# Overview of Recent Physics Results from NSTX

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**FEC IAEA Mtg.**
**St. Petersburg, RU**
**18-23 October 2014**

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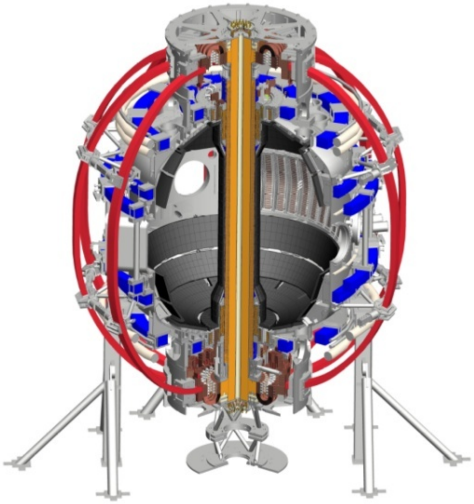

- *Culham Sci Ctr*
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*This work supported by the US DOE Contract No. DE-AC02-09CH11466

# NSTX completed operation in Fall 2010 for start of NSTX-Upgrade construction

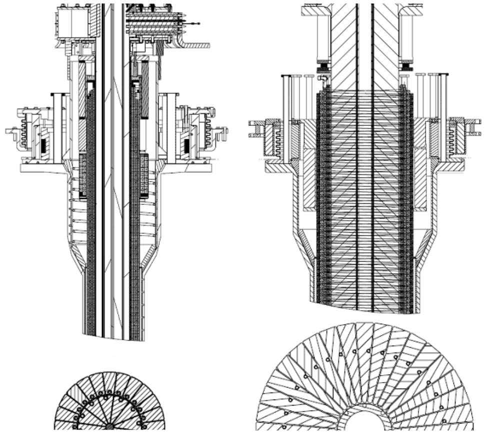
## *NSTX-U research goals address key issues that need to be resolved for next-step Spherical Tokamaks (ST)*

1. Advance ST for Fusion Nuclear Science Facility (FNSF), including non-inductive operation
   - 100% non-inductive operation
   - Stable high-performance, steady-state control
2. Develop solutions for plasma-material interface challenge
   - Mitigation of high heat flux ($q_{peak}$~40 MW/$m^2$, $P_{heat}$/S~0.5 MW/$m^2$)
   - Optimization of pedestal/SOL interface
3. Explore unique ST parameter regimes to advance predictive capability - for ITER and beyond
   - Access reduced collisionality
   - Role of high ExB and parallel flow shear
   - Understand enhanced confinement and stability

# *NSTX-Upgrade will access next factor of two increase in performance to bridge gaps to next-step STs*

Previous center-stack

**New center-stack**



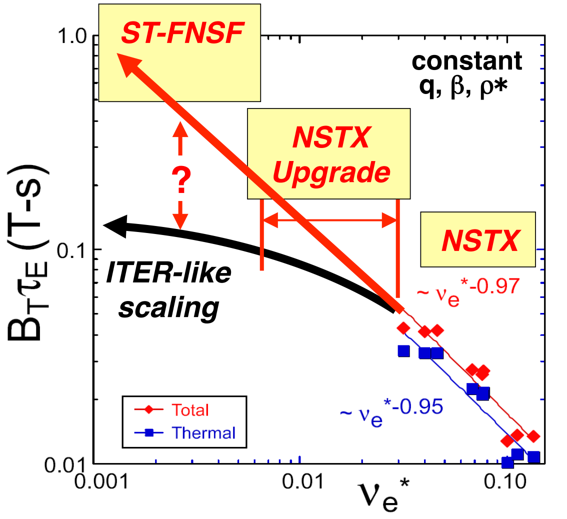
TF OD = 20cm

**TF OD = 40cm**

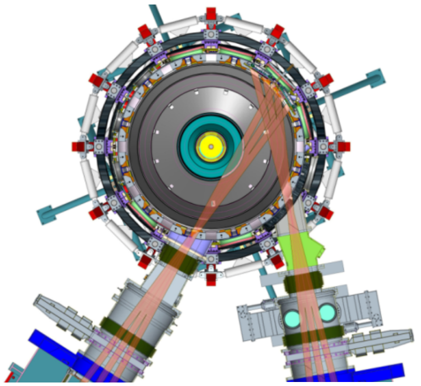
- **Reduces ν* → ST-FNSF values to understand ST confinement**
  - **Expect 2x higher T by doubling $B_T$, $I_P$, and NBI heating power**
- **5x longer pulse-length**
  - **q(r,t) profile equilibration**
  - **Test non-inductive ramp-up**

**M. Ono, FIP/P8-30, Fri PM**

**J. Menard, FNS/1-1, Sat. AM**



**Normalized e-collisionality $\nu_e^* \propto n_e / T_e^2$**

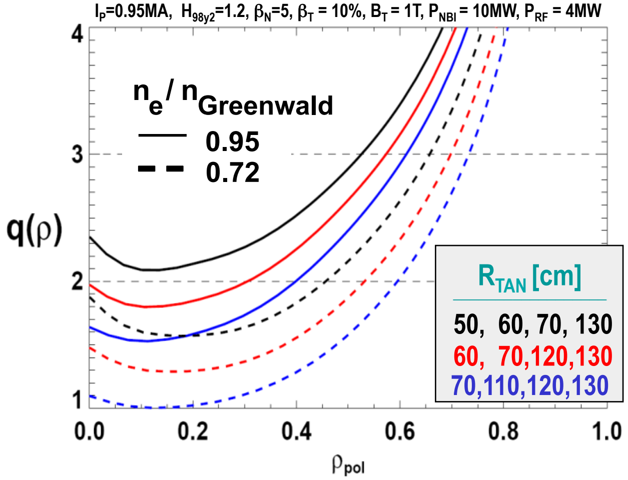


Present NBI

**New 2nd NBI**

- **2x higher CD efficiency from larger tangency radius $R_{TAN}$**
- **100% non-inductive CD with core q(r) profile controllable by:**
  - **NBI tangency radius**
  - **Plasma density, position** (not shown)

$I_P$=0.95MA, $H_{98y2}$=1.2, $\beta_N$=5, $\beta_T$ = 10%, $B_T$ = 1T, $P_{NBI}$ = 10MW, $P_{RF}$ = 4MW

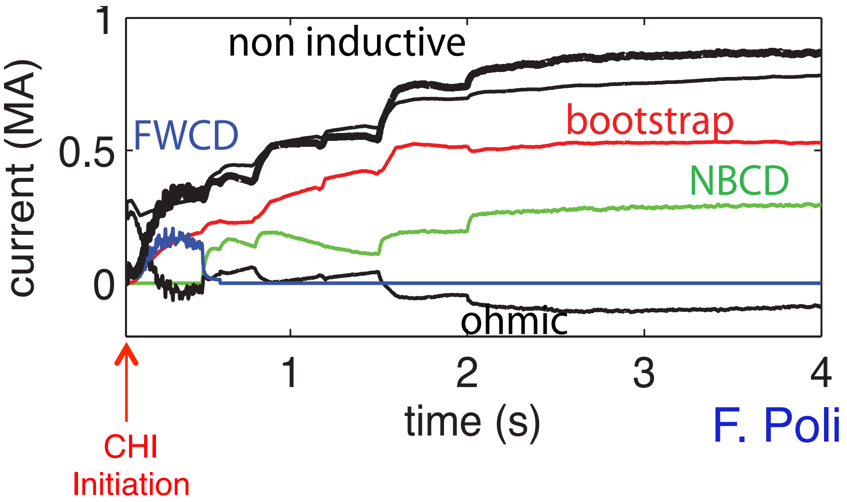


# *1. Advance ST for Fusion Nuclear Science Facility (FNSF), including non-inductive operation*

- 100% non-inductive operation
- Stable high-performance, steady-state control

- Free-boundary TRANSP predictive simulations indicate mixture of sources necessary to achieve 100% stable, non-inductive operation
  - Has been used for ITER scenario development (R. Budny, F. Poli)

NSTX-U Non-inductive Scenario



F. Poli

**Topics to be discussed**

- Coaxial Helicity Injection (CHI) physics (plasma initiation)
- HHFW deposition and losses (current ramp-up)
- NB (fast ion) physics and impact of MHD on CD (sustainment)
- Stability and control

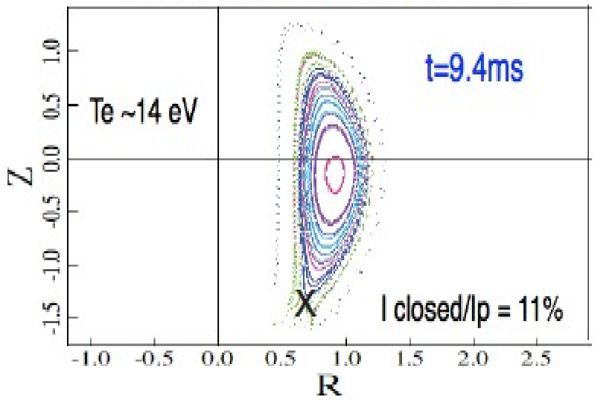
# Understand reconnection physics to extrapolate CHI discharge initiation to next-steps

**CHI Physics**

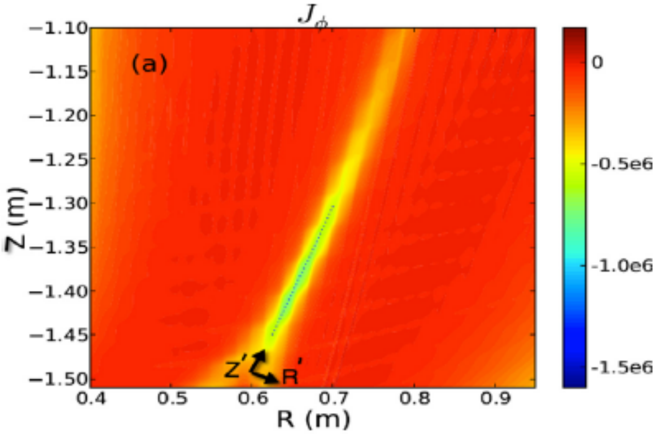
- Resistive simulations have been performed using the extended-MHD NIMROD code – physics is 2D

- Simulations reproduce flux closure for expt'l conditions
- Flux closure/plasma current scales with injector voltage time decay, flux footprint as in experiment
- Simulations indicate Sweet-Parker type reconnection
  - Elongated current sheet
  - Current sheet width
  - Inflow/outflow
- Extrapolates to 400 kA startup current in NSTX-U

**R. Raman, TH/6-55, Wed. PM**



**Elongated SP-type current sheet**



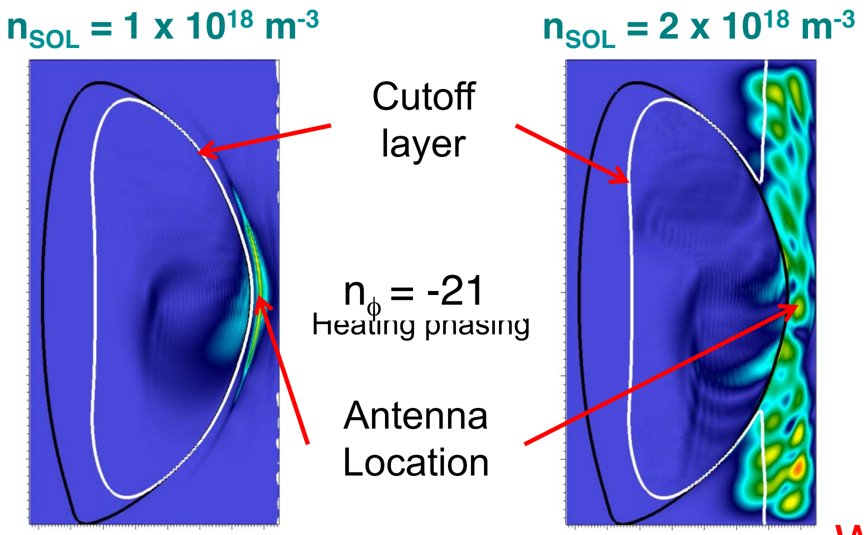
**F. Ebrahimi, Phys. Plasmas 20 090702 (2014)**

