PPPL
International Collaborations

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U.S. DEPARTMENT OF ENERGY

PRINCETON UNIVERSITY

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Overview

- International Collaboration is pervasive at PPPL
  - E.g. on NSTX-U, Theory activities
  - As part of most research thrusts and strategies

- Preparation for ITER and future burning plasmas
  - Direct tasks and ITPA

- Access to broader range of facilities and capabilities
  - Especially superconducting / long-pulse / larger scale
  - Successful collaborations are win-win
  - Often includes team of US institutions.

Goal: Improve Understanding

- Challenge and validate theories and models
- Explore new ideas and opportunities

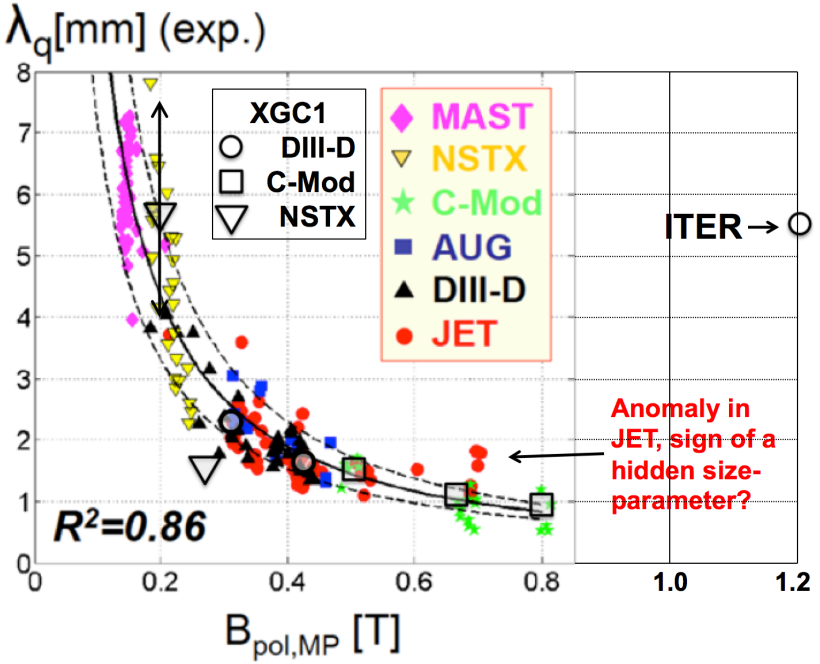
Examples:

- Extrapolation to ITER
- Liquid Plasma Facing Components and lithium-interaction initiative
- Spherical torus
- Stellarators
- Next step studies & activities

Gyrokinetic understanding of ITER divertor heat-flux width

- **Empirical data regression from present tokamak experiments shows $\lambda_q \propto 1/B_p^{1.2}$** ($\lambda_q$ = divertor heat-flux width mapped to outboard midplane)
  - Application of this scaling to ITER yields $\lambda_q \approx 1$mm, raising a severe issue for ITER operation
  - ITER is a large extrapolation from present-day tokamaks
  - A first-principles based prediction is needed

- **Study with XGC1 GK edge code**
  - Reproduces experimental results from present tokamaks
  - Simulation of ITER: λ_q =5.6mm $\gg$ 1mm due to turbulence in scrape-off layer
  - JET, the largest existing tokamak, may show signs of trend toward ITER
  - Need to understand changes in going to ITER scale. Verify in independent calcs.

