PPPL PRINCETON PLASMA PHYSICS LABORATORY

PPPL Contributions to The Road Ahead

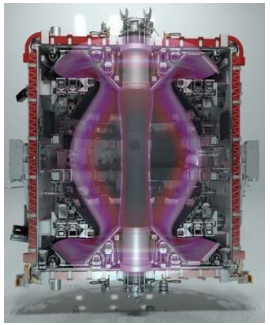
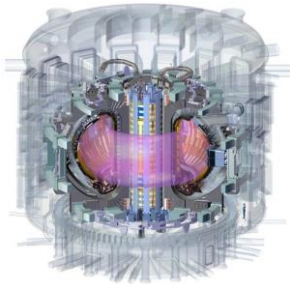
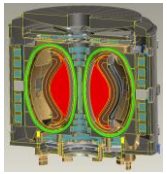
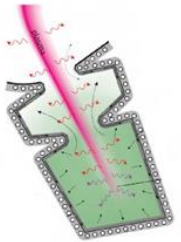
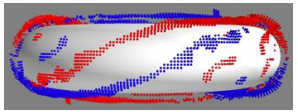
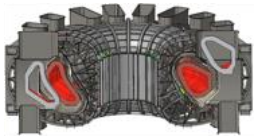
43rd Fusion Power Associates Meeting and Symposium

December 7-8, 2022 Grand Hyatt Washington

Jonathan Menard – Deputy Director for Research

Outline

- Advancing the Spherical Tokamak
- Support for ITER and Pilot Plants
- Fusion Innovations

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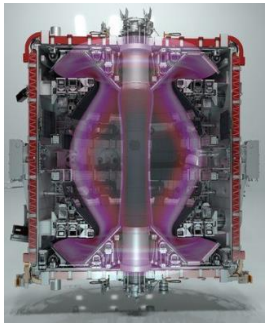

- Advancing the Spherical Tokamak
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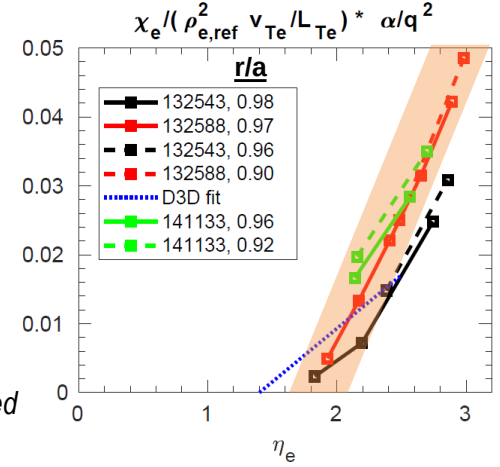
Advancing ST as a Reduced-cost Fusion Concept

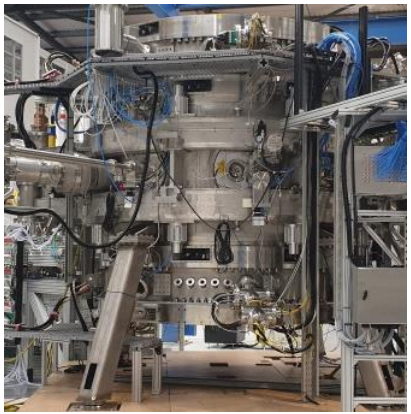
- ST τ_E scaling favorable for compact FPP
- H-mode pedestal critical for ST confinement
- Developed unified NSTX / DIII-D pedestal model
  - Non-linear Electron Temperature Gradient mode turbulence + neoclassical

$$\chi_{e,ETG} = C_{ETG} \cdot (q^2/\alpha) \cdot [\eta_e - \eta_{e,crit}] \cdot (\rho^2_{e,ref} v_{Te}/L_{Te})$$



