# Introduction to DIII-D PIT Group Activities

**G. Sinclair**
on behalf of T. Abrams & A. Dvorak

Presented at

## DIII-D Industry Event Day

November 14th, 2025

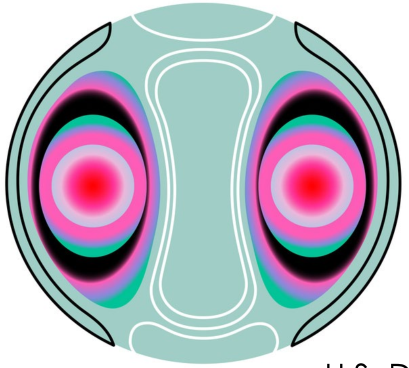
- *Goals of PIT group*
- *Topical areas and recent highlights*
- *Thrusts*
- *Next steps*

# The Plasma-Interacting Technology Group was formed in 2023 to focus and prioritize DIII-D research towards fusion pilot plant development

**Mission: Support development of plasma-interacting technologies to accelerate the engineering maturity of the FPP design space**

Plasma-material interactions

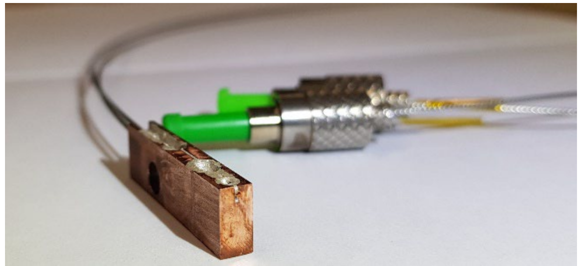
Heating & Current Drive



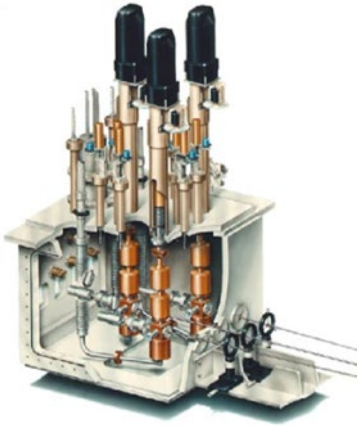
U.S. DOE

Fusion Pilot Plant

Diagnostics & Actuators



Disruption mitigation



# The PIT group engages with industry to understand their needs and provide pathway for testing on DIII-D

Group Leaders


Tyler Abrams
Scientist
General Atomics


Andrew Dvorak
Engineer
Oak Ridge National Lab

- **Leadership from industry & national lab balances innovation & scientific excellence**
- **Shift in program focus mirrors recent expansion of public-private partnerships at DOE**
- **Position DIII-D as a testbed for key fusion technologies**

# Fusion-specific technology readiness levels adopted to identify gaps and track progress towards FPP development

- **How does DIII-D track progress on technology development?**
- **Fusion TRLs adopted throughout the program (based on work in Korean program)**
  - success metric for experiments and testing campaigns executed on tokamak
- **DIII-D functions to bridge the gap from concept to prototype**

Testing and validation performed on DIII-D

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Basic studies & observations | Technology concept formulated | Critical function shown in proof of concept principle of actuators | Breadboard validation in laboratory of proof of concept solution | Prototype in laboratory | Prototype in reactor-relevant physics regimes | Robust solutions in reactor-relevant physics regimes | Actual system test at reactor scale | Actual system robust operation |

# Plasma-Interacting Technology Group consists of four topical areas to organize research tasks

- **FPP Research**
  *Morgan Shafer and Chris Holcomb, co-leaders*
  - 11 Steady-State and Pulsed Fusion Core — *A. Garofalo (B. Victor)*
  - 12 Plasma Control — *D. Eldon (J. Barr)*
  - 13 Divertor Science and Innovation — *A. McLean (J. Yu)*
  - 14 Core-Edge Integration — *H. Wang (R. Wilcox)*
  - 15 Negative Triangularity — *K. Thome (F. Scotti)*

- **Plasma Interacting Technology**
  *Tyler Abrams and Andrew Dvorak, co-leaders*
  - 21 Plasma-Material Interactions — *D. Rudakov (G. Sinclair)*
  - 22 Disruption Mitigation — *J. Herfindal (A. Lvovskiy)*
  - 23 Heating and Current Drive — *B. Van Compernolle (S.X. Tang)*
  - 24 Diagnostics and Actuators — *S. Hong (Y. Zhu)*

- **Burning Plasma Research**
  *Xi Chen and George McKee, co-leaders*
  - 31 Integrated Inductive Scenarios — *J. Hanson (N. Leuthold)*
  - 32 Turbulence and Transport — *L. Schmitz (M. Austin)*
  - 33 Pedestal and Non/Small ELM Regimes — *A. Bortolon (J. Chen)*
  - 34 Transient Control — *N. Logan (L. Bardoczi)*

# PMI Technical Area is focused on materials evaluation in an integrated environment and resultant effects on plasma performance

## Goals

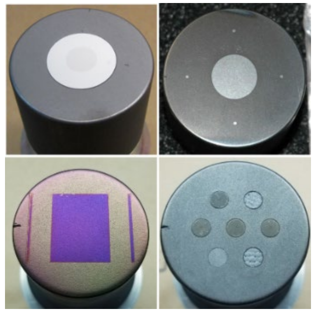
1. Inform down-selection for FPP-relevant main chamber and divertor PFC material solutions.

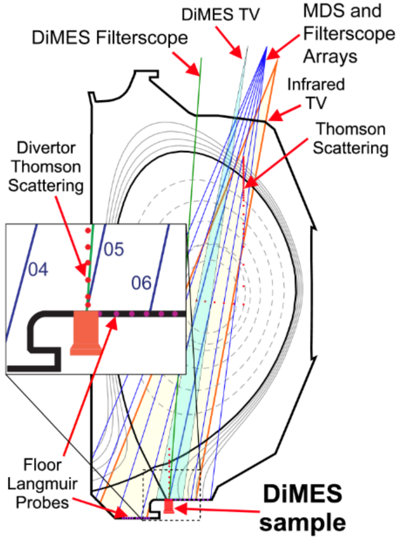
2. Support PMI modeling for ITER & FPP via studying high-Z erosion/migration/re-deposition.

3. Assess the performance of alternative materials (both solid and liquid) in high heat flux environment, including transients.

