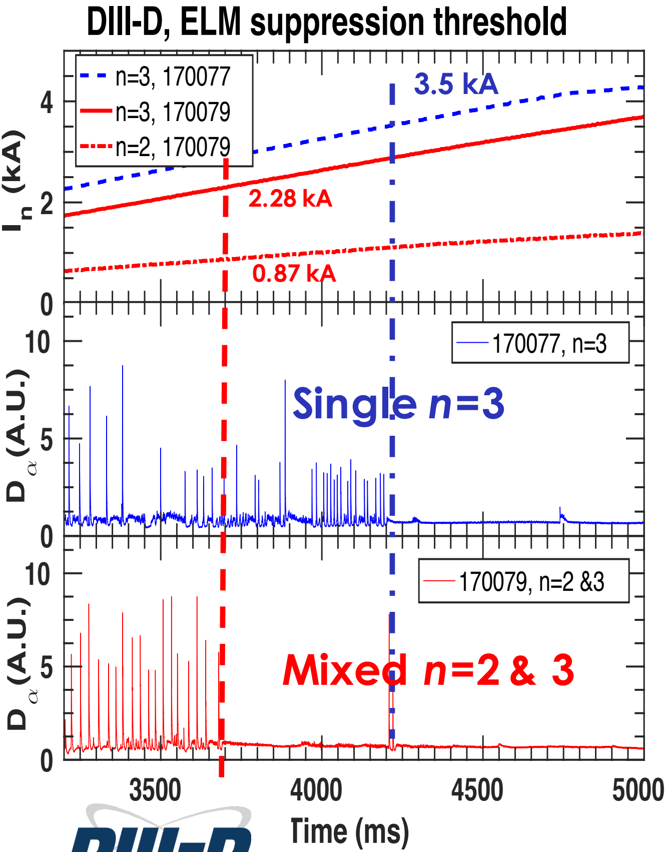
Knolker, this session

RMP Threshold Current for ELM Suppression Reduced with Mixed n = 2 + n= 3 Spectrum Fields



Y Sun, Fri AM

- **ELM suppression at 10% lower total coil current for $I_{n=3} : I_{n=2} = 3:1$**

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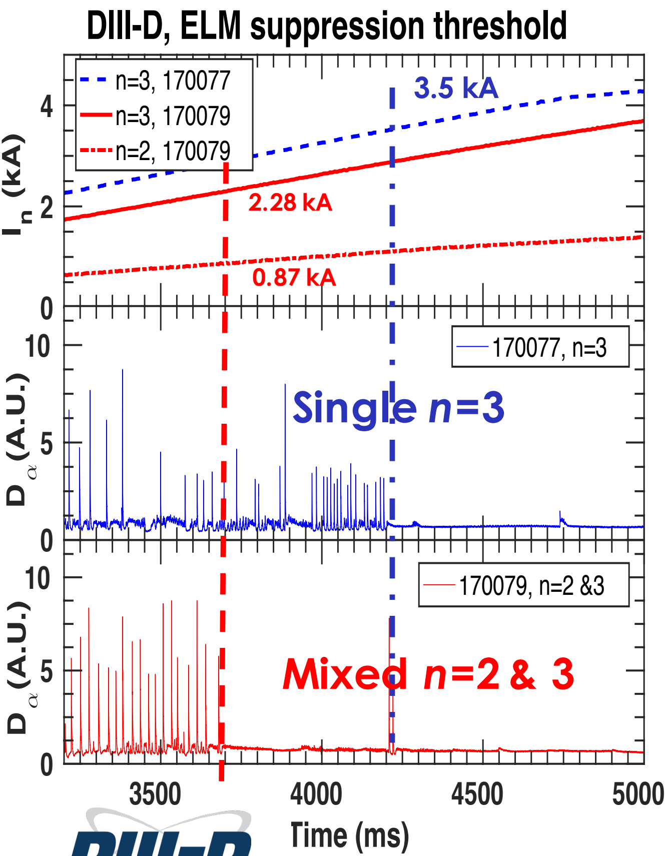