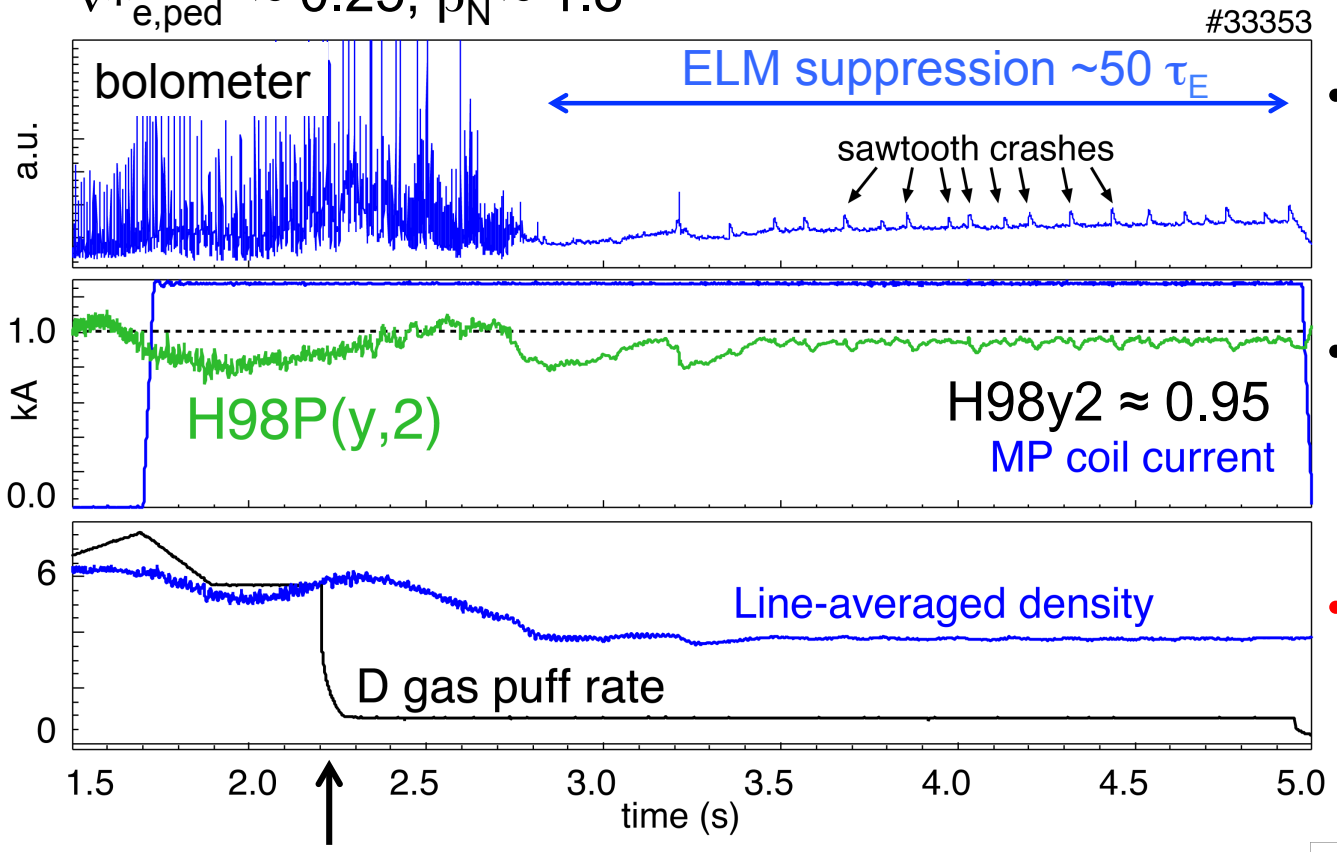


ELM Suppression with RMP Extended to AUG, in Collaboration with DIII-D

AUG has W wall, some boron Z_{eff}=1.5, low impurity dilution
DIII-D has C wall, Z_{eff}=4.5, n_D/n_e ~ 1/3

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

R. Nazikian
W. Suttrop



- Matched plasma shapes, higher $\delta \sim 0.3$
- Density threshold similar in both expts.
- Good news for ITER!

D2 gas valve turned off

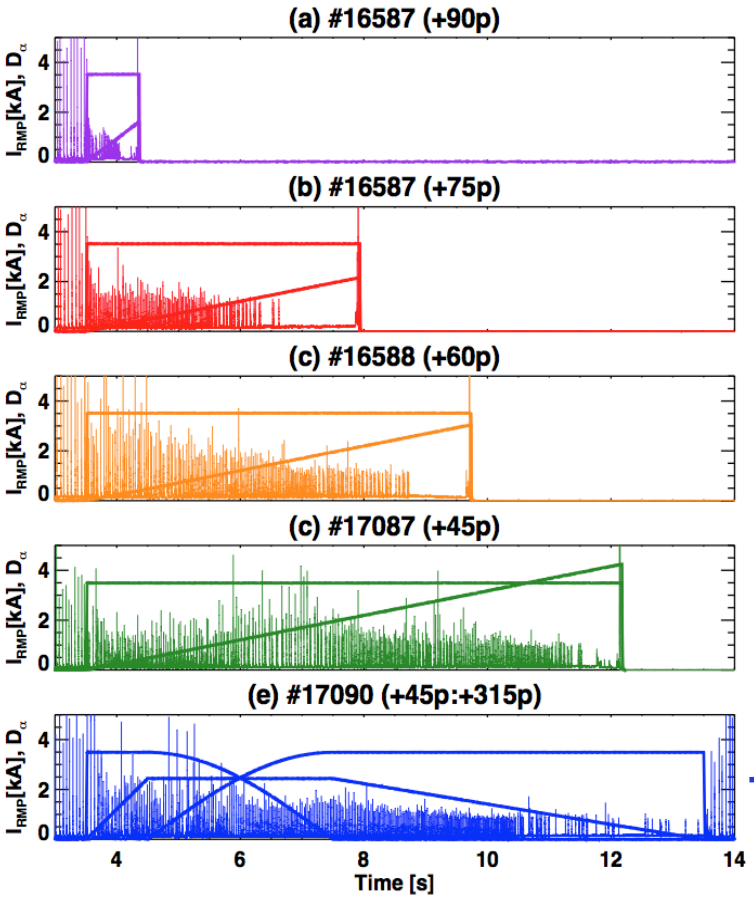
[Suttrop PPCF submitted]