4. Study real-time wall coating/conditioning by injecting low-recycling powders (B, BN, Li, Si).

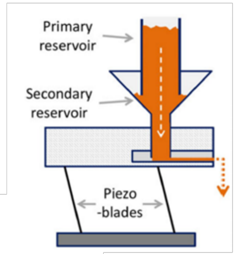
## Coupon testing

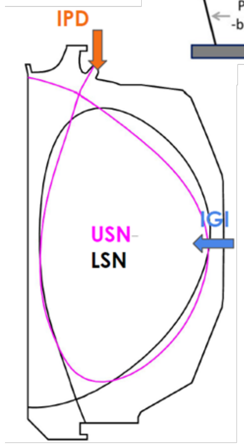




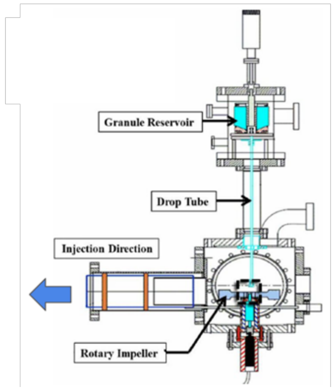

## Wall conditioning

Impurity powder dropper

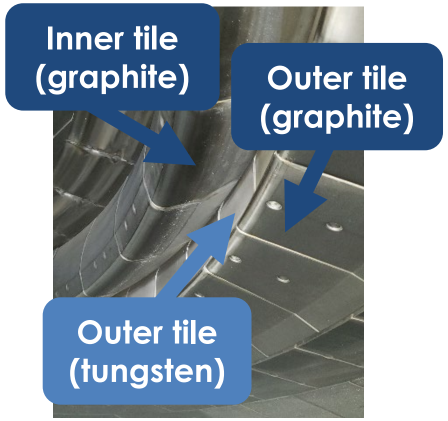



Impurity granule injector




## Divertor tile testing



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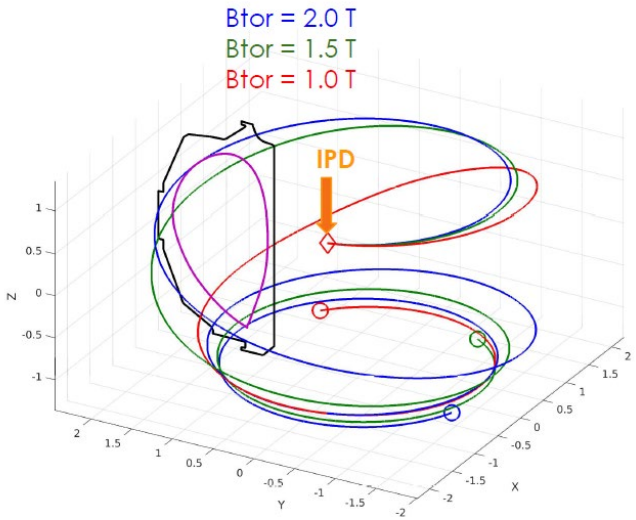
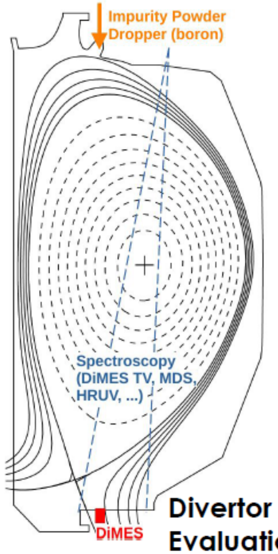
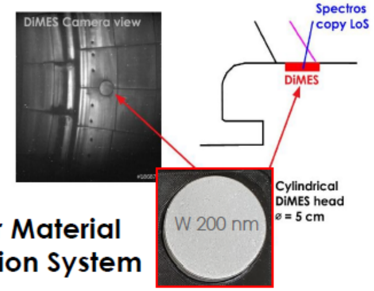
# Variation in toroidal magnetic field yielded change in measured B emissivity on divertor surface

- **Boron coatings may be used to maintain acceptable plasma performance and minimize wall deterioration**
- **Experiment studied how single-point boron injection deposits onto wall and how toroidal footprint can be actuated via toroidal magnetic field ($B_t$)**
  - Increasing B spectroscopic signal on surface with decrease in Bt was observed
  - Measurements are consistent with 3D modeling

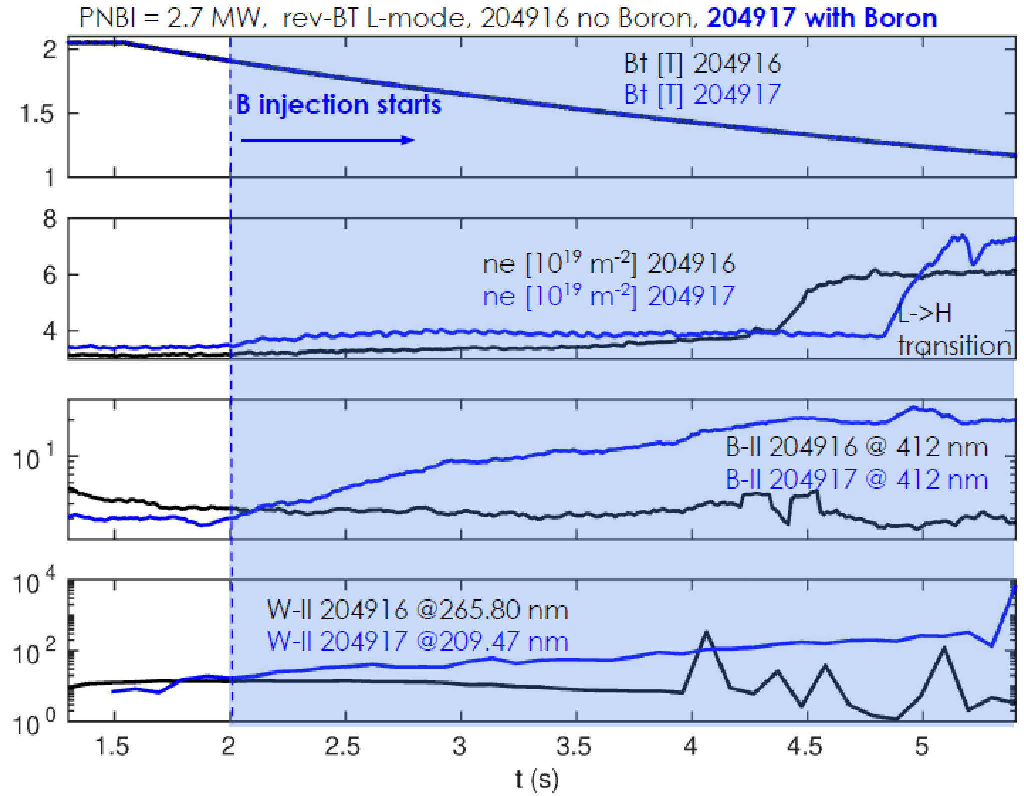



**W insert amplifies B flux signatures due to lower sticking and B→W sputtering**




**Divertor Material Evaluation System (DiMES)**



# Disruption mitigation technical area seeks to minimize the consequences of a disruption to maintain machine survivability