W. Guttenfelder – APS invited

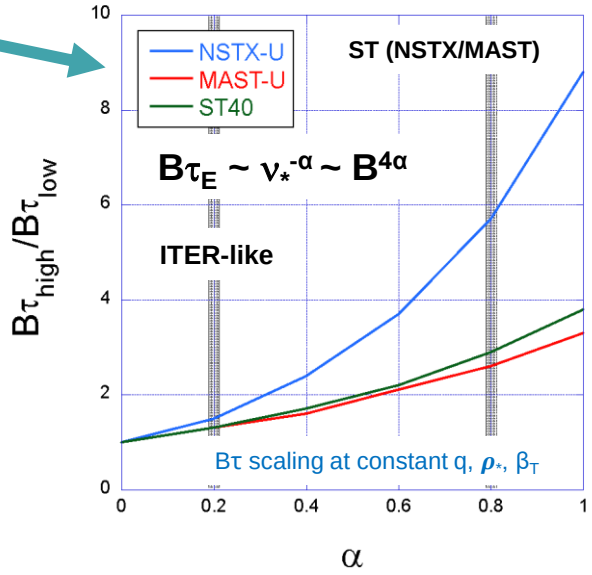
- PPPL aided Tokamak Energy in achieving fusion-relevant T_i ~ 100M ºC (8.6keV) in ST-40
  - TRANSP used to analyze transport properties and confirm hydrogenic temperatures



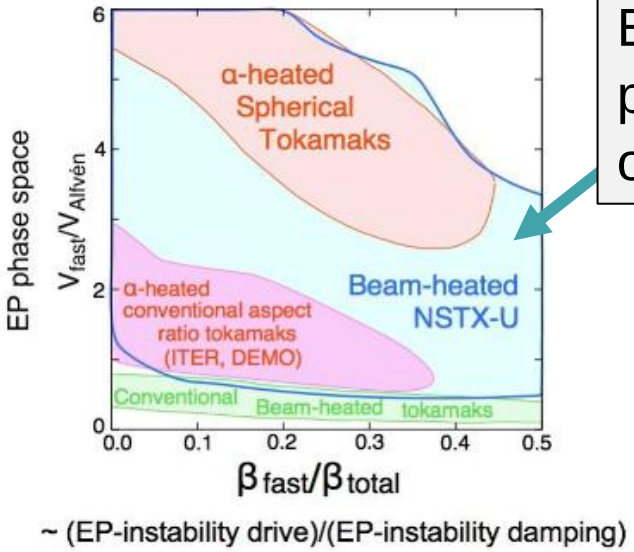
P. Thomas (Tokamak Energy), APS post-deadline invited

NSTX-U Mission Need remains strong

NSTX-U best device for assessing ν_* scaling in auxiliary heated STs



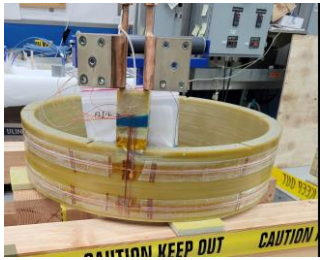
Energetic-particle phase space overlaps with FPPs



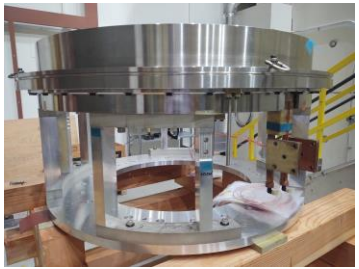
High bootstrap fraction (50-70%) + 10MW NBI-CD → Unique access and understanding of 100% non-inductive current drive scenarios

Substantial progress in NSTX-U Recovery (1)

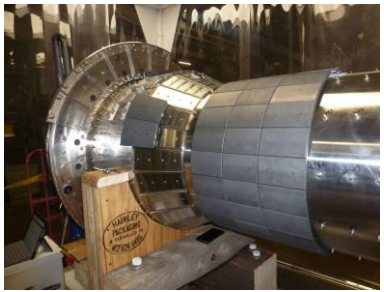
- All 6 new divertor poloidal field coils fabricated and tested