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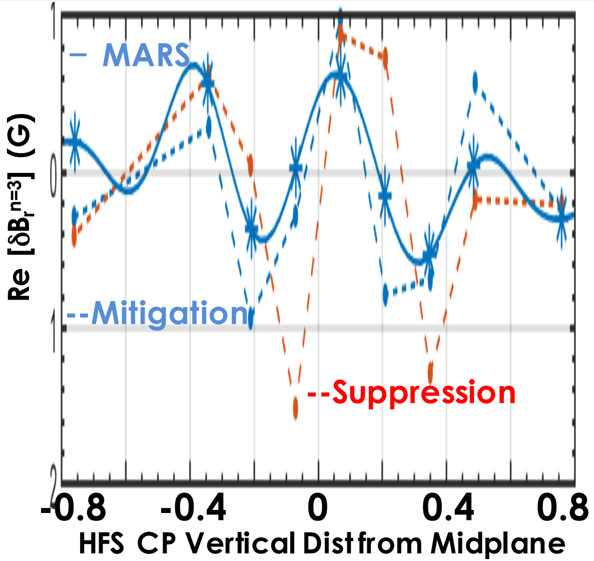

Y Sun, Fri AM

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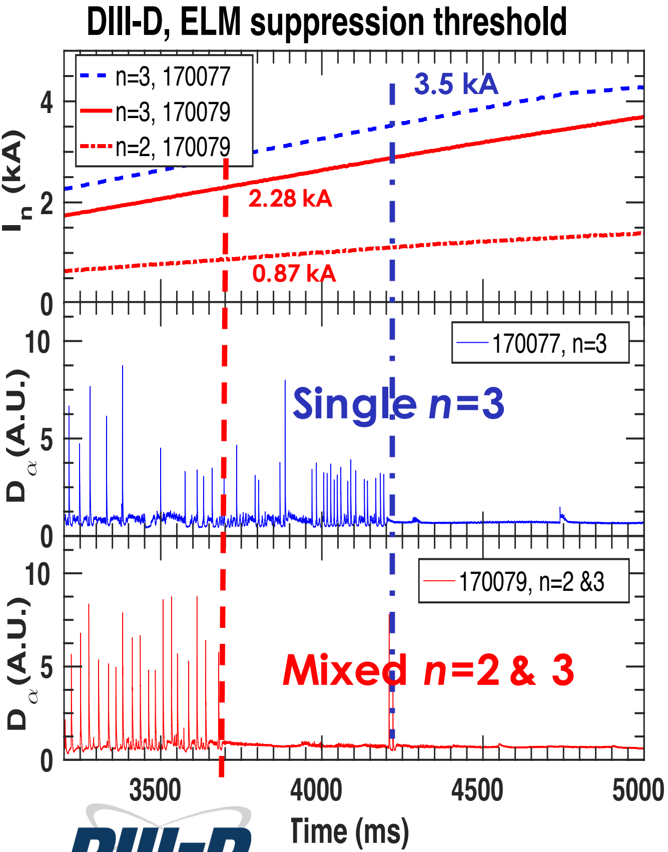
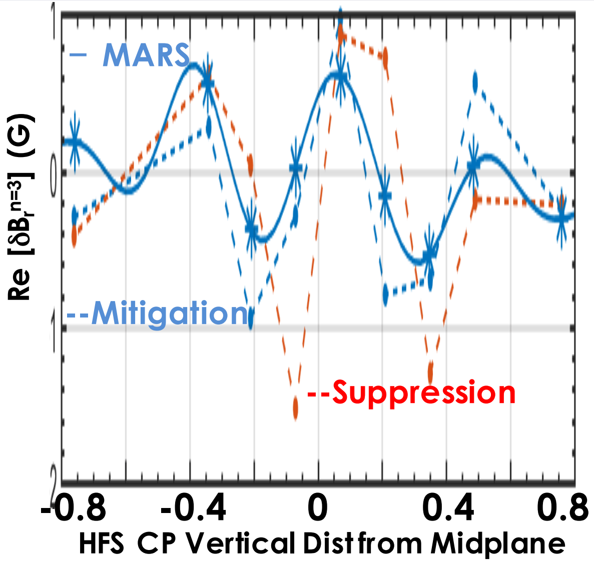