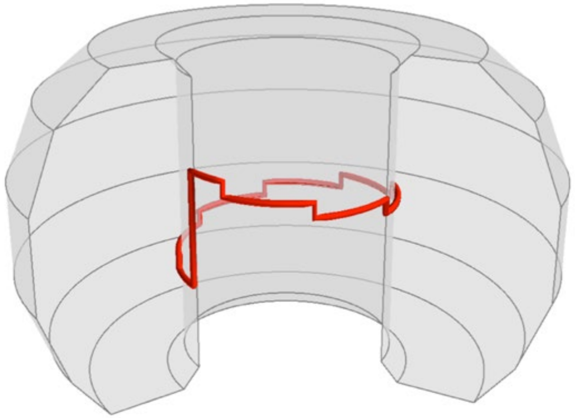
## Goals

1. Optimize particle delivery schemes by shattered pellet injection.

2. Develop methods to suppress and mitigate runaway electrons.

3. Develop alternative active disruption mitigation systems.

4. Develop passively resilient disruption mitigation systems.

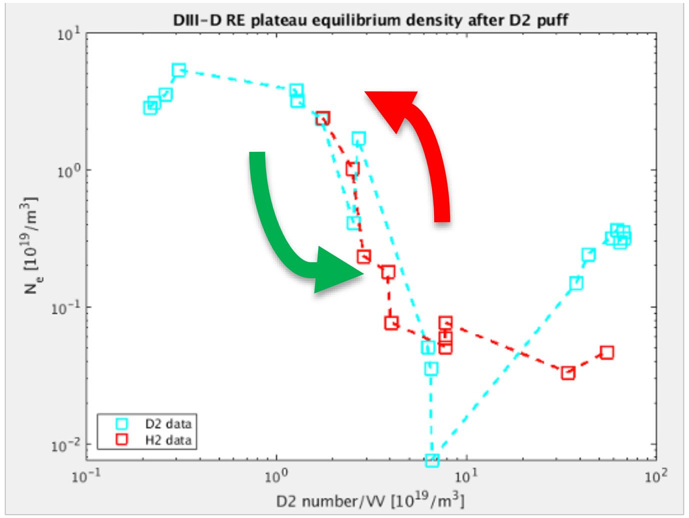


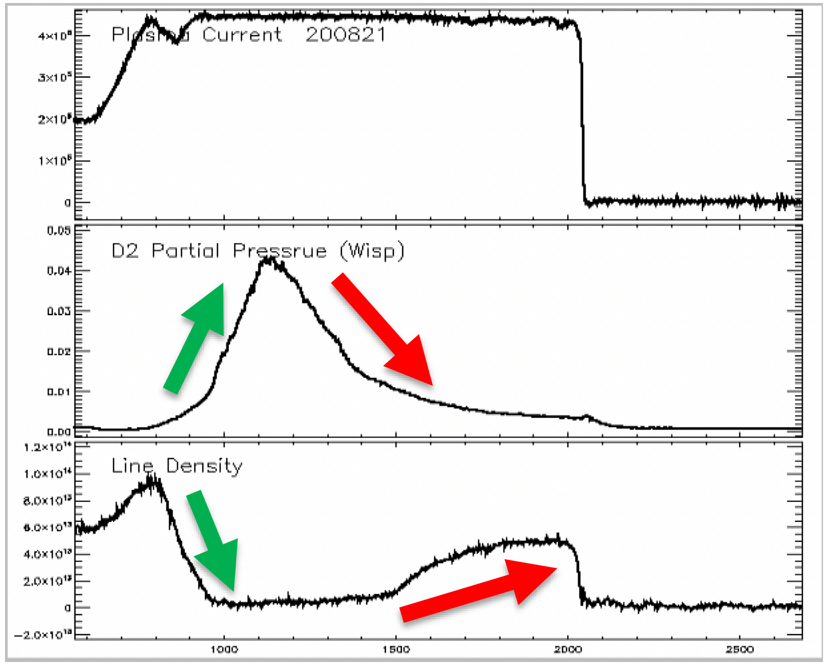
Passive runaway electron deconfinement coil (proposed)

Shattered pellet injection system

# New technique developed to safely terminate runaway electron (RE) beams

- **Recent experiment assessed the role of neutrals and $D_2$ partial pressure on accessing windows for safe RE termination**
- **New technique allows the free electron density to be determined as a function of partial pressure**
  - Achieved by slowly scanning the neutral pressure with fueling values
  - Previous technique required many shots to achieve what this captures in a single discharge
- **Novel data enables model validation and allows for direct comparison to other machines**