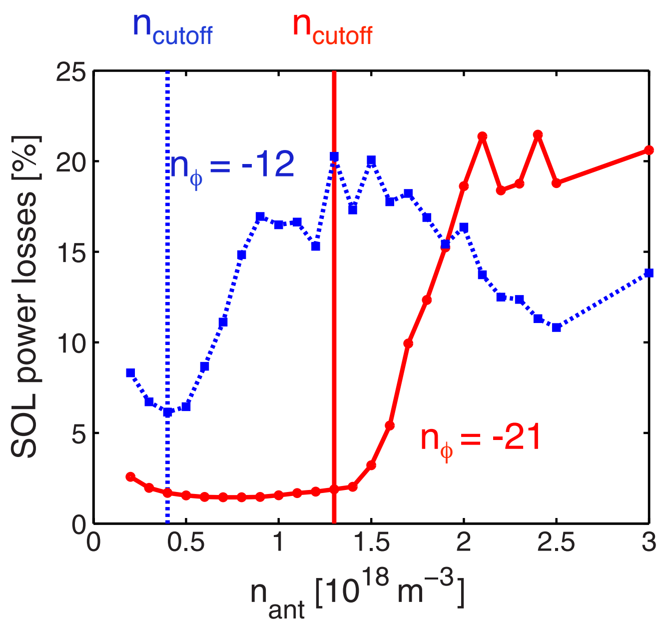
# *Understand HHFW propagation and losses in order to use it effectively for current ramp-up*

***HHFW Physics***

- AORSA simulations predict reduced HHFW SOL field amplitudes at low SOL density ($n_{ant}$)
  - Waves evanescent at low $n_{ant}$
  - Waves propagate at high $n_{ant}$
  - Higher SOL losses at higher $n_{ant}$
    - Consistent with experiment

Possible ICRF coupling issues in ITER – large outer gap, similar harmonic range





$n_{cutoff}$ will be at higher $n_{SOL}$ in NSTX-U

$$n_{SOL,cutoff} \propto \frac{k_{\parallel}^{2} B}{w}$$

Wider SOL density range with lower SOL losses

**N. Bertelli, TH/P4-14, Wed. PM**

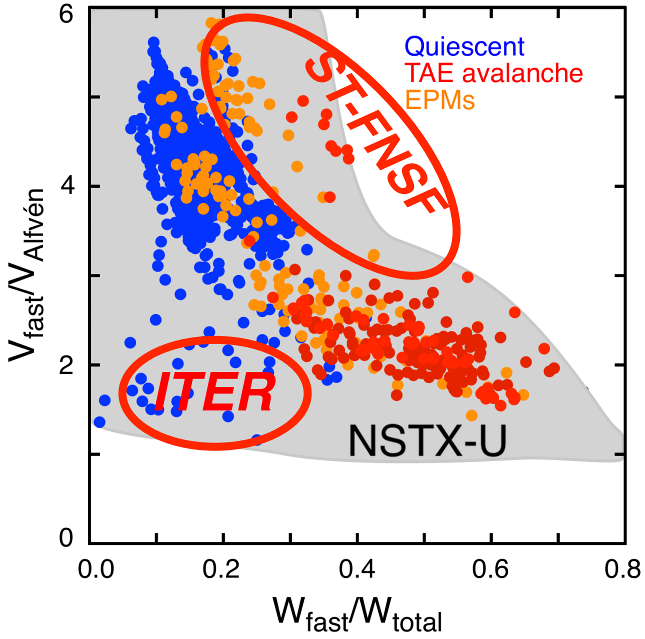
**N. Bertelli, Nuc. Fusion 54 083004 (2014)**

# *Understanding and predicting fast ion physics critical for optimizing NB current drive*

***NBI Physics***

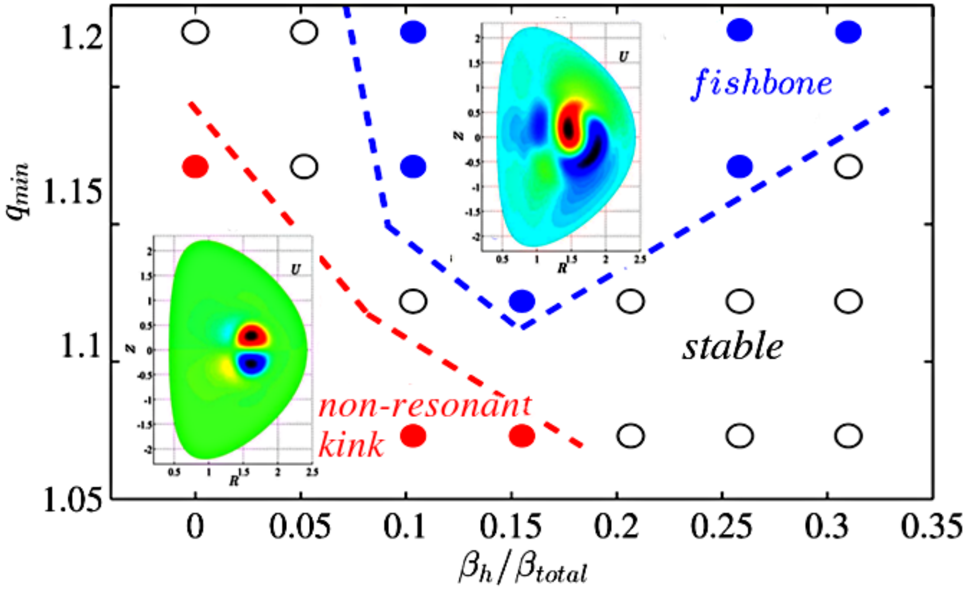
- NSTX/NSTX-U well equipped to explore broad range of Energetic Particle (EP) scenarios as required for projections to ITER, FNSF
- Redistribution of fast ions due to EP modes impact NBCD
- Mapping unstable regimes guides development of discharges with reduced or suppressed MHD

***Mapping of instabilities based on exp't DATA and TRANSP analysis***



**E. Fredrickson Nuc. Fusion 53 013006 (2013)**

Low-f MHD mapped through M3D-K code

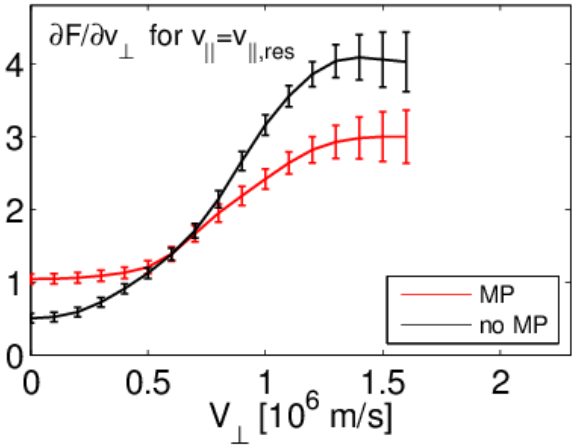


**G.-Y. Fu Phys. Plasmas 20 102506 (2013)**

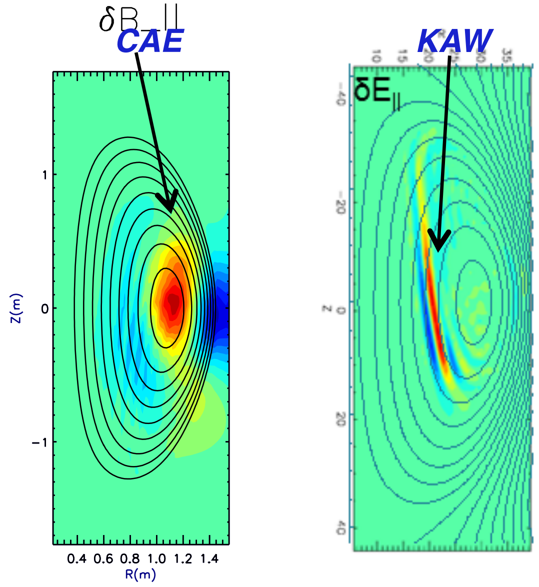
# *High frequency Alfvén activity can also impact NB heating and current drive*

***NBI Physics***

- High frequency (Global/Compressional) Alfven activity modified by 3D fields
  - Change in bursting, chirping frequencies
  - Modified *$\partial F/\partial v_\perp$* due to 3D fields
  - Assess whether RMP coils will impact AE and/or alpha/NBI fast-particle confinement for ITER (and FNSF)
- HYM code shows coupling of CAEs to Kinetic Alfven waves
  - Energy channeling from fast ions to CAE (at r/a~0) to KAW (r/a~0.3)
  - Estimate power channeling of up to ~ 0.4 MW over range of realistic (inferred) mode amplitudes (for one mode)
  - Critical for NB heating/CD profiles & thermal electron transport studies



**A. Bortolon PRL 110 265008 (2013)**



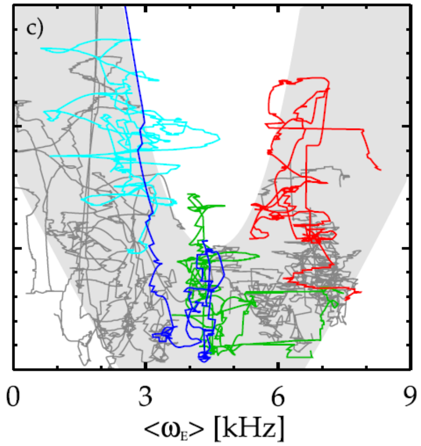
**E. Belova**

# *Rotation control is critical to plasma stability*

***Stability***

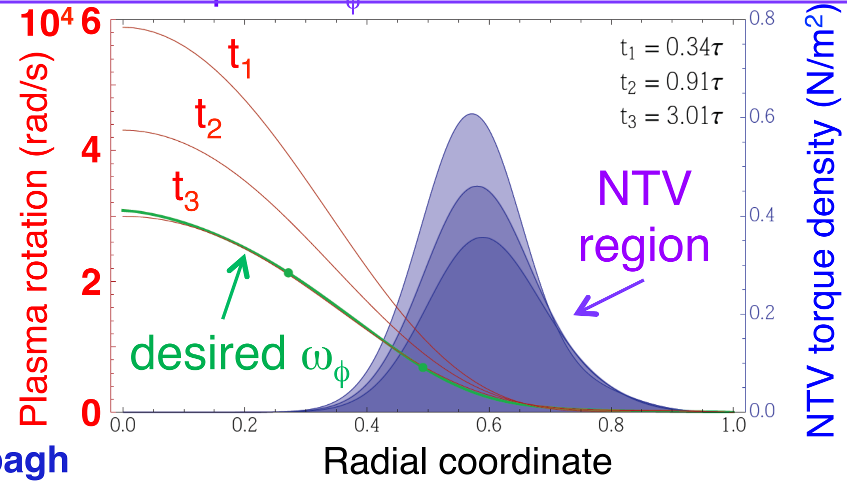
- Kinetic RWM stability theory and comparison to NSTX sets the stage for practical use in NSTX-U for disruption avoidance
  - Optimum rotation frequency for stability found
- NSTX-U controller will use Neoclassical Toroidal Viscosity (NTV) physics for the first time in rotation feedback control
  - Control toward optimum rotation frequency
- Physics basis of NTV being studied using NTVTOK (S. Sabbagh, EX/1-4), POCA (K. Kim)