- All PF coil assemblies completed

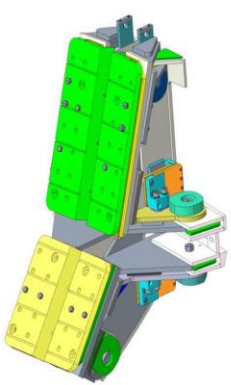


- New centerstack casing completed and delivered, PFC fit-up tested

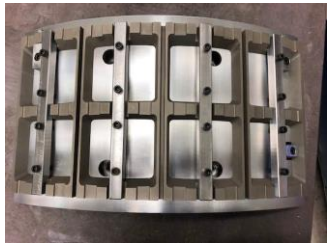


Substantial progress in NSTX-U Recovery (2)

- Passive plate supports completed



- New centerstack plasma facing components and holders fabricated



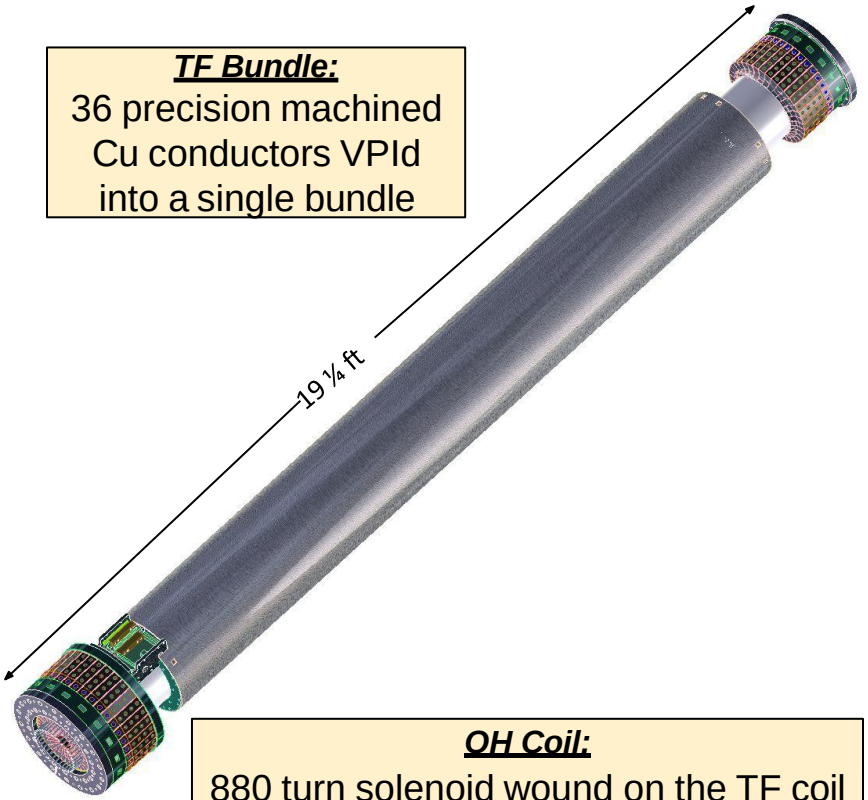
- New Personnel Safety System Safety Instrumented System (PSS-SIS) installed and tested

Trapped Key Exchange Blocks

Redundant Alarming ODH Monitors

PSS-SIS E-STOP and Search Station

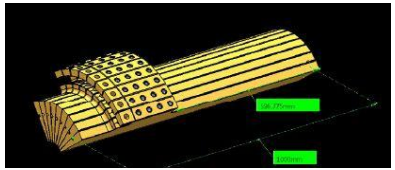
New central OH / TF magnet to be fabricated

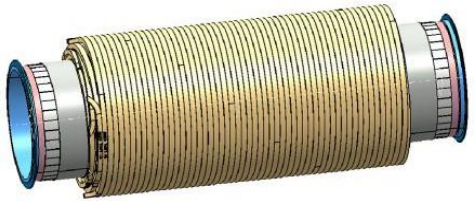


TF Bundle:
36 precision machined Cu conductors VPId into a single bundle

OH Coil:
880 turn solenoid wound on the TF coil

- Previous magnet: slow electrical insulation degradation between conductors of the TF coil
- Residual “aquapour” between OH and TF + contamination + VPI issues → insulation degradation
- ELYTT (Spain) building new magnet including design improvements and extensive prototyping