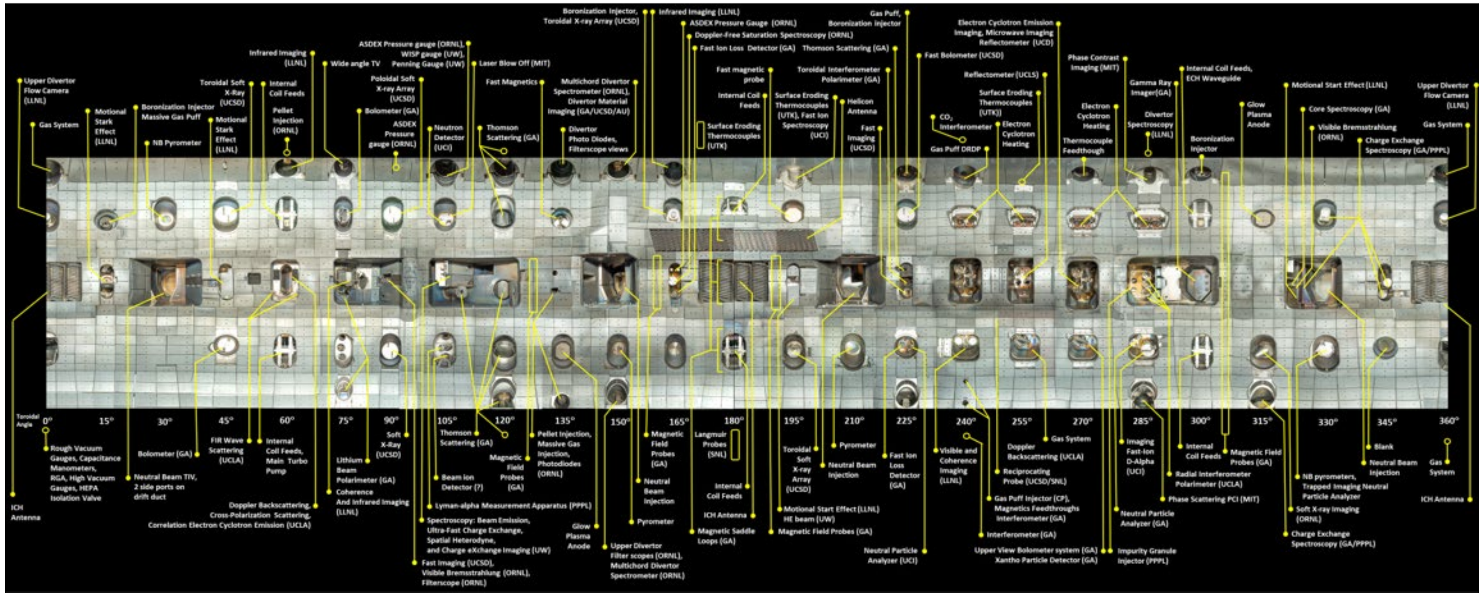



# The diagnostics & actuators technical area develops and demonstrates reactor-relevant diagnostics to ensure reliable & safe operation

## Goals

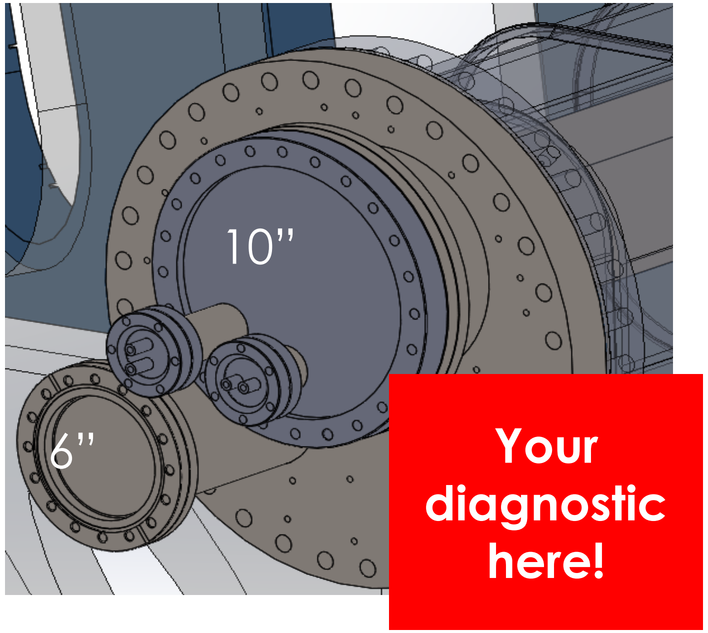
1. Identify full and reduced diagnostic suite for FPP non-nuclear and nuclear operation.

2. Develop new diagnostics for FPP non-nuclear and nuclear operation.

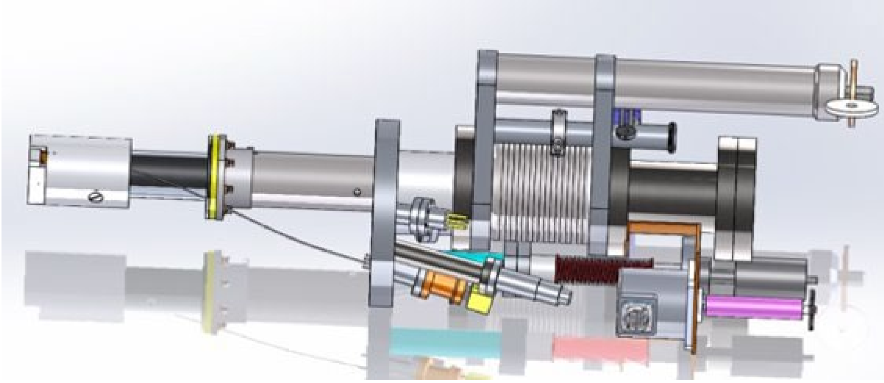


Diagnostics on DIII-D outer wall

New FPP diagnostic testing platform (proposed)




Fast ion loss detector



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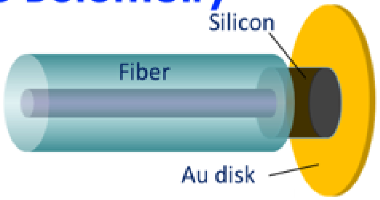
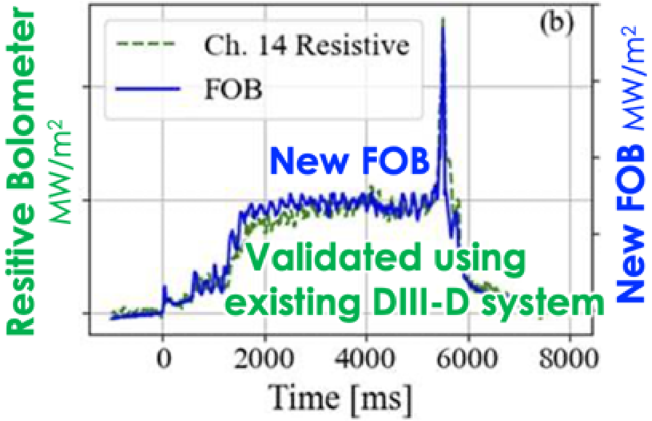
# Diagnostic Measurement Innovation for FPP is NOT an option (RAMI)

- **FPPs need advances in diagnostics**
  - Survival of plasma & neutron fluences
  - Miniaturization & modularization
  - Reduced diagnostic set with AI/ML
- **FPP Diagnostics remain underdeveloped**
  - New concept to overcome the limits of conventional diagnostics under FPP environment (e.g. FOB, neutron)
  - Integration and miniaturization of diagnostics for FPP control (new T sensor integrated into divertor and blanket)
  - Developing a compact reduced set diagnostic casettee with industry partner (Next Step Fusion)
  - Super-resolution synthetic diagnostics for real time control (P-U), spin polarized fusion detectors (UCI)