Instability measure (RFA) vs. exp. $\omega_E$ for NSTX



**J. Berkery, Phys. Plasmas 056112 (2014)**

NSTX-U state-space $\omega_\phi$ controller w/NTV as actuator



**I. Goumiri, S. Sabbagh**

## *2. Develop solutions for plasma-material interface challenge*

- Mitigation of high heat flux ($q_{peak}$~40 MW/$m^2$, $P_{heat}$/S~0.5 MW/$m^2$)
- Optimization of pedestal/SOL interface

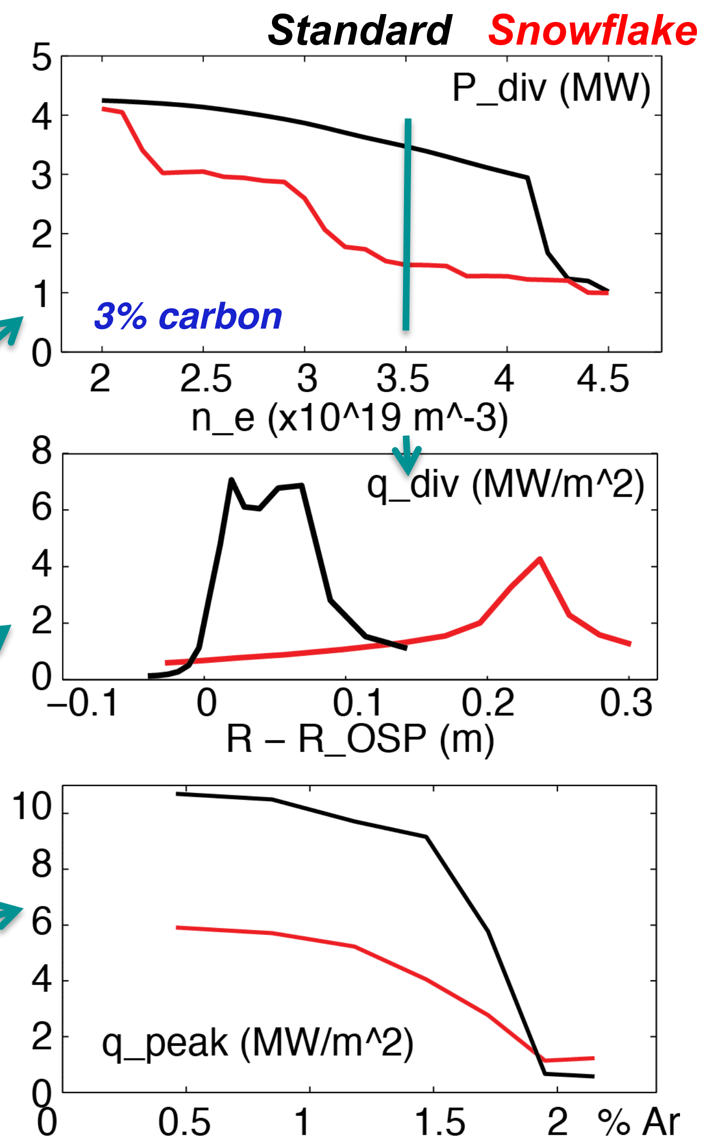
**Topics to be discussed**

- Heat flux mitigation via divertor configuration and radiation
- Development and exploration of more resilient materials (liquid lithium)
- Attractive integrated core/pedestal/divertor performance regimes

# *Modeling supports snowflake and impurity-seeded radiative divertors as heat flux mitigation candidates in NSTX-U*

***Heat flux mitigation***

- Multi-fluid UEDGE code
  - $B_T$=1 T, $I_p$=2 MA, $P_{SOL}$=9 MW
  - NSTX-like transport: $\chi_{i,e}$=2–4 $m^2/s$, D=0.5 $m^2/s$
- **Standard** and **snowflake** divertor configurations achievable using NSTX-U divertor coils
- Radiative snowflake operational densities as low as $n_e/n_{GW}$~0.4 (~$2\times10^{19}$ $m^{-3}$)
- Peak heat flux reduced by 50% over standard radiative divertor
- Less impurity seeding (argon or neon) needed in snowflake for lower peak heat flux

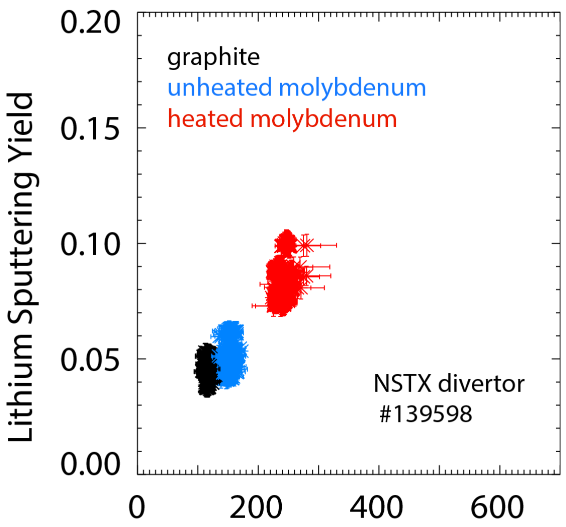


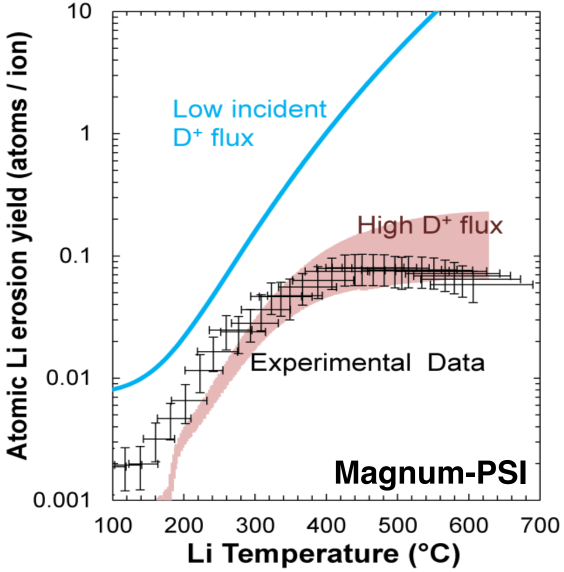
**E. Meier, TH/P6-50, Thurs. PM**

# *Temperature-enhanced erosion leads to a continuous vapor-shielding regime*

***Liquid Lithium PFCs***

- In-situ measurements indicate enhanced Li erosion in NSTX divertor targets over restricted temperature range
- Lithium erosion studies conducted up to 1300C on Magnum-PSI plasma device to mimic expected NSTX-U divertor conditions
  - Lithium evaporated layer on Mo
  - Deuterium plasma
- Suppressed lithium emission observed at high temperatures and high $D^+$ fluxes due to lithium deuteride (LiD) formation
- **Lithium trapping forms stable vapor cloud up to 1000C target temperature**
  - Motivates continuously vapor-shielded divertor target studies for heat flux mitigation
  - NSTX-U will determine maximum Li PFC temperatures consistent with good confinement

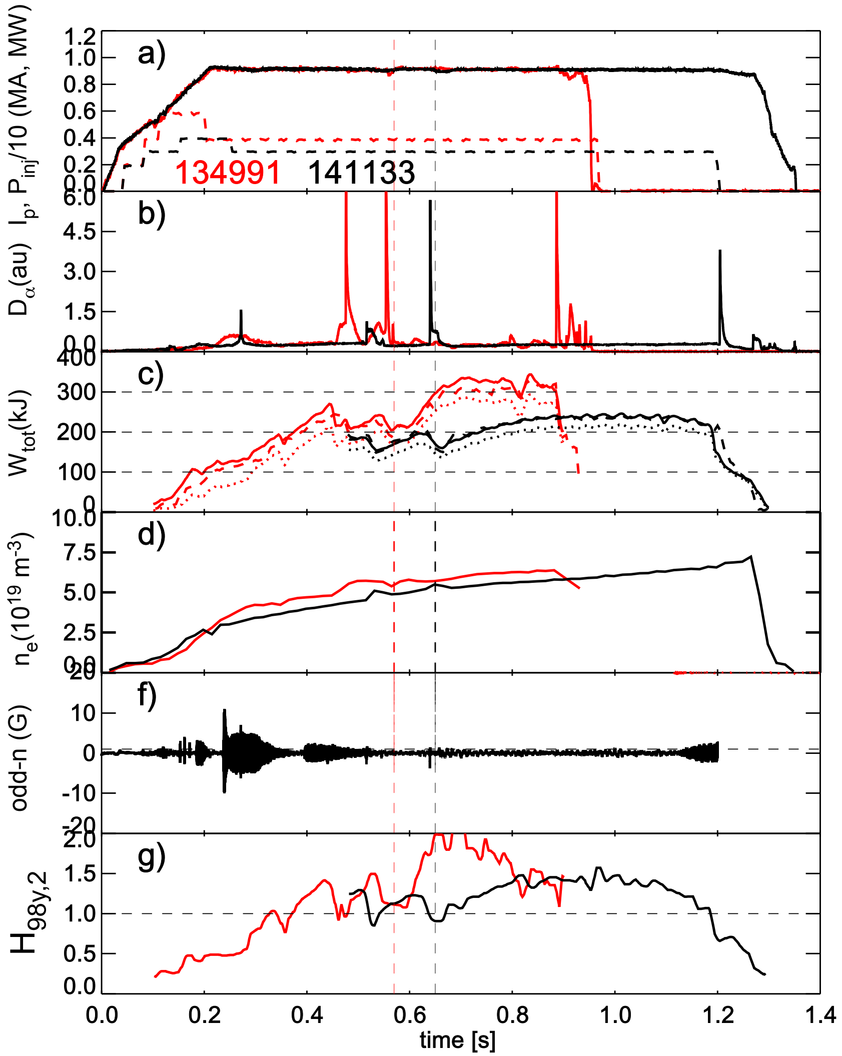




# Enhanced Pedestal H-mode provides one attractive integrated core, pedestal and divertor scenario

**Pedestal/SOL**

- EP H-mode is a high performance scenario with high wide pedestal and excellent $H_{98y2}$ (up to 2)
- New discovery of long pulse EP H-mode lasting for duration of pulse
- Lithium conditioning integral
  - EP H-mode increases $H_{98y,2}$ by 50% over already enhanced H-factor with lithium
- Related to strong velocity shear
  - Trigger with 3-D fields?
- Plan to couple with divertor solutions in NSTX-U



**S. Gerhardt, Nuc. Fusion 54 083021 (2014)**

# *3. Explore unique ST parameter regimes to advance predictive capability - for ITER and beyond*

- **Access reduced collisionality**
- Role of **high** ExB and parallel **flow shear**
- Understand enhanced confinement and stability