DIII-D NATIONAL FUSION FACILITY

ASDEX Upgrade

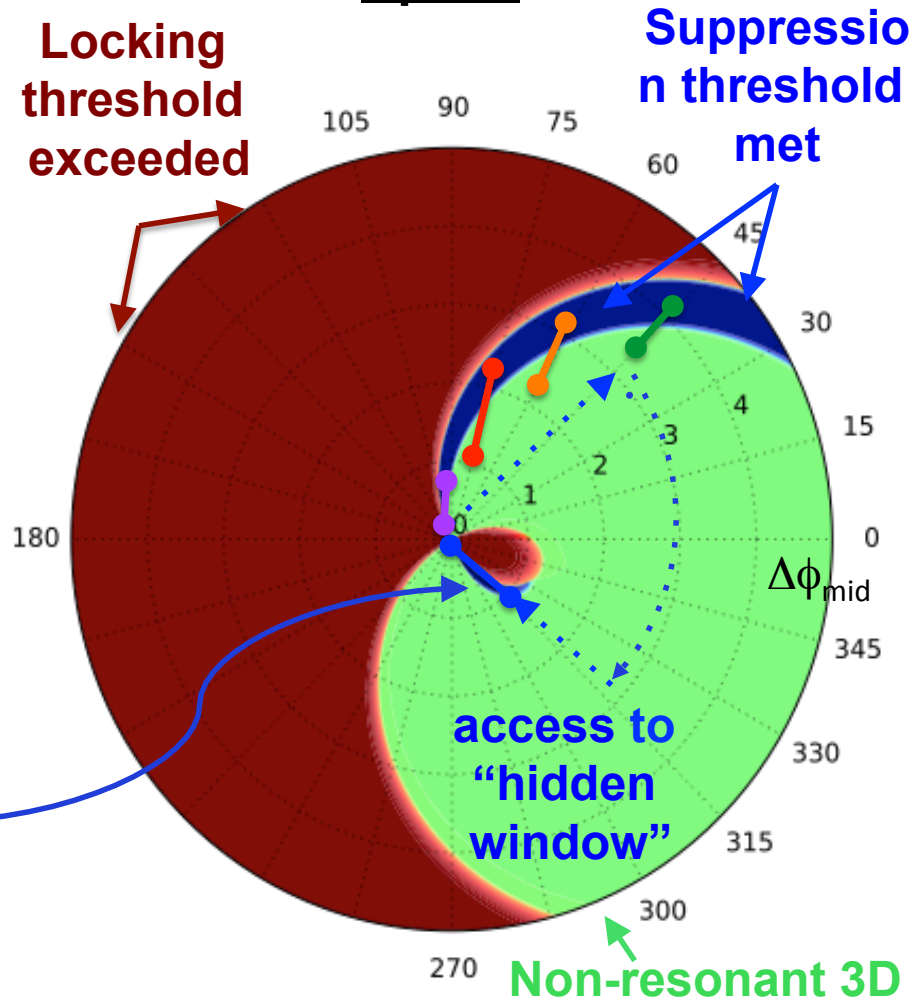
KSTAR: n=1 RMP ELM stabilization Without Locking: Understanding Validated