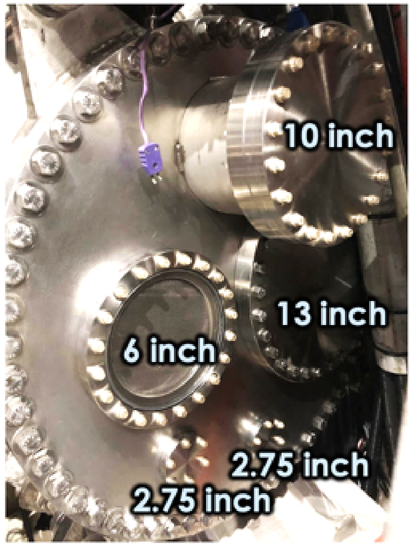
## Fiber Optic Bolometry*

nusenics

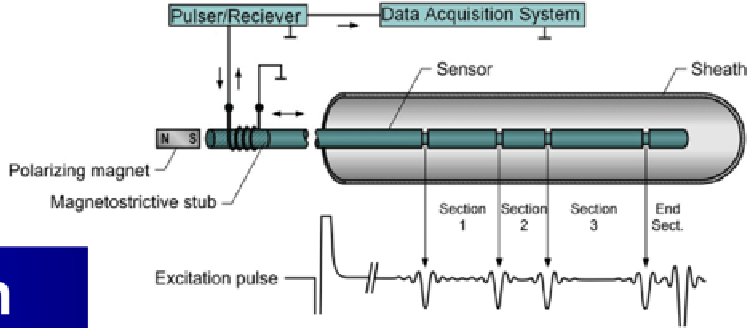



## Diagnostic platform




## Radiation hardened T sensors




**Dedicated diagnostic measurement innovation activities for FPP are essential**

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*S. Lee, et al., Rev. Sci. Instrum. 93, 123515 (2022)



X-WAVE INNOVATIONS, INC. Make state-of-the-art obsolete

# Heating & Current Drive (H&CD) technical area develops and tests flexibility and accessibility of new H&CD technologies to FPP scenarios

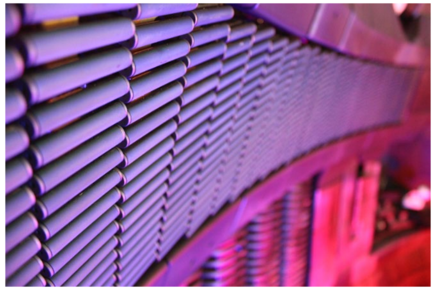
## Goals

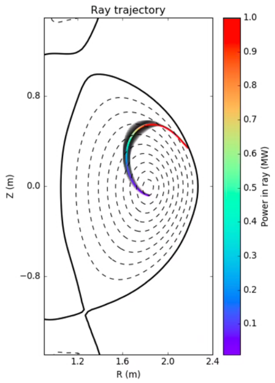
1. Evaluate the efficiency of helicon heating and current drive

2. Evaluate electron cyclotron current drive efficiency, using new top launch concept

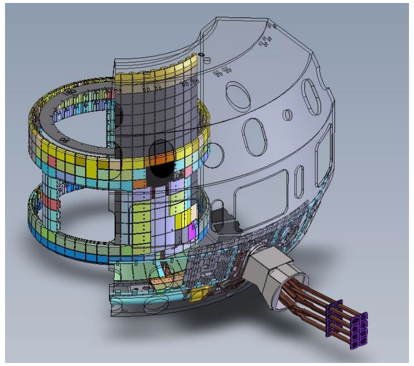
3. Demonstrate electron cyclotron heating using O-mode in high density plasmas

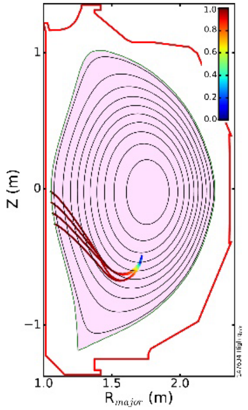
**Helicon**



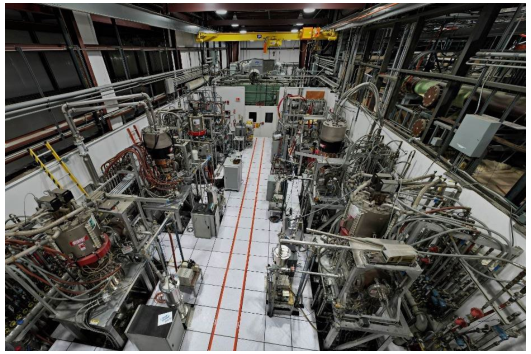


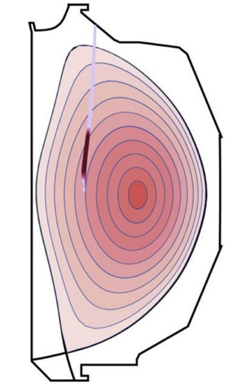

**High field side lower hybrid current drive**

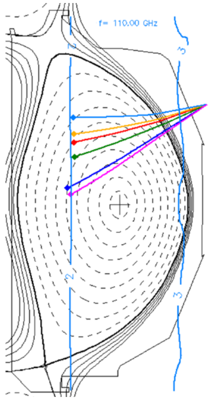





**Electron cyclotron heating & current drive**







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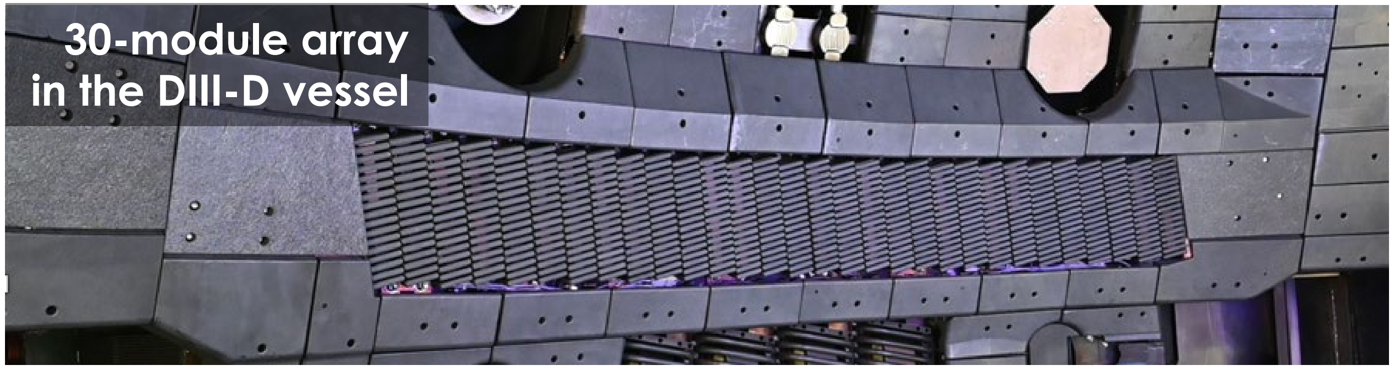
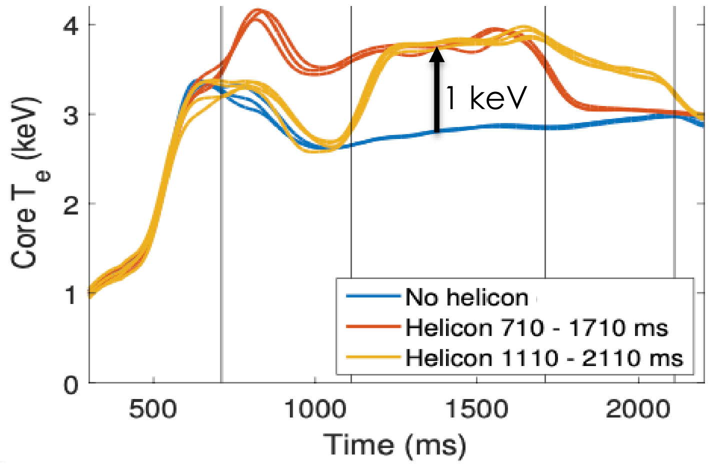
# Helicon antenna advances current drive physics and traveling wave antenna technology