→ Be able to predict confinement and transport

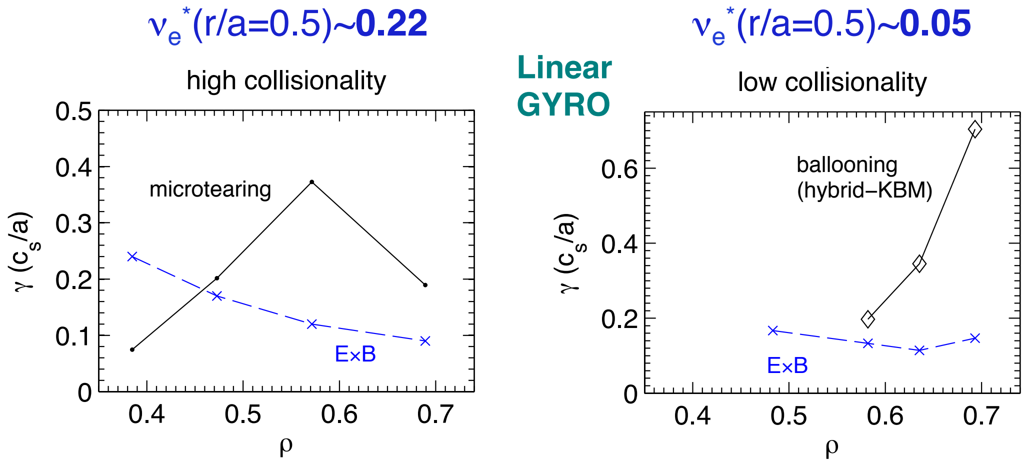
**Topics to be discussed**

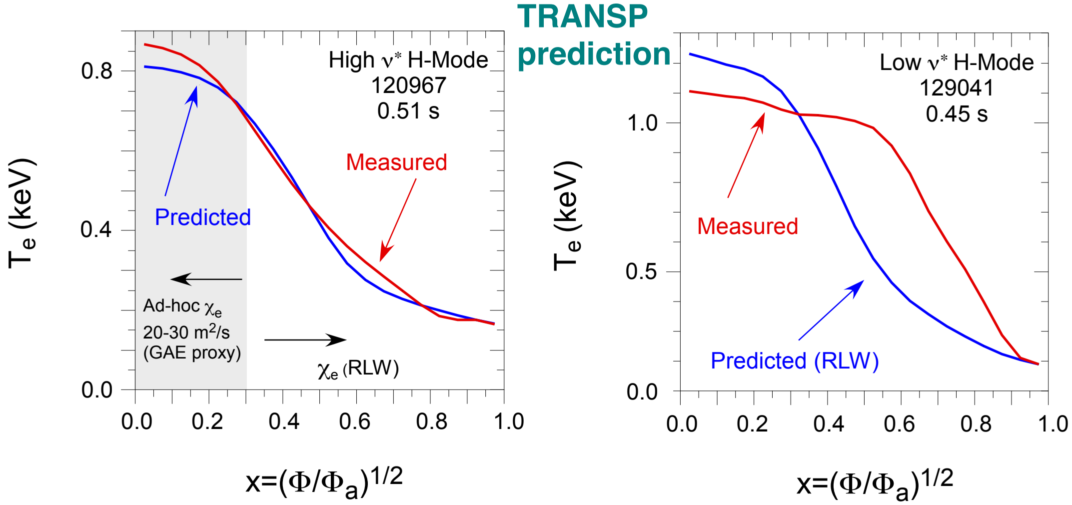
- Highly anomalous electron transport
- Neoclassical vs anomalous ions
- Fast ion transport

# *Electron transport at high collisionality well explained by microtearing modes*

***Electron Transport***

- Predictive TRANSP simulations using reduced transport model based on microtearing modes (Rebut-Lallia-Watkins, 1988)
  - $T_e$ predictions agree with measurements when microtearing predicted to be dominant
- At low collisionality, microtearing subdominant
  - Poor agreement
  - Need to develop predictive model when microtearing subdominant
- Need to develop predictive model for influence of CAE/KAW in very core

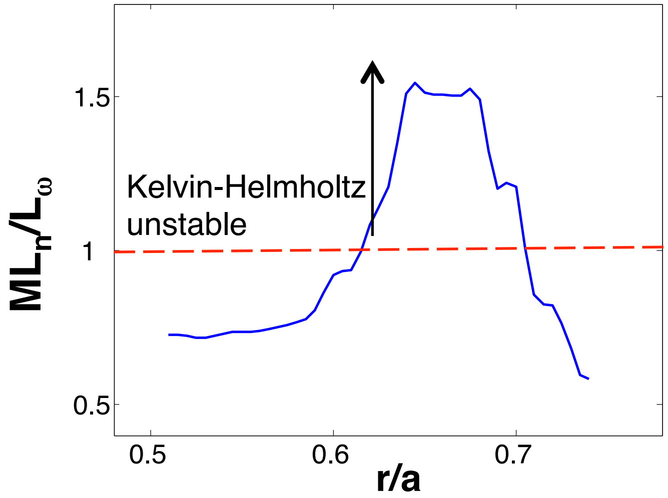




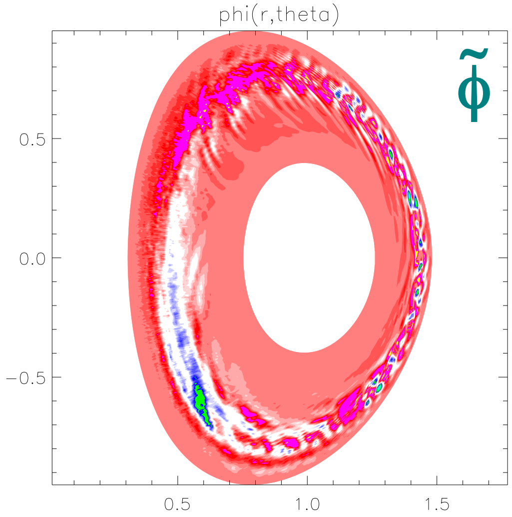
**S. Kaye, Phys. Plasmas 21 082510 (2014)**

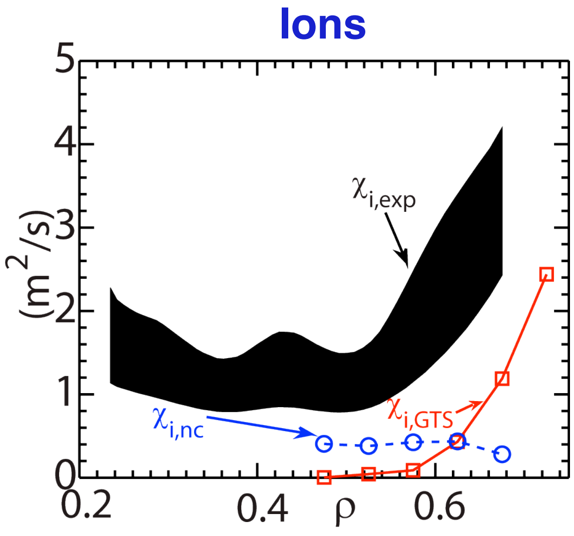
# Strong flow shear can destabilize Kelvin-Helmholtz instability

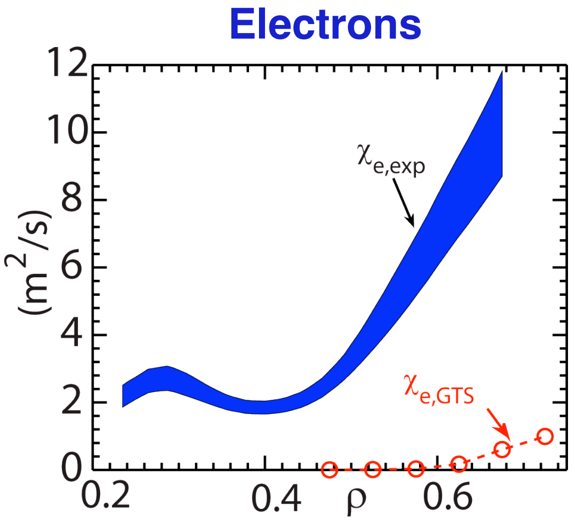
**IonTransport**



- Linear theory: $|ML_n/L_\omega|>1$ for instability
- Non-linear global **GTS** simulations indicate Kelvin-Helmholtz (K-H) unstable in L-mode
  - K-H identified in simulation by finite $k_{||}$
- K-H/ITG turbulence + neoclassical ion transport within factor of ~2 of expt'l level
  - $e^-$ transport seriously underestimated





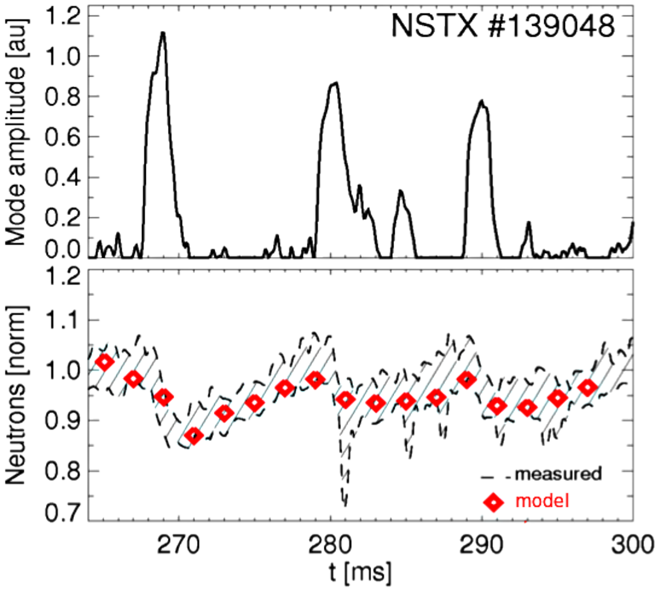


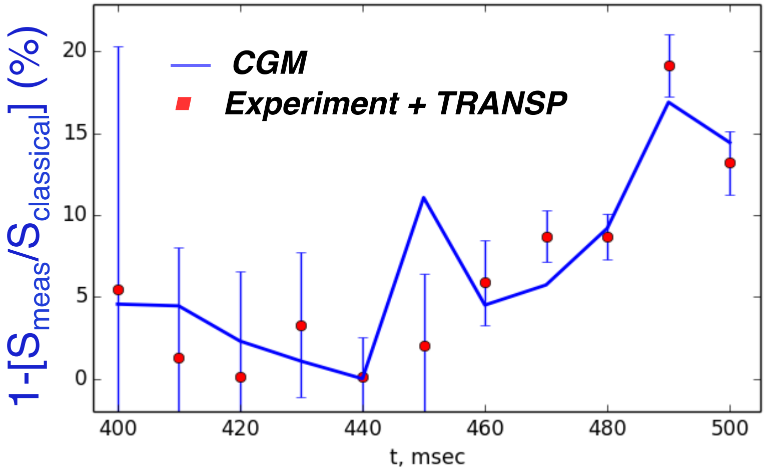
**W. Wang**

# *Predictive capability for fast ion response to Alfvén Eigenmodes has been developed*

***Fast ion transport***

- New “kick” model being implemented in NUBEAM/TRANSP **M. Podesta, EX/10-4, Fri. PM**
  - Models phase-space *kicks* in constants of motion from multiple instabilities with time-varying amplitudes
  - Provides accurate estimates for fast ion distribution function and NB-driven current
- Initial validation with stand-alone NUBEAM successful for TAEs, kink-like modes on NSTX **M. Podesta, PPCF 56 055003 (2014)**



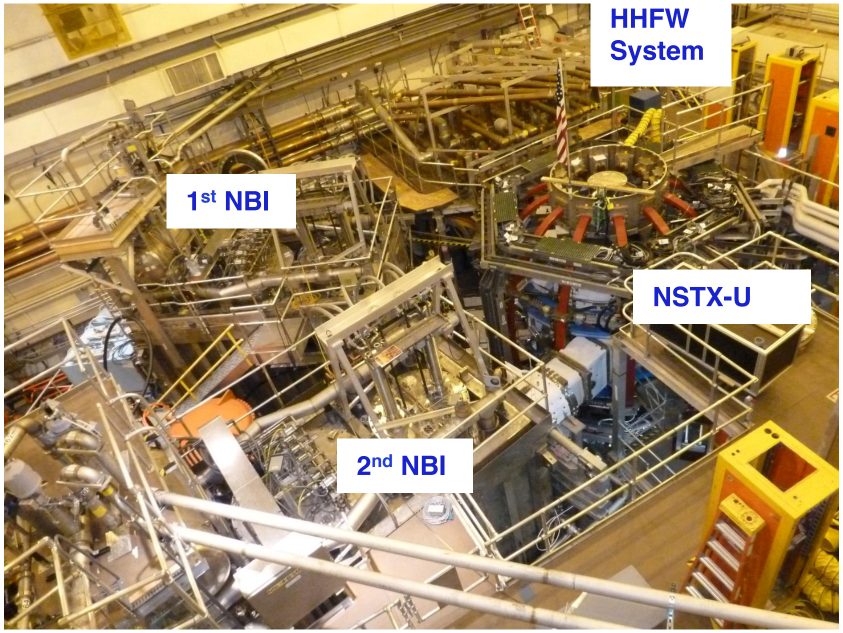


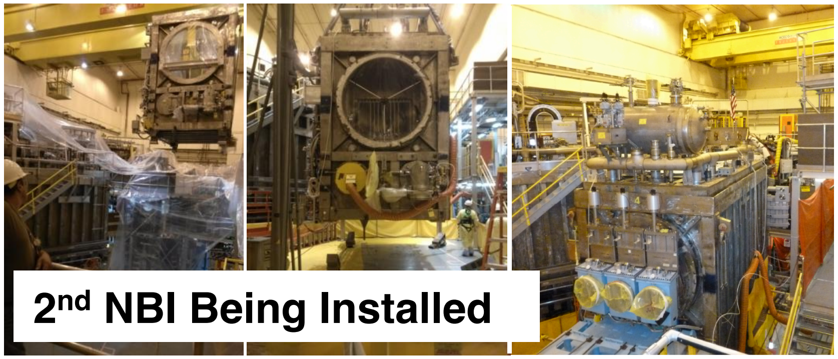
- 1.5D Critical Gradient Model (CGM) predicts relaxed fast ion profiles for given instabilities **N. Gorelenkov, EX/10-4, Fri. PM**
- Both models potentially useful for FNSF, ITER predictions