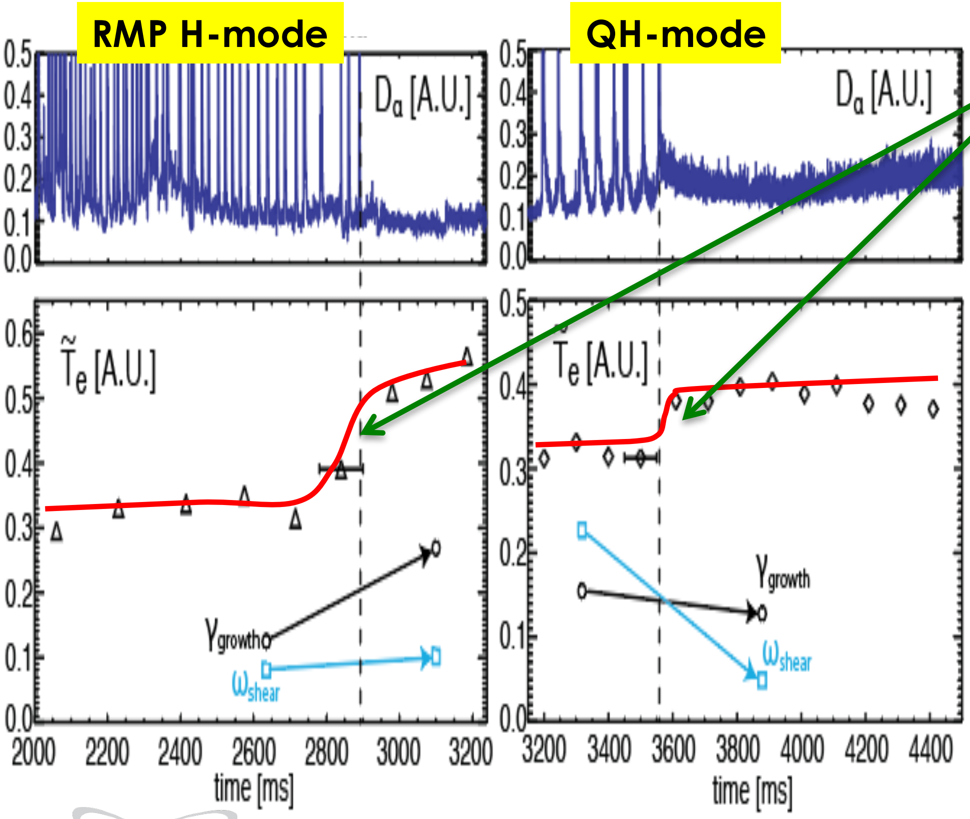
- ELM suppression at 10% lower total coil current for $I_{n=3} : I_{n=2} = 3:1$
- MARS reproduces HFS response for ELM mitigation, but not for **suppression**
- "Predict-First" analysis of plasma response to RMP guides ELM suppression access dependence on triangularity



Y Sun, Fri AM

Lyons Thur AM

Edge Electron Turbulence Increases Near Pedestal when ELMs Eliminated in Both RMP and QH-mode Plasmas