Experimental Validation of Model



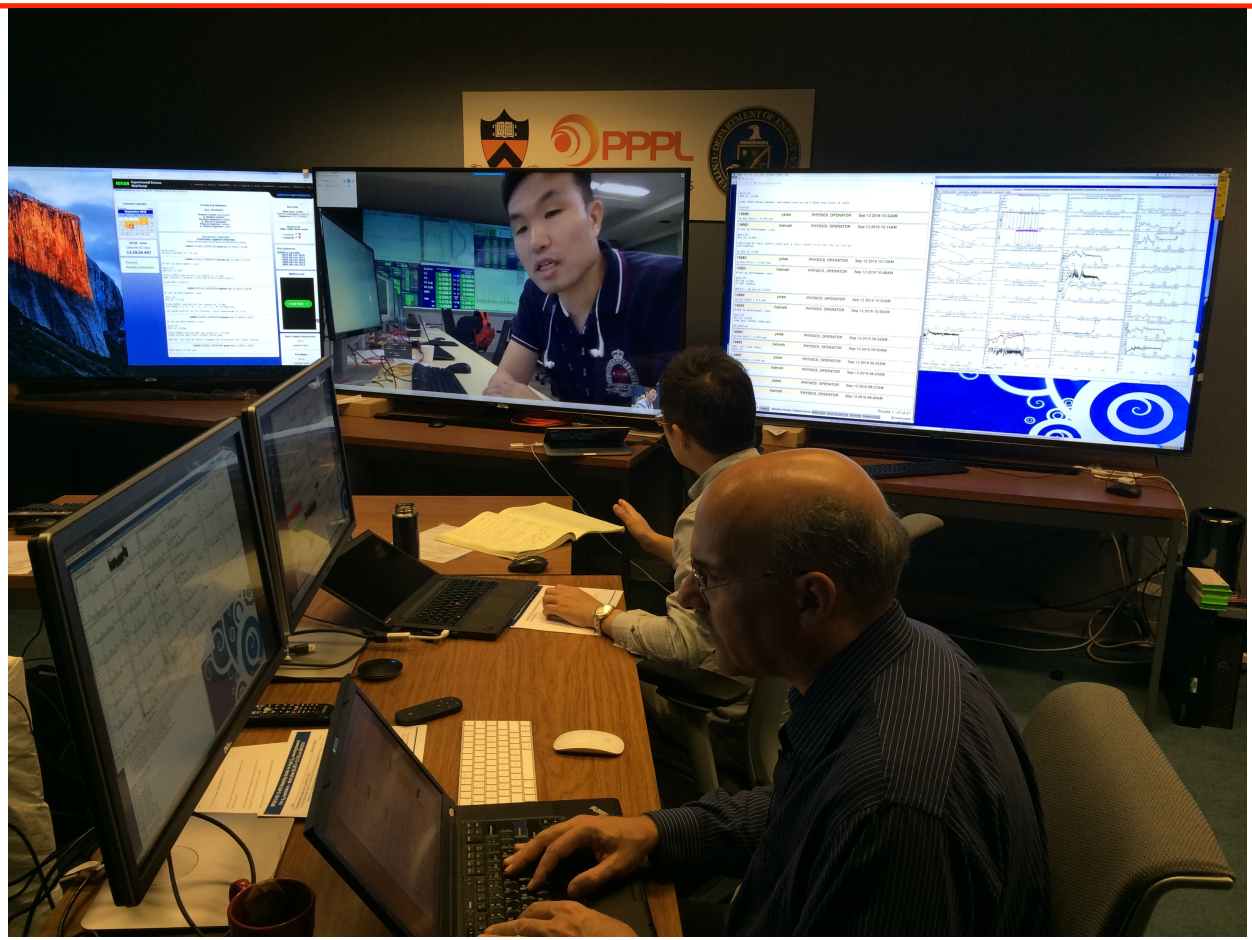
KSTAR: 3 rows of 4 coils

IPEC Prediction of stability Space



J.-K. Park

New Remote Participation Center Used for KSTAR Experiments



Internet connectivity supports routine video-conferencing, data access, and data analysis with KSTAR & other facilities.

TRANSP Integrated Analysis & Simulation

- Supports tokamak studies worldwide using reduced models.
- Develop integrated analysis and modeling towards ITER needs.
- Development choices driven via international User Group. Also international development.