TF quadrant prototype


OH bundle prototype

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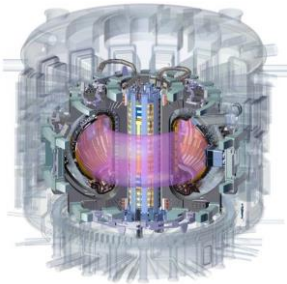
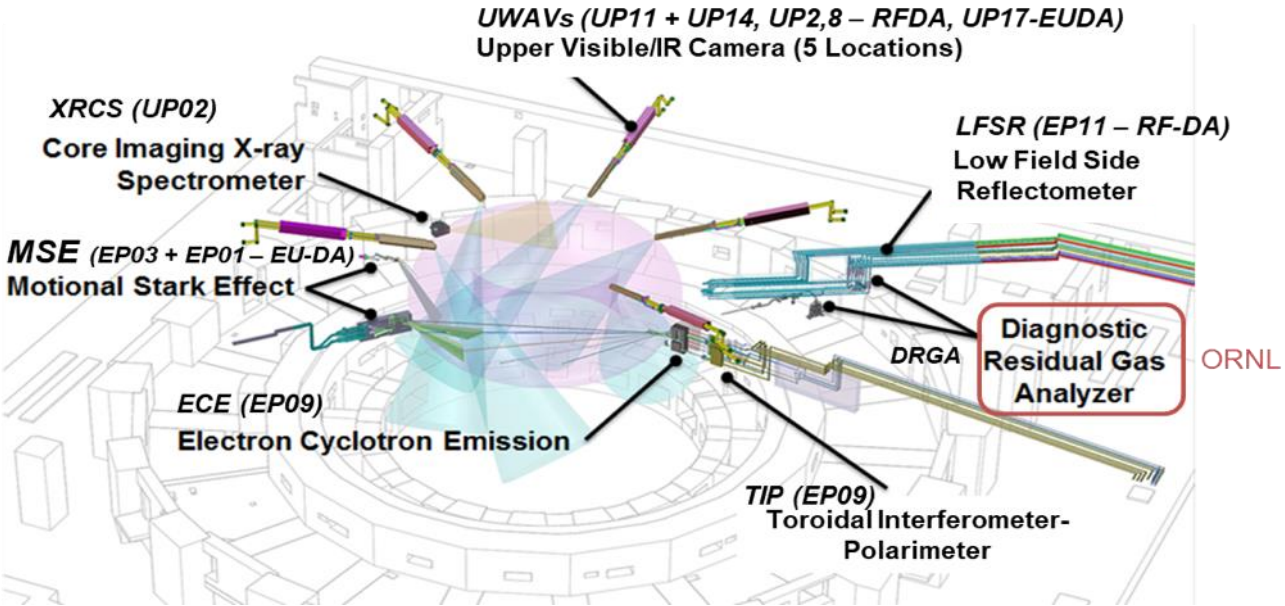


PPPL is leading U.S. ITER diagnostics project



6 Diagnostic Systems Measure Profiles of:

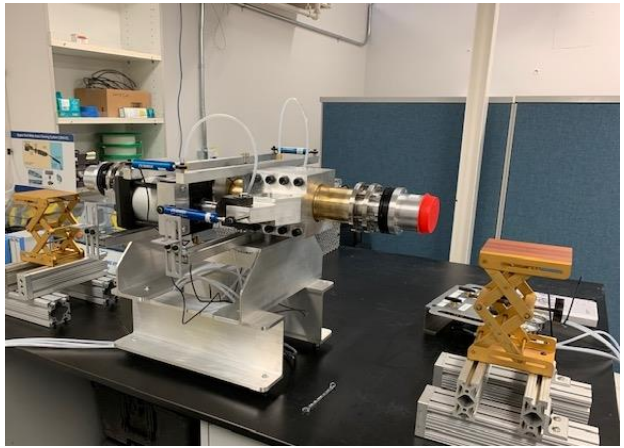
- Electrons, ions, impurities
- Rotation, magnetic field pitch, fluctuations