- **Both ne and Te fluc increase in RMP & QH**
  - Increase only when ELMs gone

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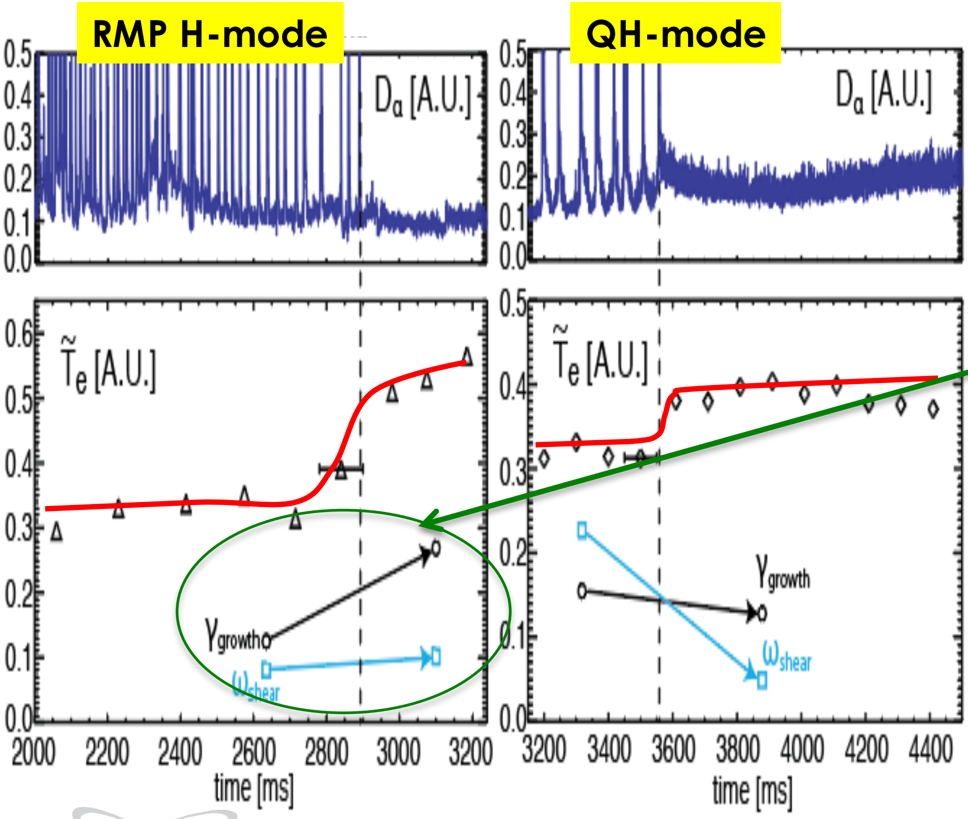
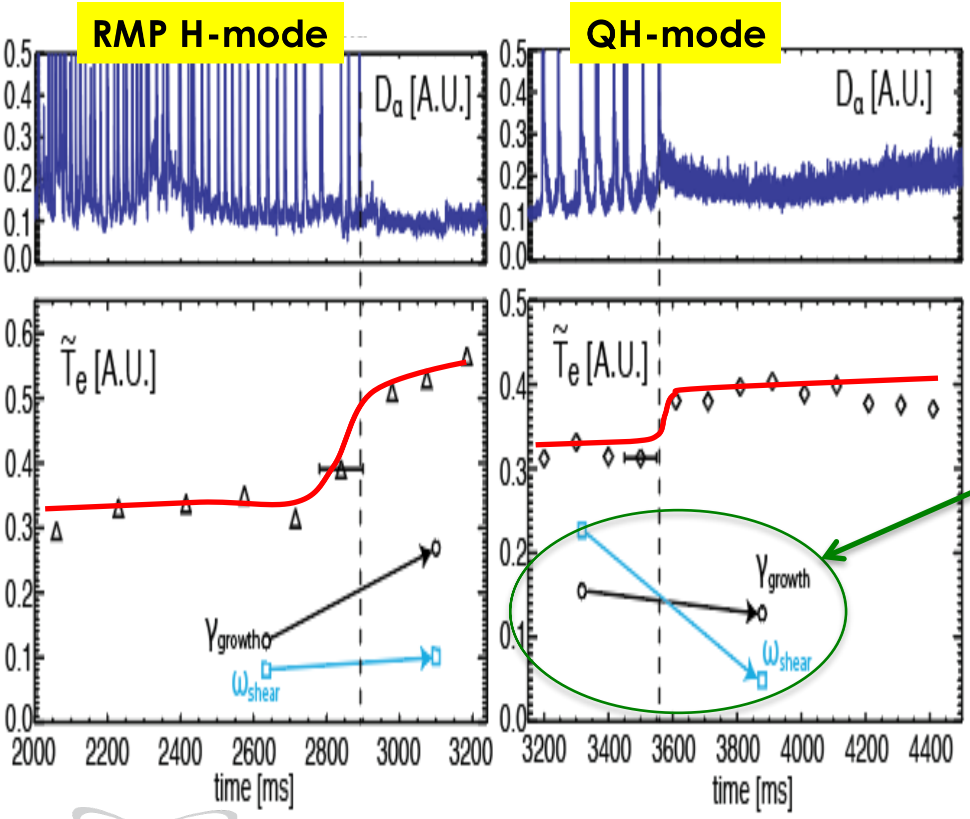


- Both ne and Te fluc increase in RMP & QH
  - Increase only when ELMs gone
- Growth rate/shearing rate ratios increase in both but for different reasons
  - RMP: inverse scale lengths up, growth rate up more than shearing rate