# NSTX-U research aims to establish physics basis for next-step STs such as an FNSF and Pilot Plant

- Develop and implement techniques for non-inductive operation from startup to sustainment
- Develop solutions to projected high heat fluxes to the PFCs
- Explore unique ST parameter regime to advance predictive capability at low collisionality, high beta and high flow and flow shear

- NSTX-U research operations will commence in Spring 2015




2nd NBI Being Installed

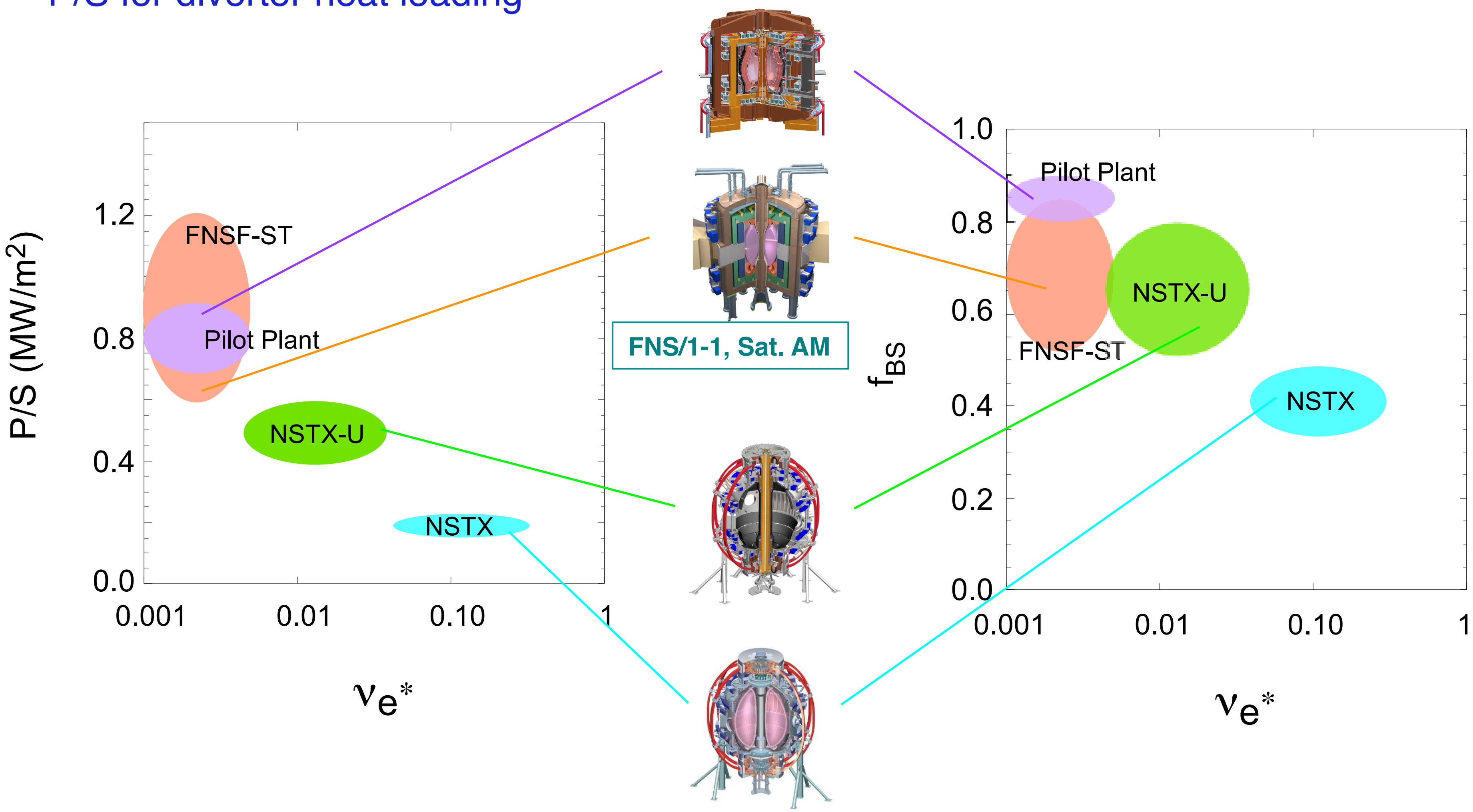
# *NSTX-U Presentations at the 2014 IAEA*

- Orals
  - Physical Characteristics of Neoclasical Toroidal Viscosity in Tokamaks for Rotation Control and the Evaluation of Plasma Response (S. Sabbagh), EX/1-4 **– Tuesday AM**
  - Effects of MHD Instabilities on Neutral Beam Current Drive (M. Podesta given by W. Heidbrink), EX/10-4 **– Friday PM**
  - Configuration studies for an ST-based Fusion Nuclear Science Facility (J. Menard given by L. El-Guebala), FNS/1-1 **– Saturday AM**
- Posters
  - Developing and Validating Predictive Models for Fast Ion Relaxation in Burning Plasmas (N. Gorelenkov), TH/P1-2 **– Tuesday AM**
  - Computation of Resistive Instabilities in Tokamaks with Full Toroidal Geometry and Coupling Using DCON (J.-K. Park), TH/P1-5 **– Tuesday AM**
  - Full Wave Simulations for Fast Wave Heating and Power Losses in the Scrape-off Layer of Tokamak Plasmas (N. Bertelli), TH/P4-14 **– Wednesday PM**
  - Impact of 3D Fields on Divertor Detachment in NSTX and DIII-D (J.-W. Ahn), EX/P6-53 **– Thursday PM**
  - Experimental Observation of Nonlocal Electron Thermal Transport in NSTX RF-Heated L-Mode Plasmas (Y. Ren), EX/P6-43 **– Thursday PM**
  - The Role of Lithium Conditioning in Achieving High Performance, Long Pulse H-Mode Discharges in the NSTX and EAST Devices (R. Maingi), EX/P6-54 **– Thursday PM**
  - Modeling Divertor Concepts for Spherical Tokamaks NSTX, NSTX-U, and ST-FNSF (E. Meier), TH/P6-50 **– Thursday PM**
  - Transient CHI Plasma Start-up Simulations and Projections to NSTX-U (R. Raman), TH/P6-55 **– Thursday PM**
  - Progress Toward Commissioning and Plasma Operation in NSTX-U (M. Ono), FIP/P8-30 **– Friday PM**

# Backup

# *NSTX-Upgrade will access next factor of two increase in performance to bridge gaps to next-step STs*

- Collisionality for transport and stability
- P/S for divertor heat loading
- $f_{BS}$ (boostrap fraction) for non-inductive CD



**FNS/1-1, Sat. AM**

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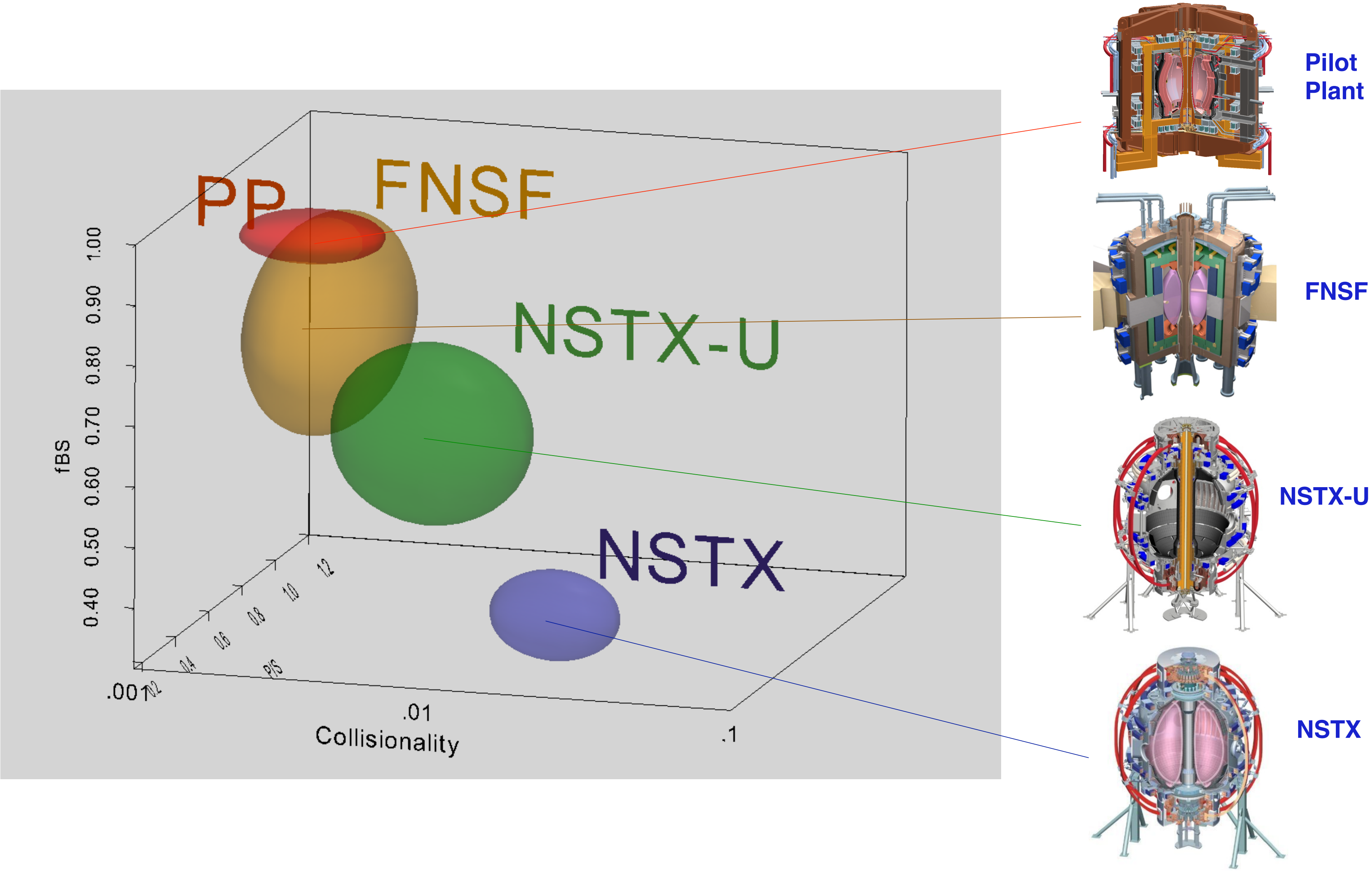
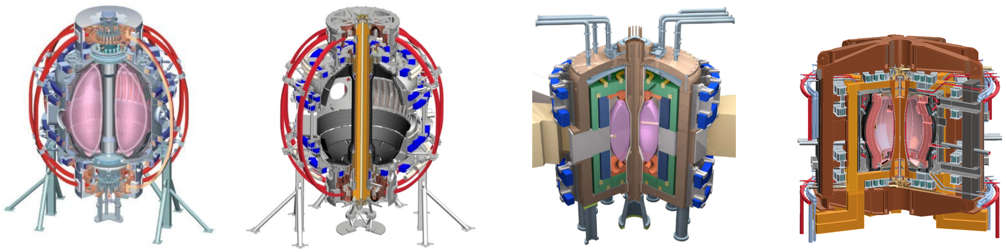