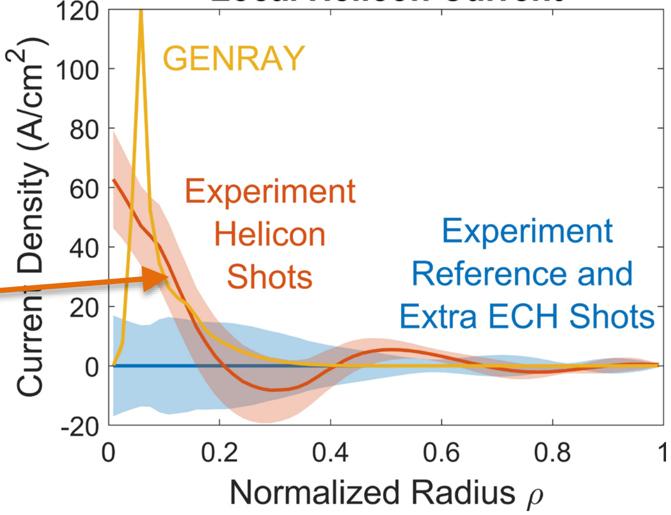

**~1 keV $T_e$ increase due to helicon**




- **Comb-line traveling wave antenna technology**
  - MW-level system at 476 MHz
  - Highly directional wave launch, fast wave polarized
  - Input impedance load resilient to changes in plasma loading, e.g. due to ELMs

**First demonstration of helicon current drive in plasmas where slow mode cannot propagate**

**Local Helicon Current**



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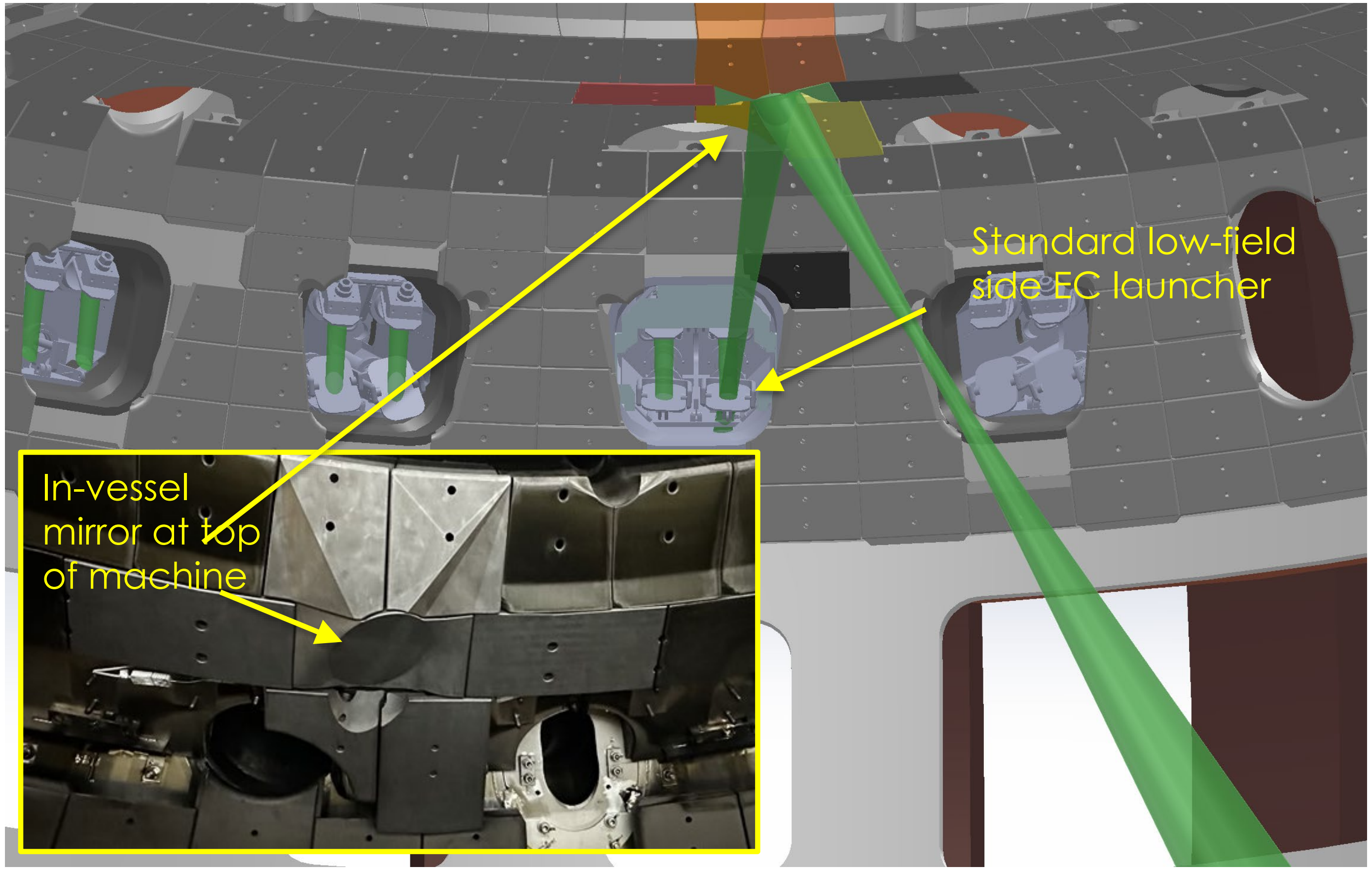
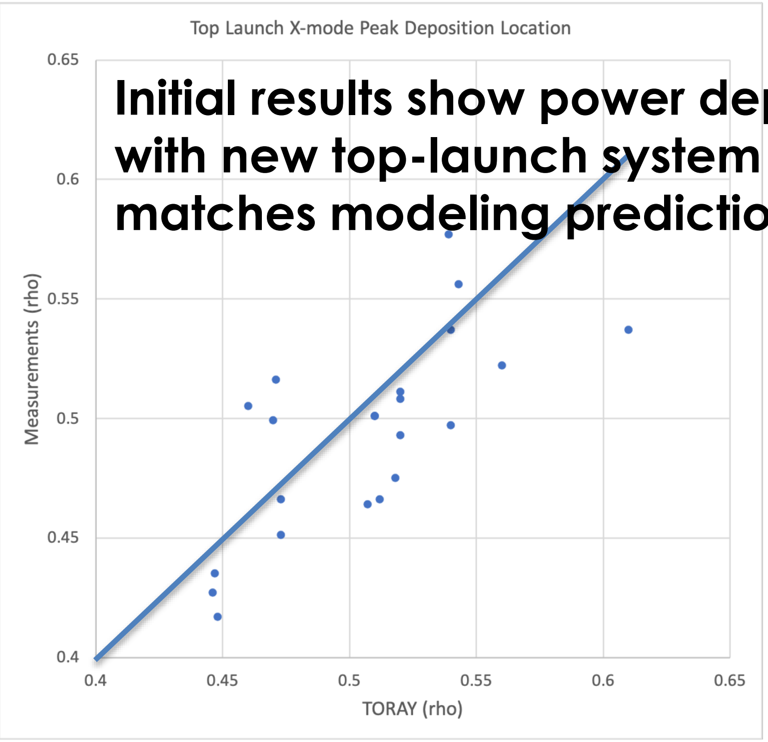
# Top-launch ECCD enabled with in-vessel re-focusing mirror to double low-field-side ECCD efficiency