  - TRANSP being integrated into IMAS, to enable use for ITER.
  - TRANSP integrated into OMFIT for current experiments. Strong partnership with DIII-D OMFIT team

TRANSP Upgrades being Accelerated

	2015	2016	2017+
RF	• EC: TORBEAM • LH: GENRAY+CQL3D	• HHFW, ECRF: GENRAY+CQL3D	• MPI GENRAY for multiple antenna • Implement TORIC MPI over toroidal modes
NUBEAM	• Feedback on fast ion diffusivity (via neutrons) • fast ion diffusion due to MHD • 3D Halo neutrals multiple CX	• NB deposition in SOL	• GPU support • Critical gradient model for interaction of fast ions with MHD
RF & Fast Ions	• TORIC → NUBEAM (kick operator)	• TORIC ← NUBEAM (pass distribution function)	• Improve self-consistency of TORIC and NUBEAM
Isolver FB equilibrium and control	• Shape Control	• Toroidal rotation in equilibrium calc.	• MSE constraint • MHD stability evaluation • TRANSP as kernel in Plasma Control System Simulation Project (PCSSP)
PT-Solver	• Flux based implicit solver	• Impurity dens. prediction • EPED1 via lookup table	• Pellet ablation model • PTSOLVER speedup • NTV model for momentum transport
Framework			• Modularization

Black: released to users Blue: beta-testing Red: under development

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New International Collaboration Centers

- Control of the Plasma-Material Interface for Long Pulse Optimization in EAST
  - Lead PI: Rajesh Maingi (PPPL)

- Control and Extension of High Performance Scenarios to Long Pulse
  - Lead PI: David Humphreys (GA), Co-PI: Raffi Nazikian (PPPL)

- Disruption Prediction and Avoidance in High Beta Long Pulse KSTAR Plasmas
  - Lead PI: Steven Sabbagh (Columbia U.), Co-PI: Steve Scott (PPPL)

Using these collaborations (and W7X) to develop remote collaboration/operation paradigms, preparing for ITER.

Multi-institutional US-ASIPP PMI collaboration initiated

Lithium delivery systems and science (PPPL, UI-UC, LANL)

- Flowing liquid lithium limiter as primary PFC
- Lithium granule injector – ELM pace-making
- Lithium powder injector – real time conditioning, ELM control
- Lithium granule dropper – new; conditioning & ELM control?

Heat flux physics and divertor design (PPPL, UT-K, ORNL)

Erosion with mixed PFC materials (MIT, UT-K)

- Core SXR upgrade for impurities (JHU)

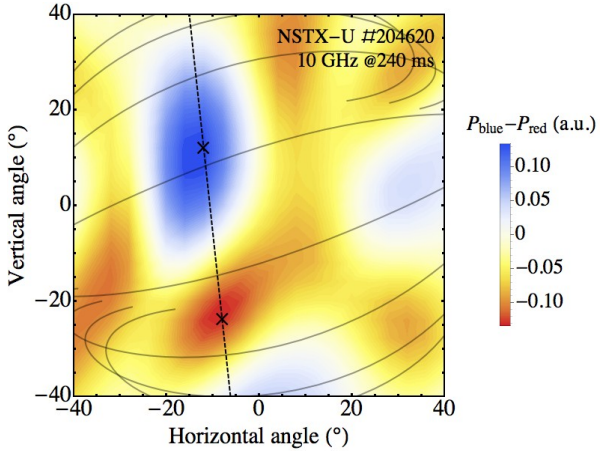
Explore use of Lithium radiative cooling for access to detachment

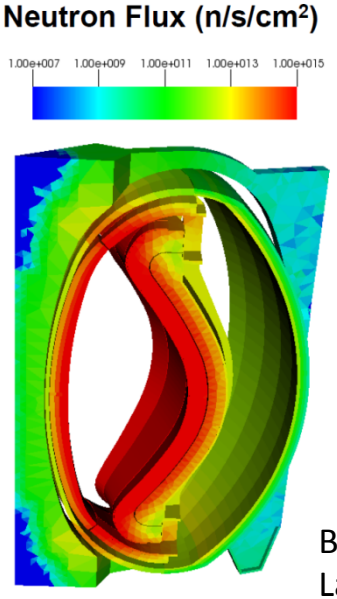
PPPL serves to facilitate and coordinate activities

NSTX-U and MAST-U Collaboration on ST Understanding

- Scenario development in MAST-U and NSTX-U, MAST-U 1st plasma
- Advanced divertors: Snowflake and Super-X; liquid metals
- Advanced diagnostics
  - Synthetic Aperture Microwave Imaging
  - Measure magnetic field pitch angle via EBW emission: MAST, NSTX-U
  - Doppler Back-scattering (MAST)
- CCFE: Neutronics calculations for Low-A HTS Pilot Plant
- Coordinate program goals via advisory committees