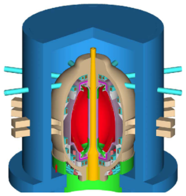
# *NSTX completed operation in Fall 2010 for start of Upgrade construction*

- NSTX-Upgrade will access next factor of two increase in performance to bridge gaps to next-step STs

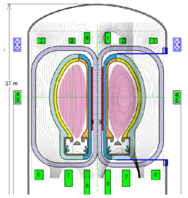


| Parameter | NSTX | **NSTX Upgrade** | Fusion Nuclear Science Facility | Pilot Plant |
|---|---|---|---|---|
| Major Radius $R_0$ [m] | 0.86 | **0.94** | 1.3 | 1.6 – 2.2 |
| Aspect Ratio $R_0$ / a | ≥ 1.3 | **≥ 1.5** | ≥ 1.5 | ≥ 1.7 |
| Plasma Current [MA] | 1 | **2** | 4 – 10 | 11 – 18 |
| Toroidal Field [T] | 0.5 | **1** | 2 – 3 | 2.4 – 3 |
| Auxiliary Power [MW] | ≤ 8 | **≤ 19*** | 22 – 45 | 50 – 85 |
| P/R [MW/m] | 10 | **20** | 30 – 60 | 70 – 90 |
| P/S [MW/m$^2$] | 0.2 | **0.4-0.6** | 0.6 – 1.2 | 0.7 – 0.9 |
| Fusion Gain Q | | | 1 – 2 | 2 – 10 |

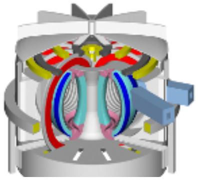
**Low-A Power Plants**



**ARIES-ST (A=1.6)**



**JUST (A=1.8)**



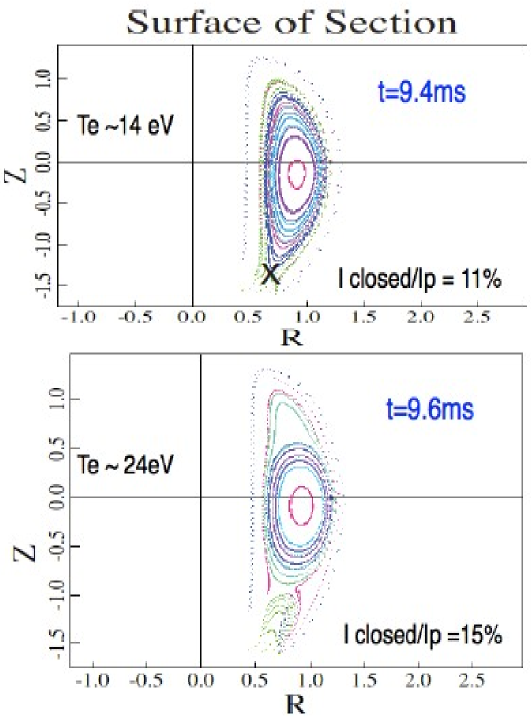
**VECTOR (A=2.3)**

# Understand reconnection physics to extrapolate CHI discharge initiation to next-steps

**CHI Physics**

- Resistive simulations have been performed using the extended-MHD NIMROD code – physics is 2D

- Simulations with magnetic diffusivities similar to exp't produce flux closure
- Flux closure/plasma current scales with injector voltage time decay, flux footprint as in experiment
- Simulations indicate Sweet-Parker type reconnection
  - Elongated current sheet
  - Current sheet width
  - Inflow/outflow



**F. Ebrahimi**

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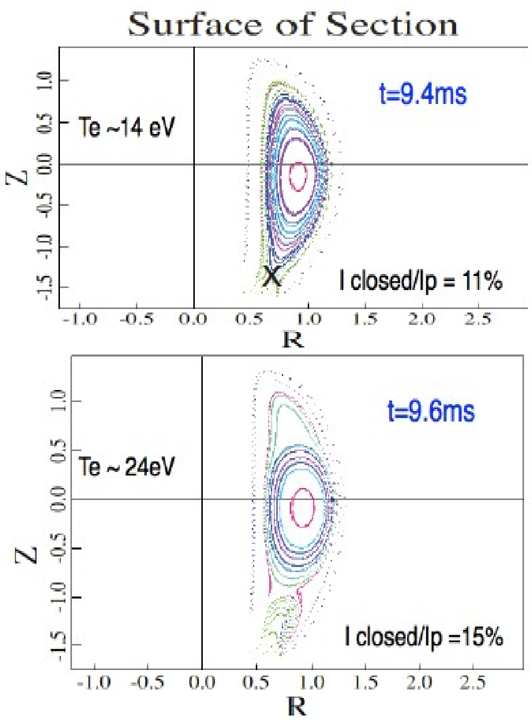

**F. Ebrahimi**

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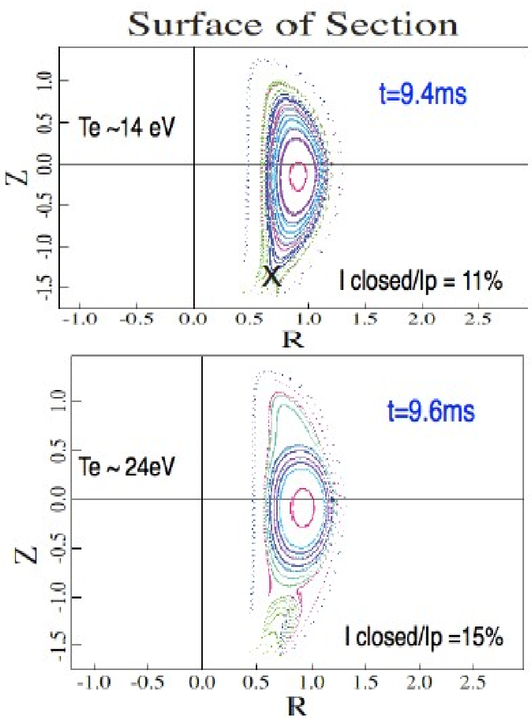
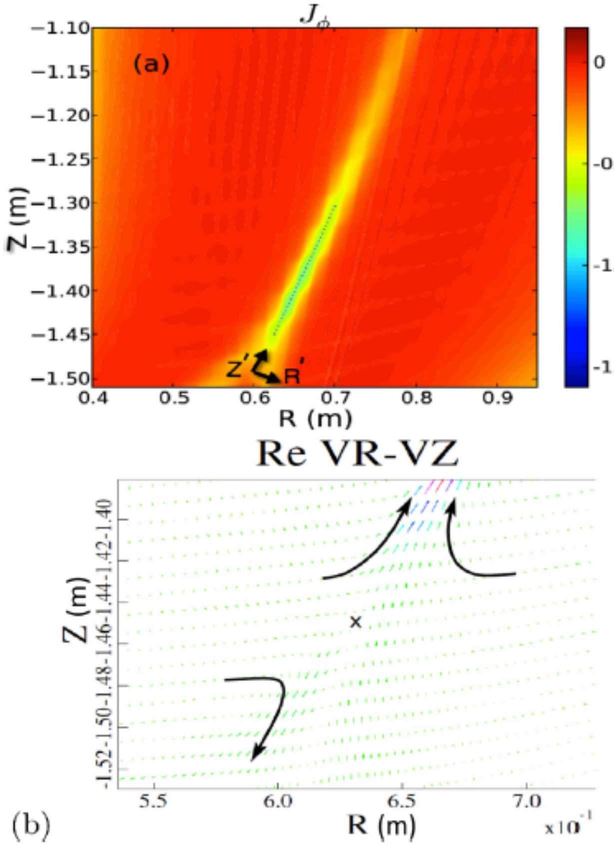


**F. Ebrahimi**

**Elongated SP-type current sheet**



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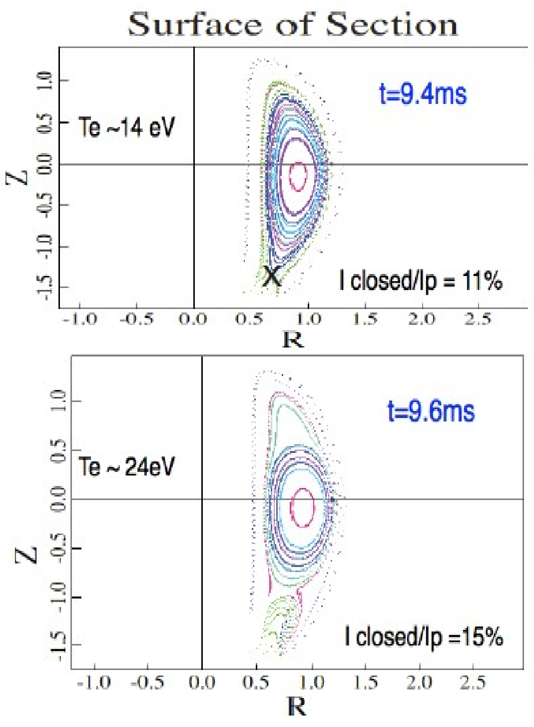

**F. Ebrahimi**

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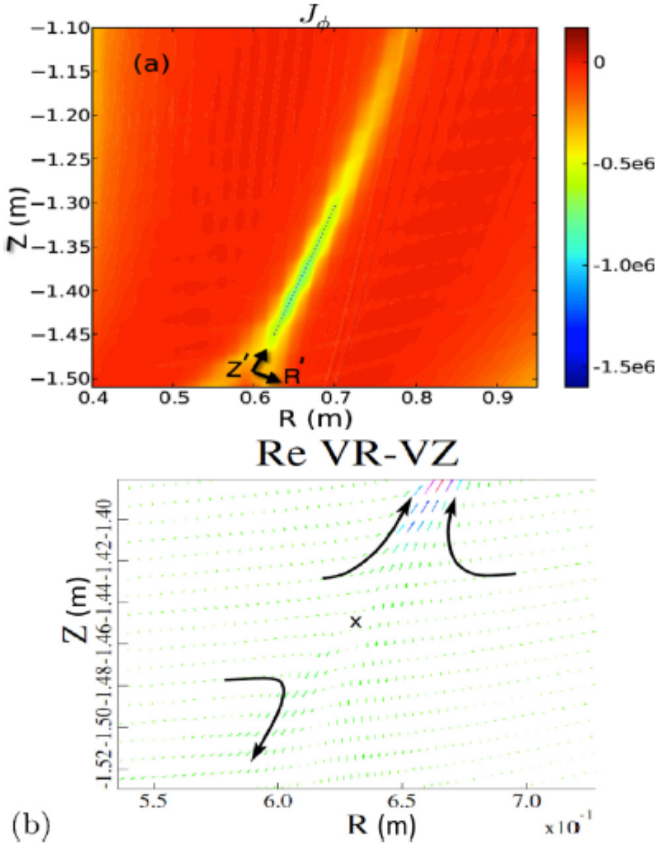
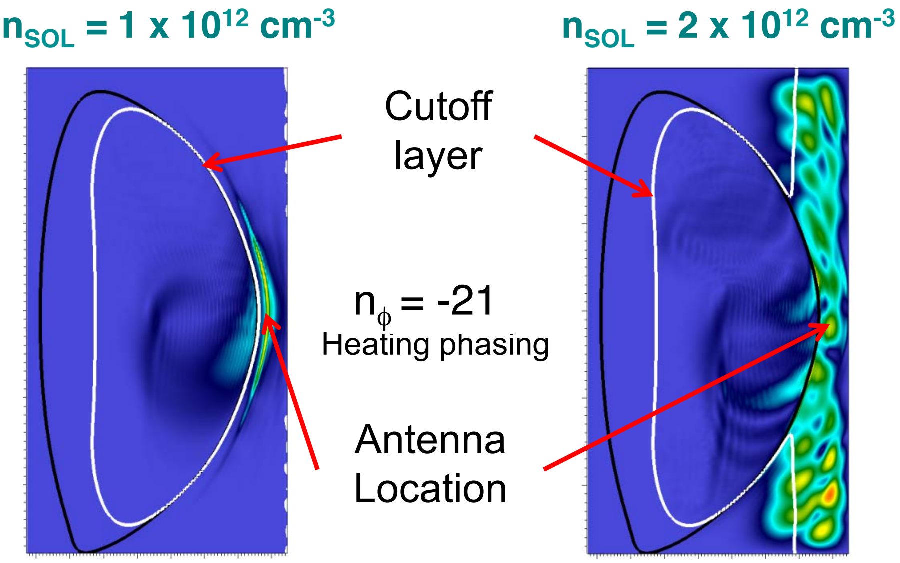