- **Top-launch ECCD was shown in the past to double ECCD efficiency for off-axis current drive compared to low-field-side launch ECCD**




- **New system with in-vessel re-focusing mirror simplifies implementation at a fraction of the cost**

# Two research thrusts were executed during the last campaign (2024-2025) to address urgent challenges and gaps

## FPP Research
*Morgan Shafer and Chris Holcomb, co-leaders*

- **11 Steady-State and Pulsed Fusion Core** — *A. Garofalo (B. Victor)*
- **12 Plasma Control** — *D. Eldon (J. Barr)*
- **13 Divertor Science and Innovation** — *A. McLean (J. Yu)*
- **14 Core-Edge Integration** — *H. Wang (R. Wilcox)*
- **15 Negative Triangularity** — *K. Thome (F. Scotti)*
- **16 Thrust: Shape Rise Divertor** — *T. Wilks (T. Osborne)*

## Plasma Interacting Technology
*Tyler Abrams and Andrew Dvorak, co-leaders*

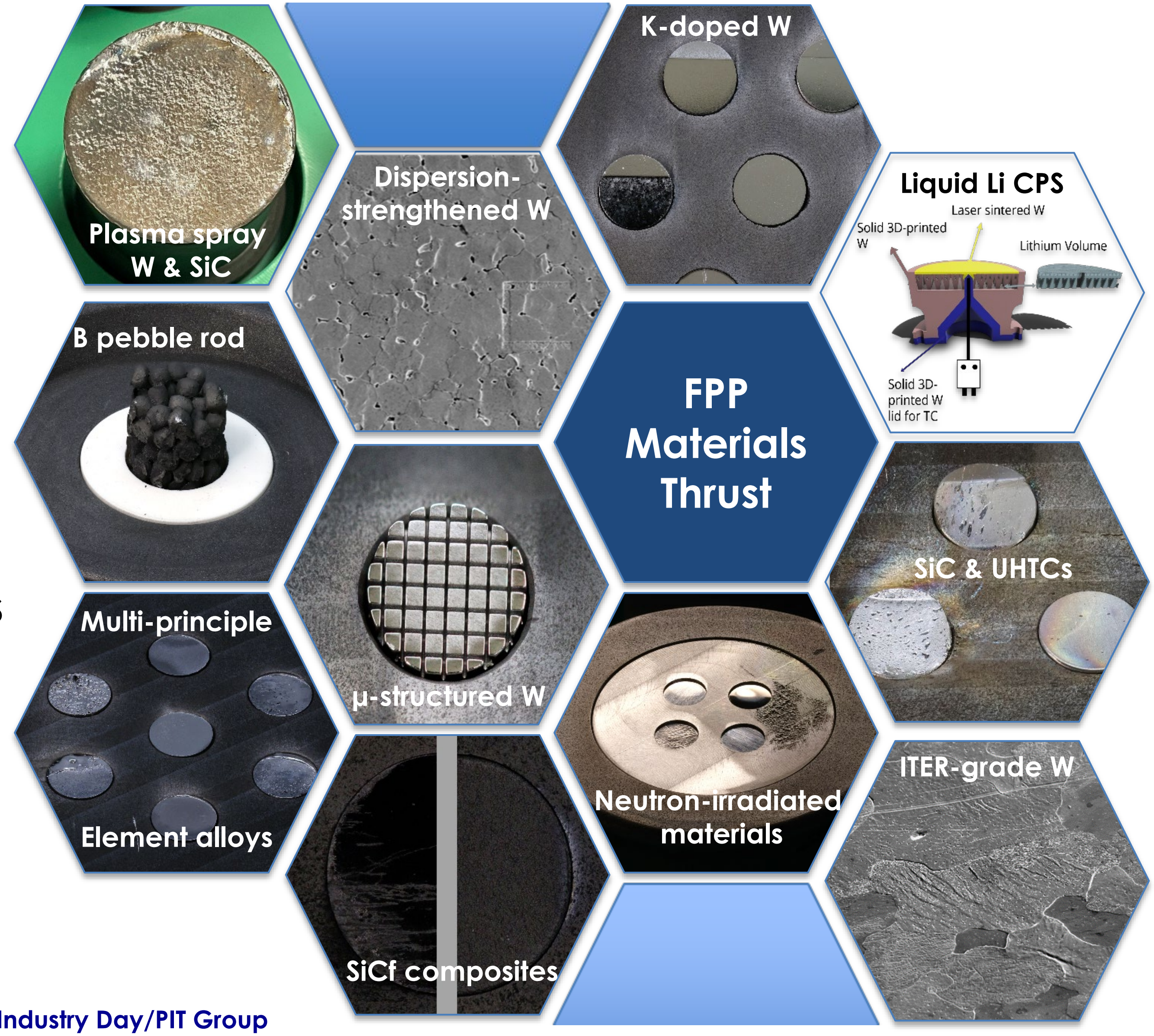
- **21 Plasma-Material Interactions** — *D. Rudakov (G. Sinclair)*
- **22 Disruption Mitigation** — *J. Herfindal (A. Lvovskiy)*
- **23 Heating and Current Drive** — *B. Van Compernolle (S.X. Tang)*
- **24 Diagnostics and Actuators** — *S. Hong (Y. Zhu)*
- **25 Thrust: FPP Candidate Wall Materials** — *J. Coburn (F. Effenberg)*
- **26 Thrust: High Field Side LHCD** — *M. Cengher (A. Seltzman)*
- FY26: **Thrust: FPP Wall Conditioning** — *F. Effenberg (I. Bykov)*