Measured angle matches EFIT





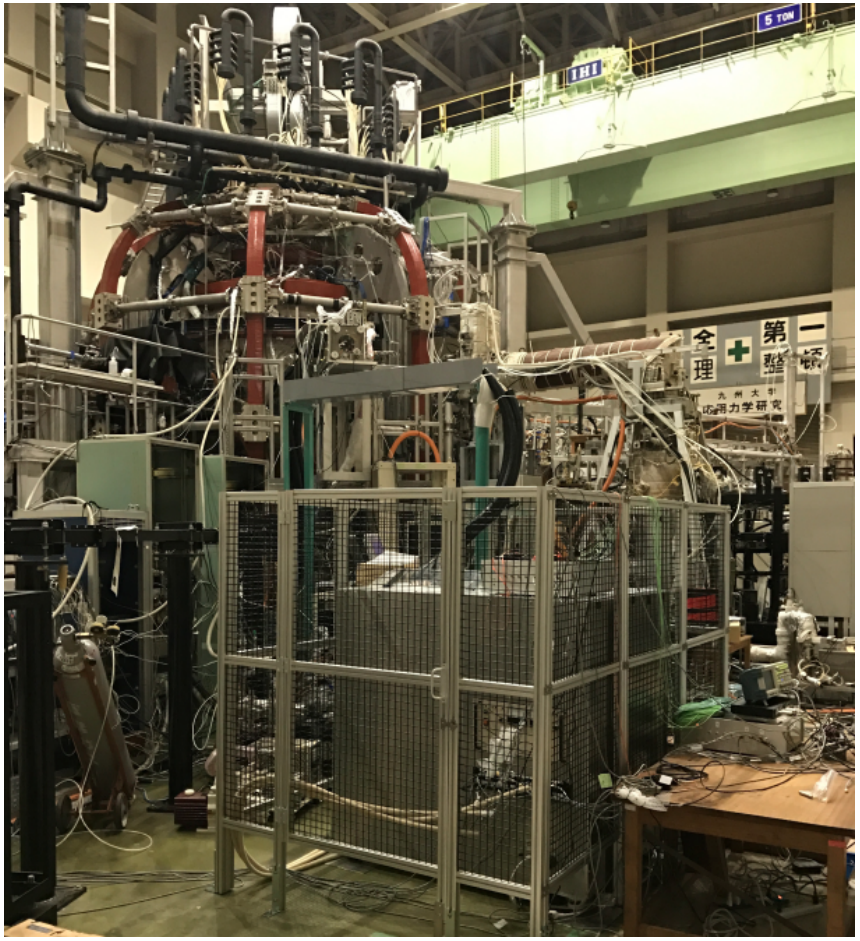
Bethany Colling
Lancaster University
Ph.D. thesis in Nuclear Engineering

QUEST (Japan) Collaboration Started

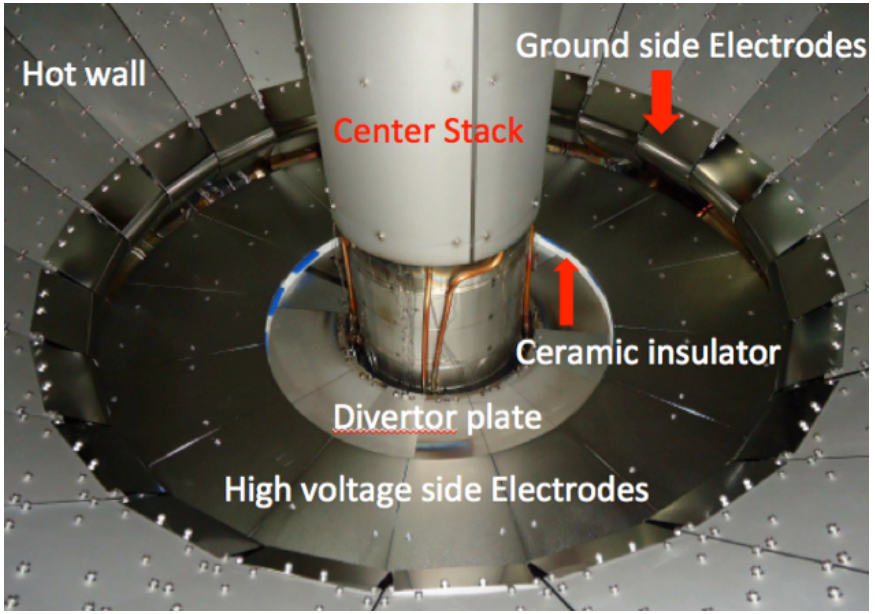
CHI-startup and ECH/EBW sustainment physics