- **Critical for understanding ITER burning plasmas**
- **Informs U.S. Fusion Pilot Plant design and operation**

Highlights: Low Field Side reflectometer (LFSR)

Measures edge electron density profile, fluctuations, plasma rotation using microwaves reflected by plasma

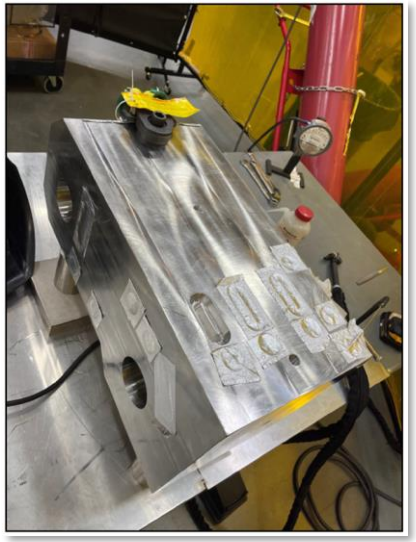
- Waveguide Joint Test Moment Loader Ready for Virtual Network Analyzer (VNA) Installation at General Atomics



- Test Antenna Block Assembly (TABA)

Antenna Block Assembly
Water Circuit Welding Trial

Antenna insertion trials



TABA Block Welding

Highlights: TIP, LFSR, Motional Stark Effect

Captive Components for TIP and LFSR

These are transmission line supports that had to be fabricated ahead of time to allow installation at the ITER site in France





First plasma diagnostics hardware delivery to the IO – arrived in Marseille July 2022

Motional Stark Effect (MSE)

Determines spectral properties of light emitted from H/D/T atoms injected by heating or neutral beams to determine magnitude of magnetic field as a function of position

Vacuum Chamber Installed – Mirror Cleaning Facility at PPPL

First plasma produced to prototype mirror cleaning methodology

PPPL supporting fusion public-private partnerships

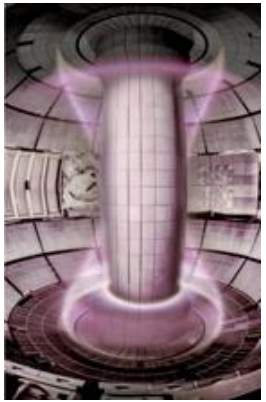
- DOE recently launched Milestone-based Fusion Development Program fostering public-private partnerships for FPP design

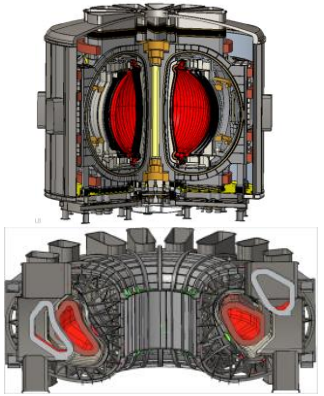
- DOE bold decadal vision emphasis: Fusion Pilot Plants (FPP) = small net electric power
  - Spherical Tokamak potentially reduced-cost FPP
  - Other PPPL expertise of interest to partners:
    - Physics-engineering integration
    - Diagnostics, liquid metals, PFCs, blankets
    - Stellarators: MHD equilibrium & stability (M3D-C1), transport, turbulence, energetic particles, exhaust

DEPARTMENT OF ENERGY (DOE)
OFFICE OF SCIENCE (SC)
FUSION ENERGY SCIENCES (FES)