## Burning Plasma Research
*Xi Chen and George McKee, co-leaders*

- **31 Integrated Inductive Scenarios** — *J. Hanson (N. Leuthold)*
- **32 Turbulence and Transport** — *L. Schmitz (M. Austin)*
- **33 Pedestal and Non/Small ELM Regimes** — *A. Bortolon (J. Chen)*
- **34 Transient Control** — *N. Logan (L. Bardoczi)*
- **35 Thrust: Fast Ions, Turbulence and Alfvén Waves** — *X. Du (W. Heidbrink)*
- **36 Thrust: High Opacity and Density Operation** — *Z. Yan (S. Haskey)*

# The FPP Candidate Materials Thrust subjected reactor-relevant plasma-facing materials to high heat and particle fluxes

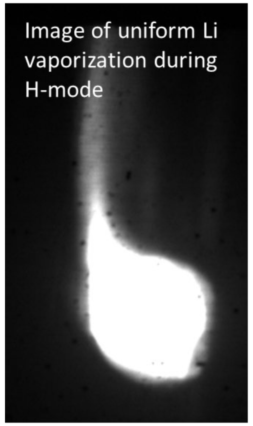
- **Goal: testing multiple classifications of materials, including solid and liquid, under plasma conditions relevant to FPP**
  - Advance material TRLs through integrated testing and down-selection
- **In 2024: 17 novel plasma-facing materials (PFMs) from 8 institutions were successfully tested using the DiMES system**
- **In 2025: 44 novel PFMs from 12 institutions were successfully tested**

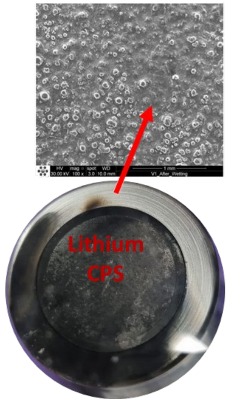


# The thrust exposed several samples from industrial partners to qualify material performance

## 2024 Results Highlights

- First demonstration of liquid Li CPS system on a tokamak → uniform vapor cloud emission
- Dispersion-strengthened W down-selected to TiC variant
- Successful stress tests of W & SiC coatings:
- Down-selected functionally-graded W/SiC variants
- W Heavy Alloys: redeposition, arcing, surface morphology change
- Good fiber integrity for SiCf/SiC and Wf/SiCf/W




## 2025 Experiment Results Highlights

- First testing of neutron-irradiated samples (W, SiC) in DIII-D using DiMES
- "Fusion Materials Industry Day" completed experiments from 4 private industry users
- Excellent performance by industrial W alloys (K, Re doped) and additively-manufactured W
- Down-selection of ceramic materials (Helion Energy) → bulk SiC
- First demonstration of boron pebble rod concept (Thea Energy)
- Enhanced heat flux testing of W-Ta alloys, WfW composites, SiCf/SiC, AM-W, μ-structured W

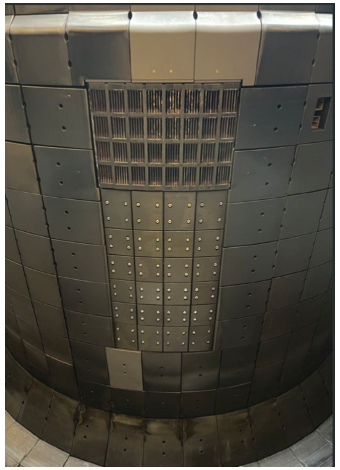
# The lower hybrid current drive thrust allocated resources to increasing the power coupled to the plasma from the newly-installed system

- **Goals**
  - demonstrate efficient off-axis current drive compatible with high temperature plasmas and scalable to reactors
  - validate high field side wave propagation
- **Motivation: launching RF waves from high field side yields increased penetration & efficiency**
- **System installed and tested during 2025 campaign**
  - LHCD power injected into 500 discharges
  - Maximum power coupled ~245 kW
  - obtained pulse lengths up to 2000 ms at 100 kW
- **Validated models of wave propagation & plasma response**

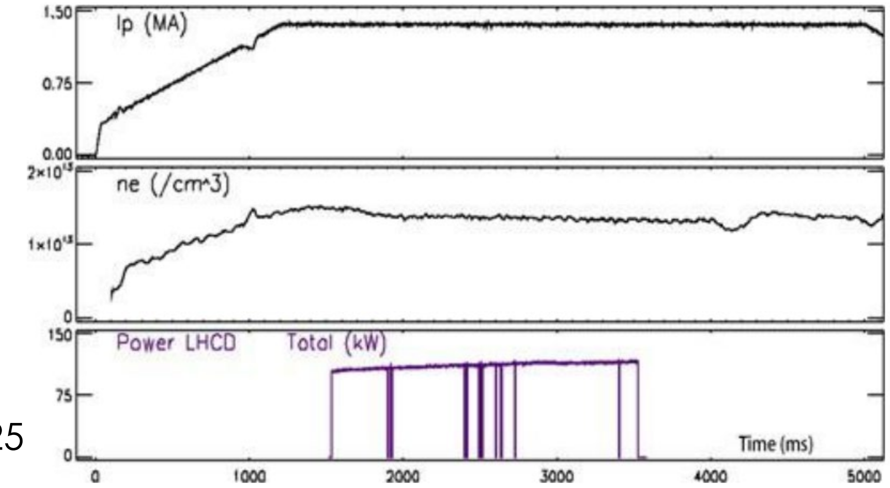
**Design**

Seltzman AIP Conf. Proc. 2023

**Installation**



**Measuring power coupled to plasma**




Wukitch SET meeting 2025

# The PIT group continues to seek new partnerships to leverage DIII-D for private fusion development

- **DIII-D is a user facility equipped to support testing and validation of fusion technologies**
  - recent and future upgrades support industry-driven R&D
- **Research in the PIT group focuses on exploiting capabilities to address gaps for pilot plant**
  - Increasing TRL of rector-relevant materials
  - Plasma diagnosis in nuclear environment
  - Efficient RF heating and current drive
  - RE suppression and mitigation
- **Contact us to learn how DIII-D can support your work!**
  - Tyler Abrams: abrams@fusion.gat.com
  - Andrew Dvorak: dvoraka@fusion.gat.com