QUEST Mission:

- **Steady-state operation with ECH/EBW**
- **All metal hot wall and closed divertor**



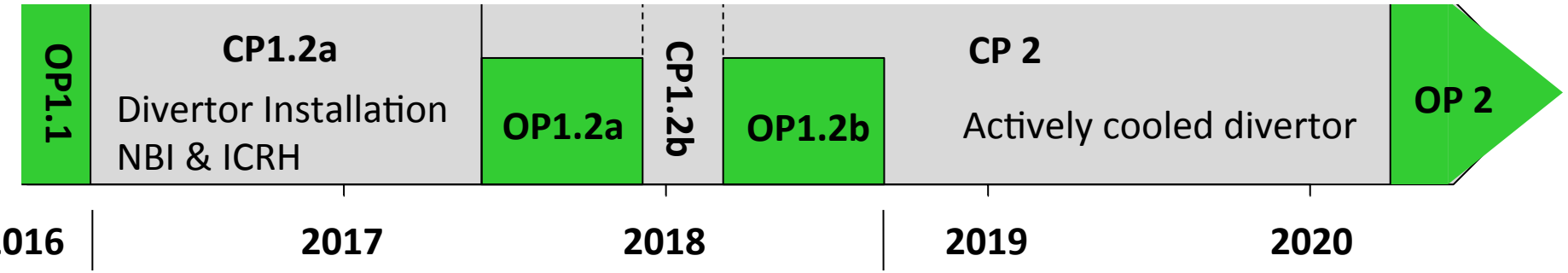
QUEST CHI Experiment tests high-Z electrode operation



QUEST is the largest ST in Japan

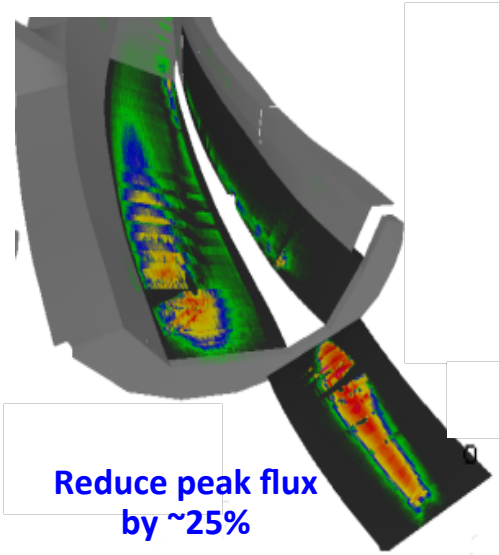
Strong Collaboration on W7X

US Team: PPPL, ORNL, LANL, Wisconsin, MIT, Auburn, Xantho Tech.