MILESTONE-BASED FUSION DEVELOPMENT PROGRAM

FUNDING OPPORTUNITY ANNOUNCEMENT (FOA) NUMBER:
DE-FOA-0002809





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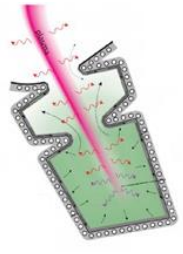
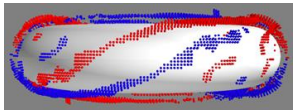
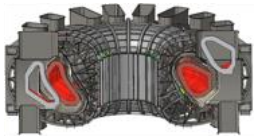
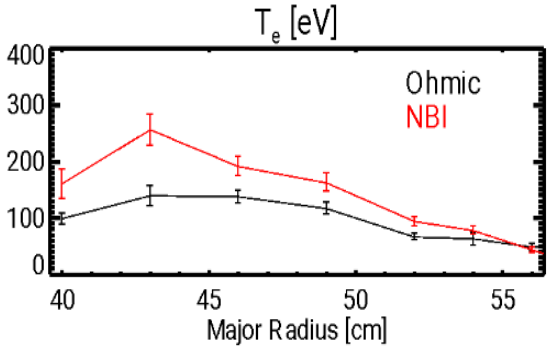


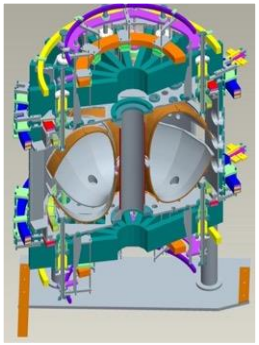




PPPL advancing liquid lithium walls and divertors

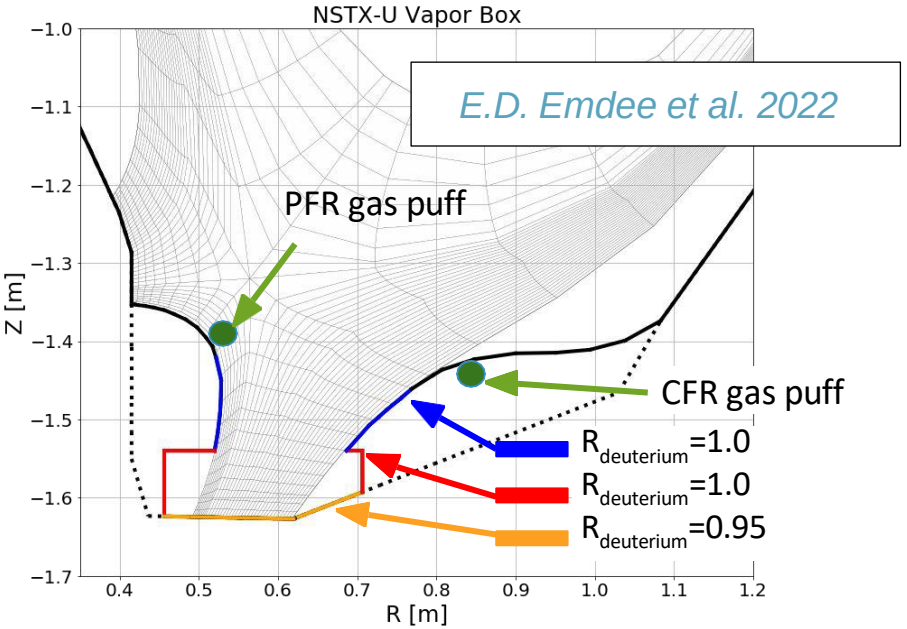
- Li pumps hydrogenics, reduces cold particle influx, increases edge and core temperature
- Lithium Tokamak eXperiment-β (LTX-β) recently demonstrated broad-to-flat T_e profiles with NBI and no confinement reduction





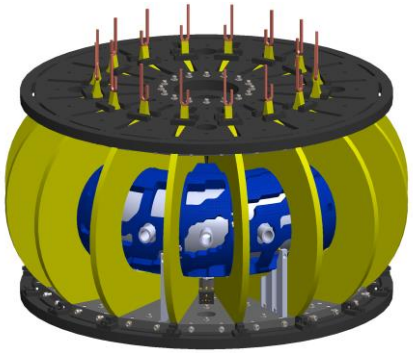
D. Boyle et al. - submitted to Nuclear Fusion