C. Sung, Mon NOON

Edge Electron Turbulence Increases Near Pedestal when ELMs Eliminated in Both RMP and QH-mode Plasmas



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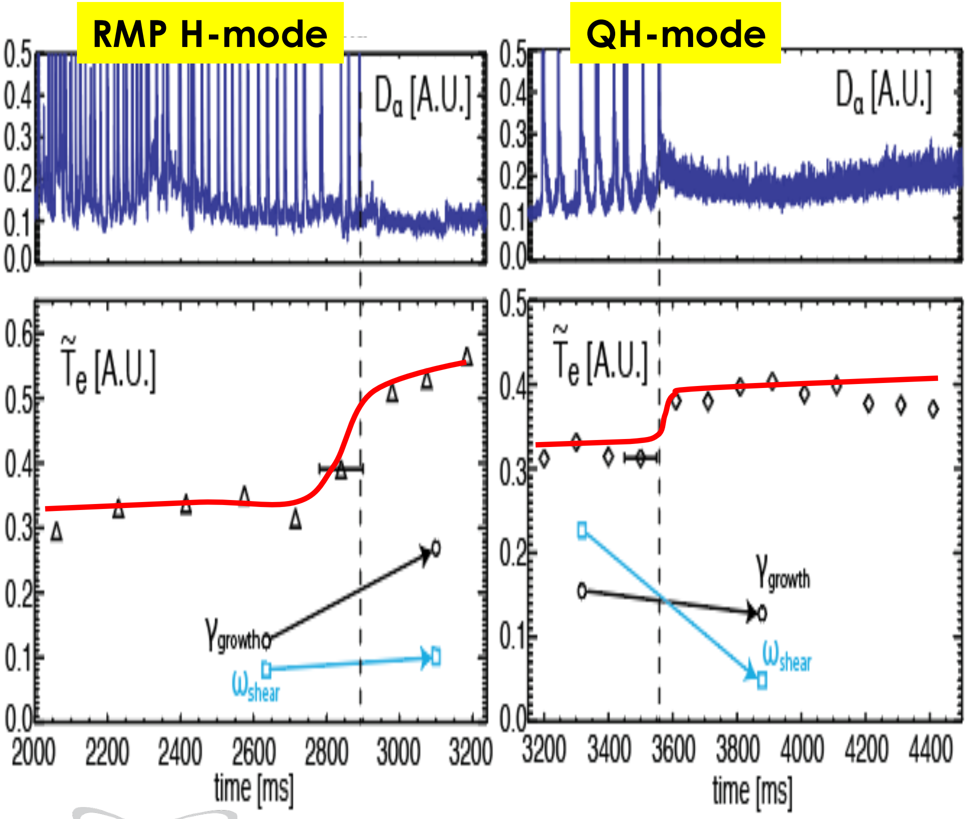

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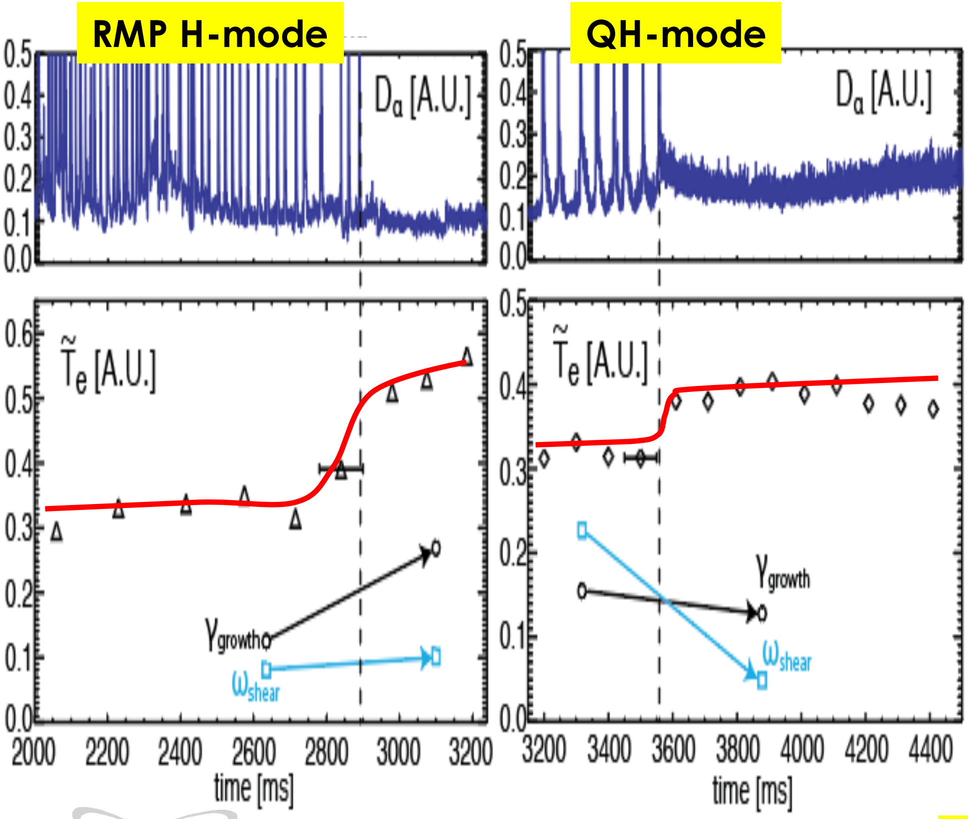