Enhancements for W7X Partnership

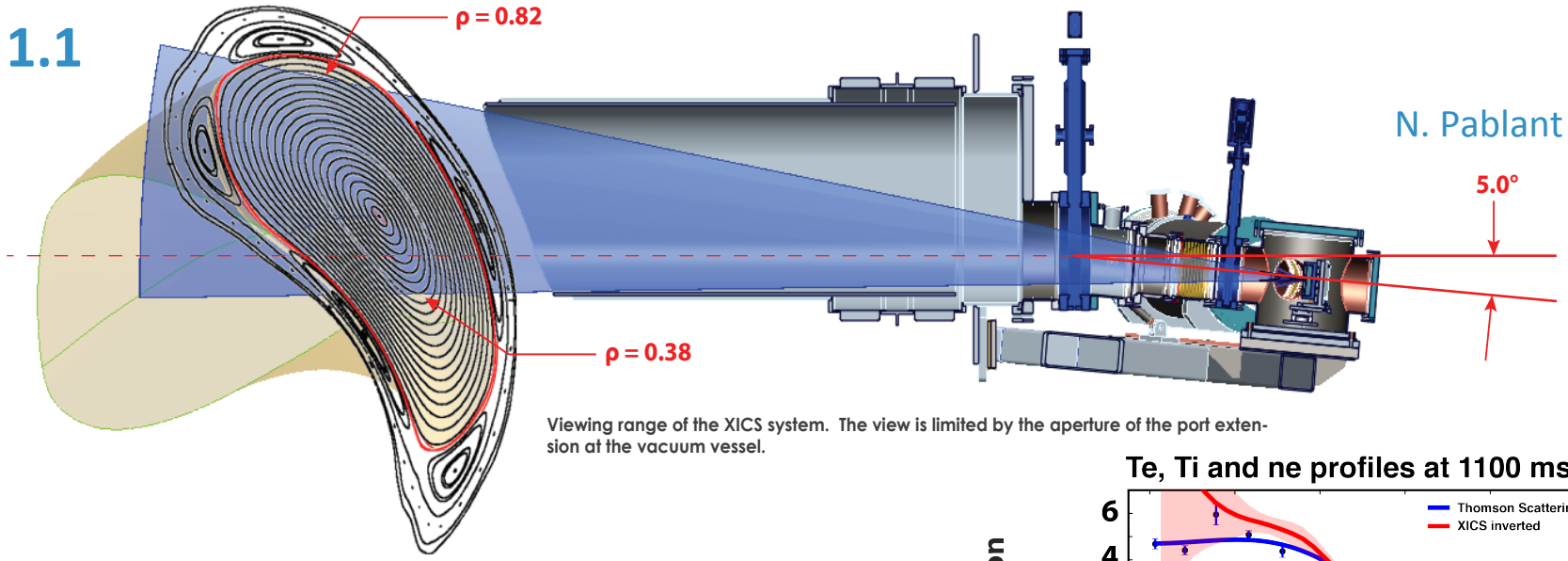
- Additional detectors for XICS: improve profile coverage
- Divertor test scraper element, installed before OP1.2b
- Improved equilibrium modeling, transport analysis



Re-joining LHD Collaboration for D-experiments

PPPL XICS provided kinetic profiles for W7-X

OP 1.1

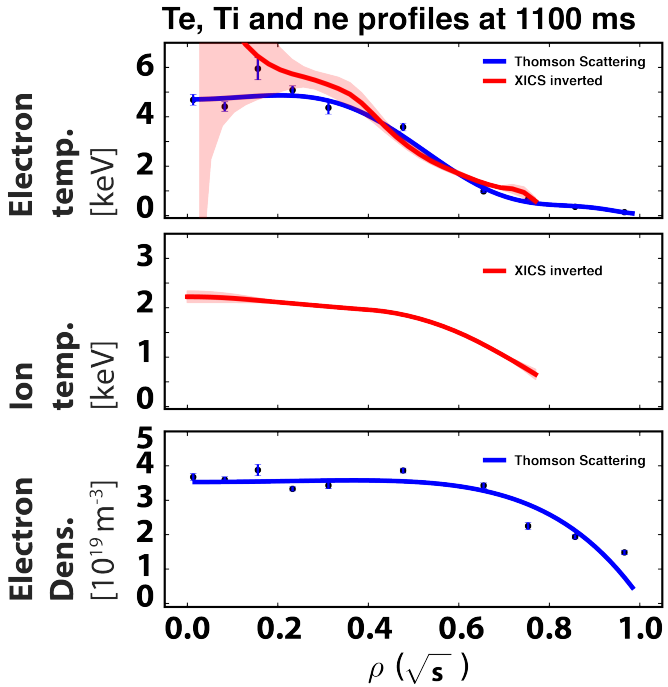


Viewing range of the XICS system. The view is limited by the aperture of the port extension at the vacuum vessel.

XICS provided time resolved profiles of:

- Ion temperature (T_i)
- Electron temperature (T_e)
- Perpendicular rotation ($u_\perp$)
- Argon impurity density (n_{Ar})

Also: trim coils, magnetics analysis



Next Step Studies

Goal: study and develop options for future program elements

- Fusion nuclear science facility requirements and program plan, based on standard tokamak (C.Kessel et al).

- Participate in design studies for
  - CFETR
  - KDEMO

Summary

- International collaboration important in almost all fusion activities
  - Develop and validate understanding on full range of facilities
- Will become fundamental as we approach ITER exploitation
- Crucial to advance many topics and strategies
  - Long pulse sustainment (superconducting magnet facilities)
  - Scaling to larger size; divertor & PFC development
  - Stellarators