- NSTX-U Li vapor box divertor projected to reduce divertor heat flux 10x (SOLPS-ITER: 90MW/m^2 → 9MW/m^2)

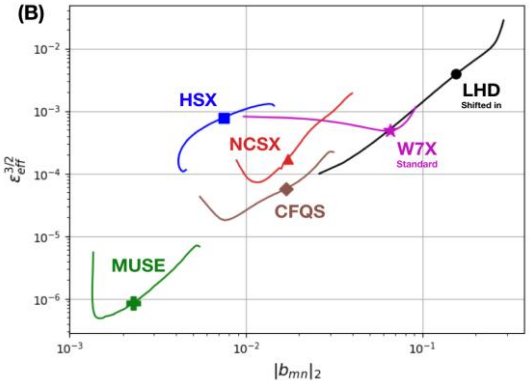


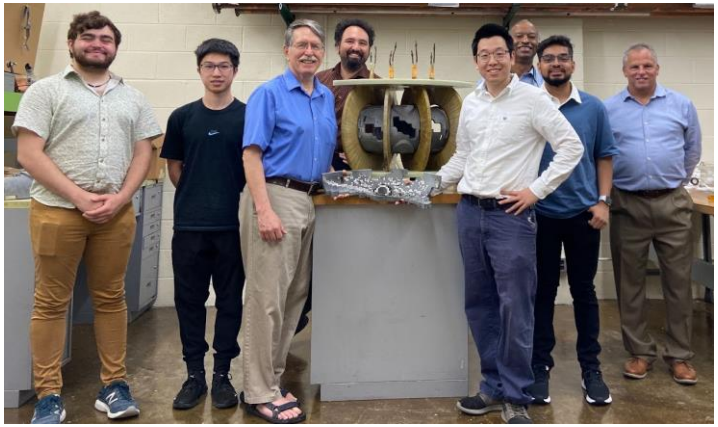
MUSE permanent magnet stellarator being assembled