# *Understand HHFW propagation and losses in order to use it effectively for current ramp-up*

- AORSA simulations predict reduced HHFW SOL field amplitudes at low SOL density ($n_{ant}$)
  - Wave is evanescent at low density
  - Wave can propagate at higher density
- Higher SOL losses at higher density
  - Consistent with experiment



**N. Bertelli**

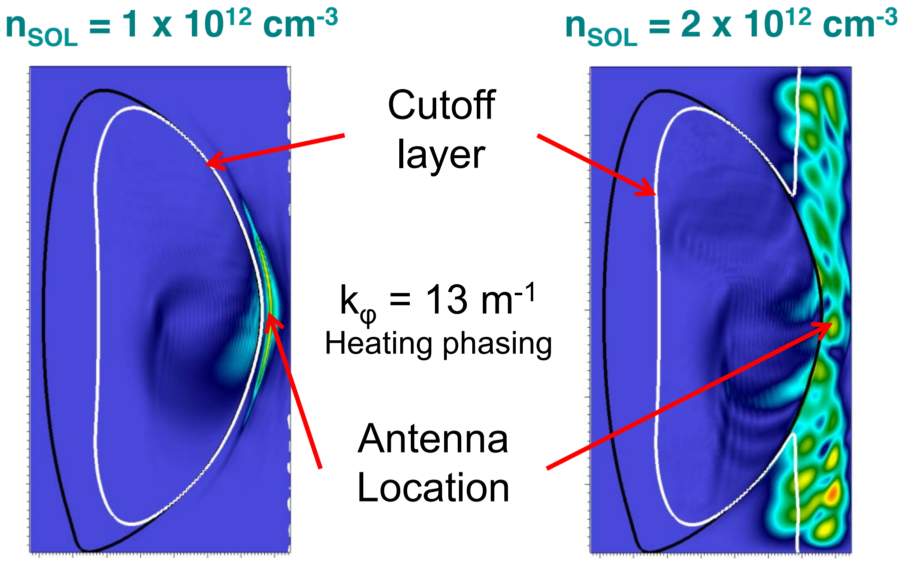
**TH/P4-14, Wed. PM**

# *Understand HHFW propagation and losses in order to use effectively for current ramp-up*

***HHFW Physics***

- HHFW field amplitude depends on location of righthand cutoff
  - When region in front of antenna is cut off (low $n_{SOL}$), low field amplitudes
  - When region in front of antenna is propagating (high $n_{SOL}$), high field amplitudes

AORSA simulations predict reduced SOL losses with existence of evanescent region at low SOL density ($n_{ant}$)



**$n_{SOL}$ = 1 x $10^{12}$ cm$^{-3}$**

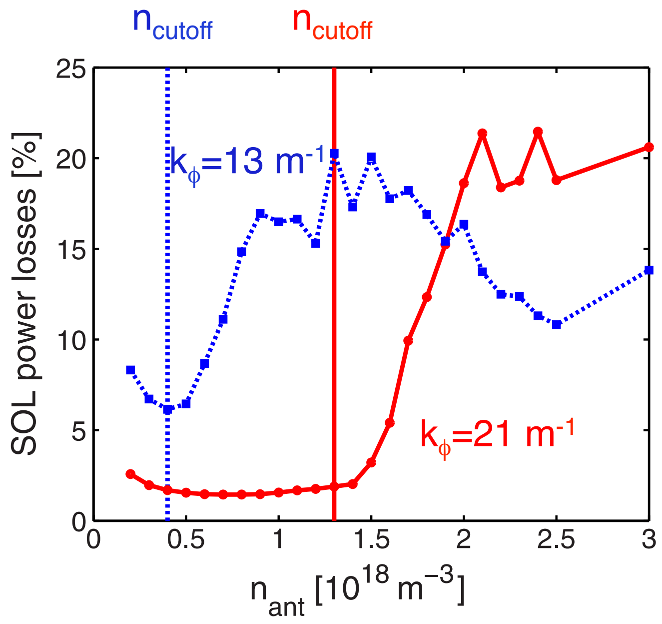
**$n_{SOL}$ = 2 x $10^{12}$ cm$^{-3}$**

Cutoff layer

$k_\varphi$ = 13 m$^{-1}$
Heating phasing

Antenna Location

**N. Bertelli**



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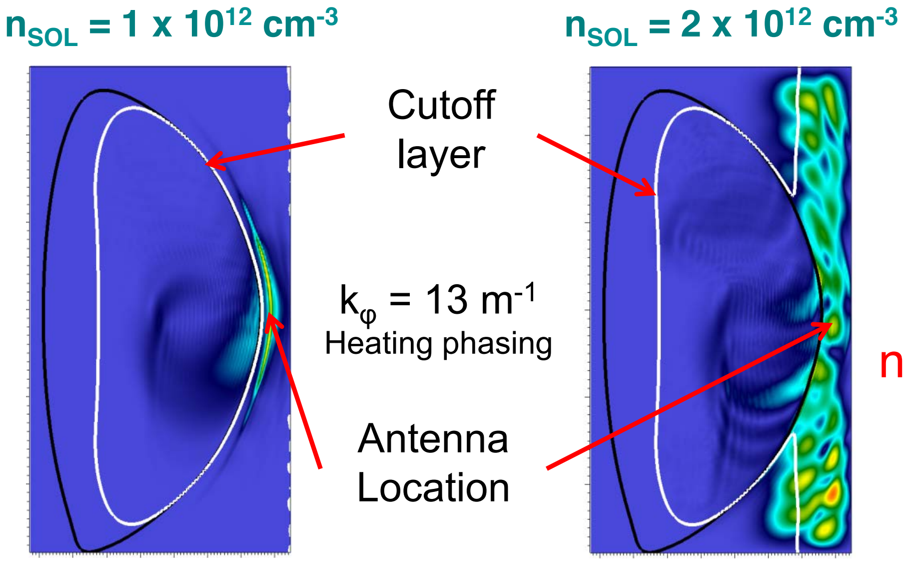
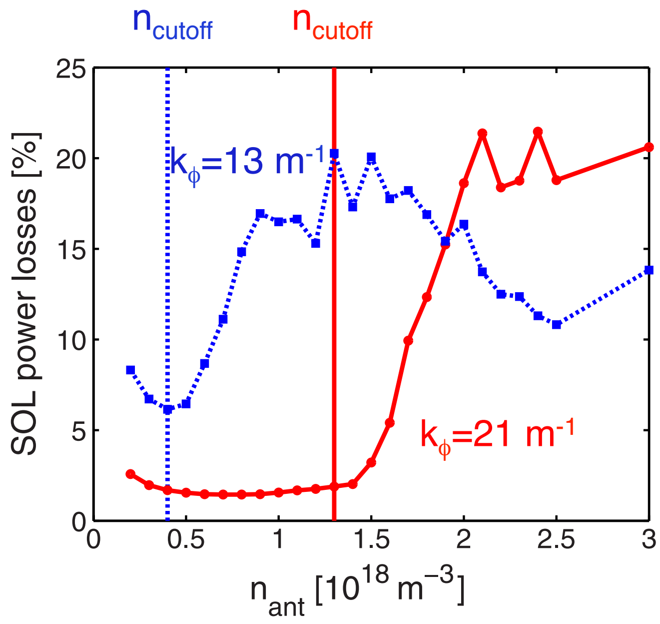


**N. Bertelli**



$n_{cutoff}$ will be at higher $n_{SOL}$ in NSTX-U

$$n_{SOL,cutoff} \propto \frac{k_{\parallel}^{2} B}{w}$$

Wider SOL density range with lower SOL losses

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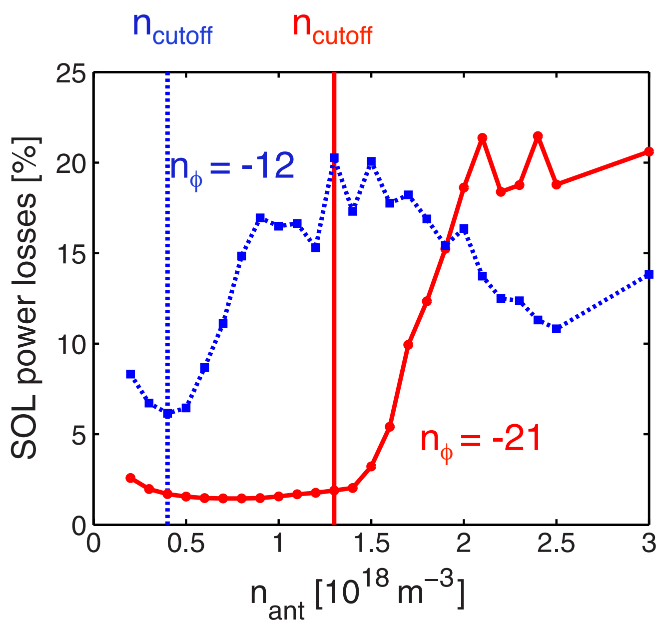
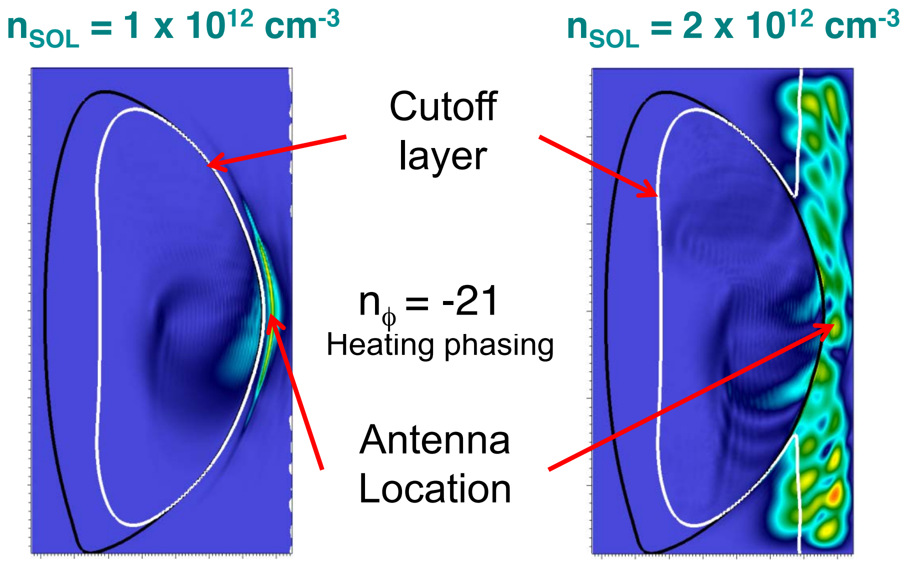