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- CGYRO tracks both changes well
  - Turbulence increase consistent with increase in growth/shearing ratio
- Wide pedestal QH extended to ITER relevant LSN and low torque

Burrell (Chen), Weds PM

C. Sung, Mon NOON

DIII-D Program Much Broader Than Can Be Described Here – See Invited and ITER Talks Plus Two Poster Sessions

Review Talk			
Tues	8:00	Snyder	REVIEW: Physics of the Tokamak Pedestal, and Implications for Magnetic Fusion Energy
Invited Talks			
Mon	11:00	Staebler	Transport Barriers in Bootstrap Driven Tokamaks
Mon	Noon	C. Sung	Physics of thermal transport and increased electron temperature turbulence in the edge pedestal
Tues	10:00	Wilcox	Toroidally asymmetric density profiles and turbulence induced by applied 3D fields in DIII-D
Tues	2:00	Ashourvan	Validation of Kinetic-Turbulent-Neoclassical Theory for Edge Intrinsic Rotation in DIII-D Plasmas
Weds	10:00	Paz-Soldan	Spatio-temporally resolved measurement of RE momentum distributions during controlled dissipation
Weds	Noon	Pace	Manipulating Energetic Ion Velocity Space to Control Instabilities and Improve Tokamak Performance
Thurs	9:30	Lyons	Predict-first experimental analysis using automated and integrated MHD modeling
Thurs	10:00	Turco	Understanding the stability of the low torque ITER Baseline Scenario in DIII-D
Thurs	2:00	Luce	Experimental Challenges to Stiffness as a Transport Paradigm
Fri	9:30	Y. Sun	Dynamic ELM and divertor control using resonant toroidal multi-mode magnetic fields in DIII-D and EAST
Fri	10:00	Samuell	Imaging Main-Ion and Impurity Velocities for Understanding Impurity Transport in the Tokamak SOL
Fri	Noon	H. Guo	An innovative small angle slot divertor concept for long pulse advanced tokamaks
Fri	Noon	Spong	First observation of runaway electron-driven whistler waves in tokamaks
TO4 Oral Session on Research in Support of ITER-I			
Weds	2:00	Herfindal	Superposition of dual shattered pellet injections for disruption mitigation
Weds	2:48	Clement	Plasma response control using advanced feedback techniques
Weds	3:24	Carlstrom	Prototype testing of the ITER Toroidal Interferometer and Polarimeter (TIP) on DIII-D
Weds	3:36	Orlov	Divertor Heat Flux Control with 3D Stochastic Magnetic Fields during ELM Suppression.
Weds	3:48	Hinson	Enhancement of Helium exhaust by resonant magnetic perturbations in DIII-D
Weds	4:00	Burrell	Expansion of Parameter Space for Wide-Pedestal, Quiescent H-mode Plasmas in DIII-D
Weds	4:24	Baylor	Pellet Fueling of ELM Mitigated ITER Baseline Scenario Plasmas on DIII-D*
Weds	4:36	Luce	Exploring an Alternate Approach to Q=10 in ITER
DIII-D Posters Tuesday and Wednesday Mornings			