Table-top scale



Highly quasi-axisymmetric vs. previous experiments

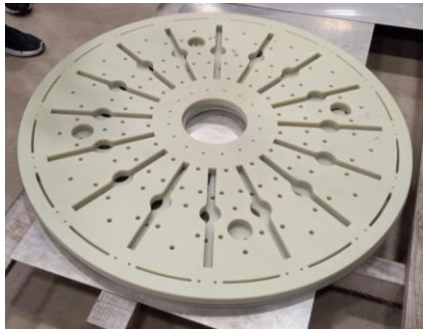




All parts now in-hand for final assembly

Glass vacuum vessel

3D printed quadrant with PMs



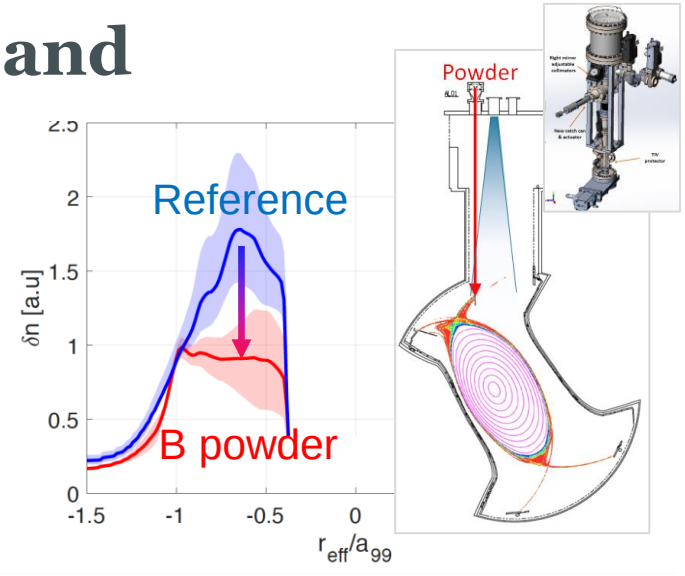
G10 structural support plates

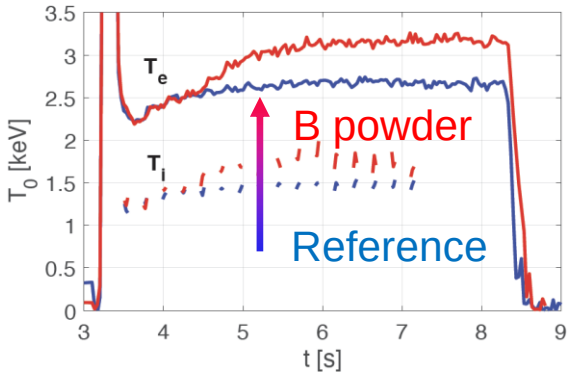
TF power supply

Boron powder reduces turbulence and increases confinement in LHD

- Turbulent fluctuations reduced by ~1/2
- Ion temperature increased up to 35%
- Likely that Ion Temperature Gradient (ITG) turbulence is suppressed by profile modifications + increase of Z_{eff}
- This regime should be accessible in other stellarators such as W7-X

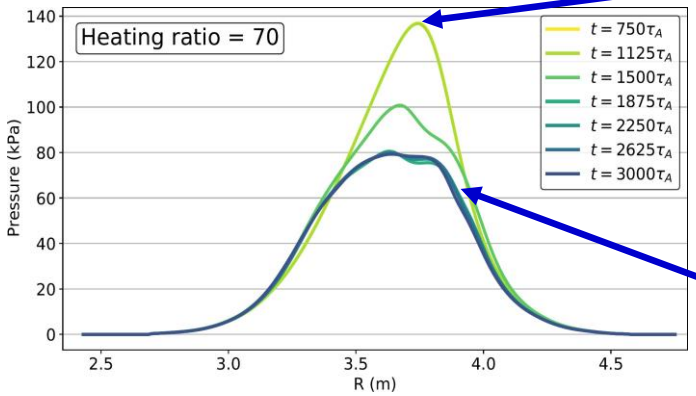
F. Nespoli et al., Nature Physics 2022





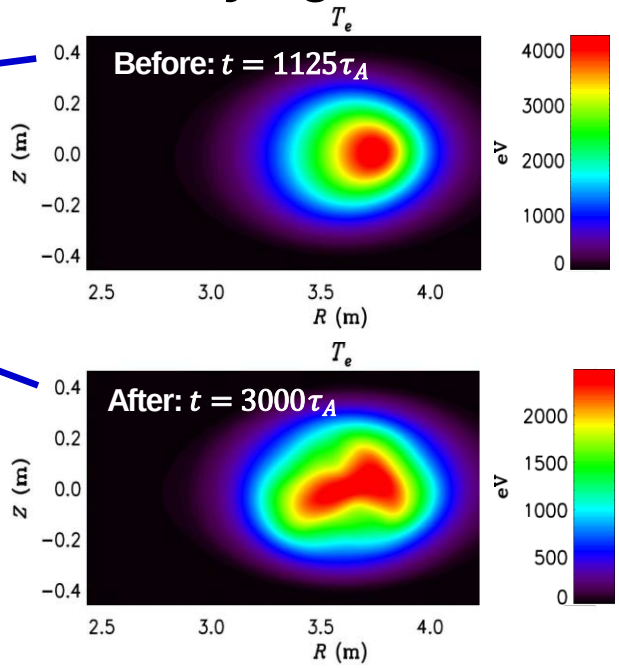
Advanced simulation is key to fusion innovation

- Flagship M3D-C1 non-linear MHD code extended to stellarators



Adelle Wright, Nate Ferraro

- **Studying beta limits in LHD**



- Increased heating → n=1 then n=2 modes destabilized
- Multiple n → chaotic magnetic fields → temperature flattening broadly consistent with experiment

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Thank you!