TH/P4-14, Wed. PM

**N. Bertelli**

$n_{cutoff}$ will be at higher $n_{SOL}$ in NSTX-U

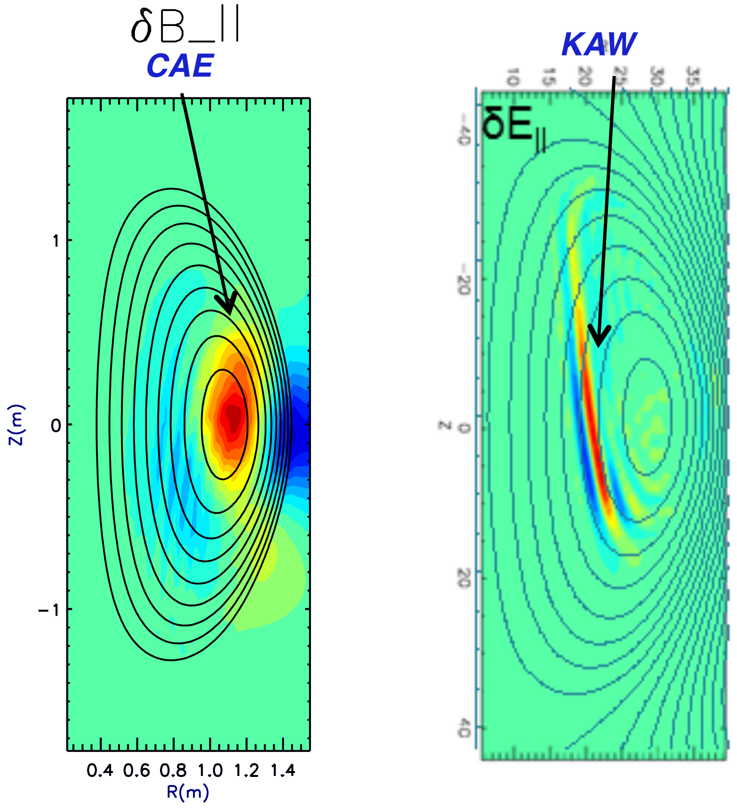
$$n_{SOL,cutoff} \propto \frac{k_{\parallel}^{2} B}{w}$$

Wider SOL density range with lower SOL losses

# *High frequency Alfvén activity can also impact NB heating and current drive*

***NBI Physics***

- High frequency (Global/Compressional) Alfven activity modified by 3D fields
  - Change in bursting, chirping frequencies
  - Modified $\partial F/\partial v_\perp$ due to 3D fields
  - Assess whether RMP coils will impact AE and/or alpha/NBI fast-particle confinement for ITER (and FNSF)
- HYM code shows coupling of CAEs to Kinetic Alfven waves
  - Energy channeling from fast ions to CAE (at r/a~0) to KAW (r/a~0.3)
  - Estimate power channeling of up to ~ 0.4 MW over range of realistic (inferred) mode amplitudes (for one mode)
  - Critical for NB heating/CD profiles & thermal electron transport studies



**E. Belova**

Future Work: Perform non-linear HYM simulations to calculate actual level of energy transfer and effect on $T_e$; develop predictive capability

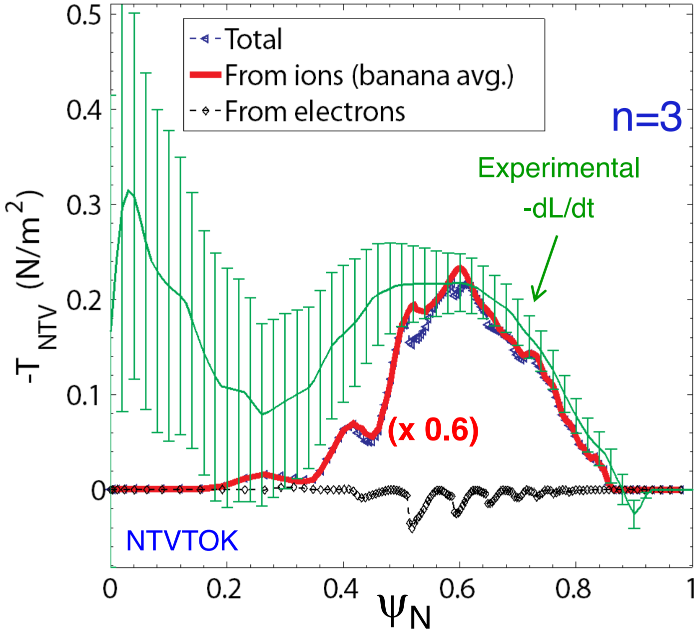
# *Understanding the physics basis for NTV crucial for predicting effects in NSTX-U*

***Stability***

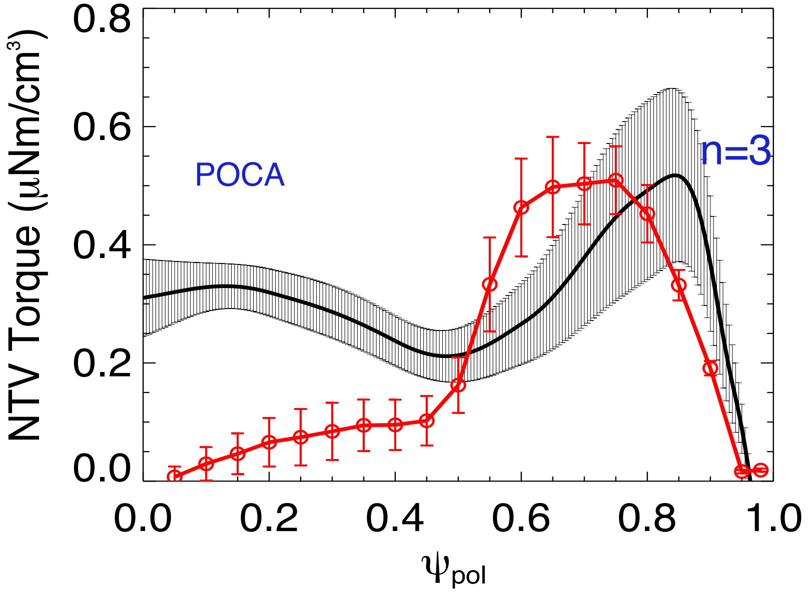
- POCA, NTVTOK – Indicate importance of kinetic resonances, collisionality

- NTVTOK
  - Valid for all collisionality regimes for $e^-$, $i^+$
  - Importance of finite orbit effects average flux surface δr over banana width)

- POCA
  - Follows individual guiding center orbits
  - Calculates δf in non-axisymmetric ideal equilibrium determined by IPEC



**S. Sabbagh**



**K. Kim**

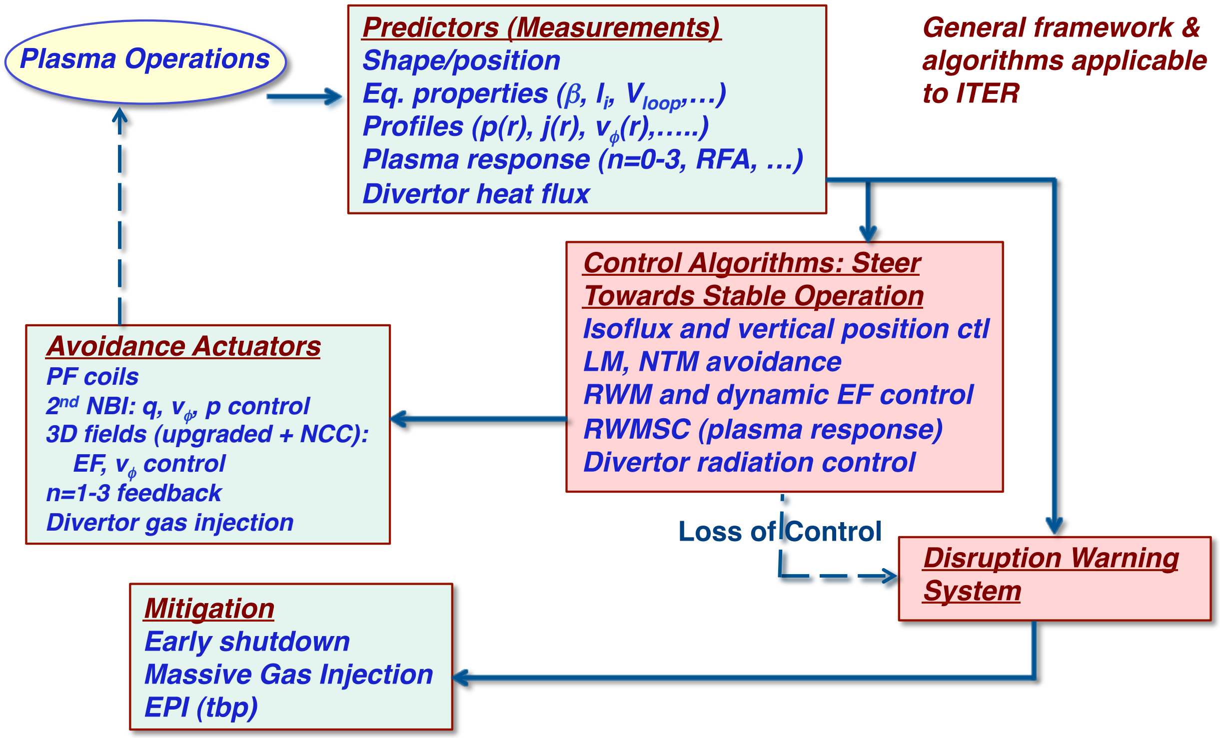
**EX/1-4, Tues. AM**

Understanding rotation braking from RMP will be important for ITER ELM control

# *An integrated disruption Prediction-Avoidance-Mitigation (PAM) framework is being developed*

***Control***

- Key elements are:
  - State-space controller for stability control
  - Physics-based disruption warning algorithm with >96% success rate
  - MGI system with gas injection at different poloidal locations



*Plasma Operations*

***Predictors (Measurements)***
*Shape/position*
*Eq. properties ($\beta$, $l_i$, $V_{loop}$,…)*
*Profiles ($p(r)$, $j(r)$, $v_\phi(r)$,…..)*
*Plasma response (n=0-3, RFA, …)*
*Divertor heat flux*

*General framework & algorithms applicable to ITER*

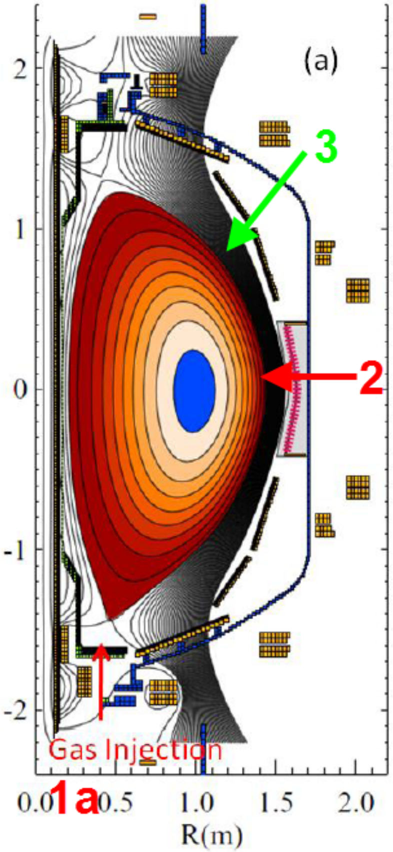
***Control Algorithms: Steer Towards Stable Operation***
*Isoflux and vertical position ctl*
*LM, NTM avoidance*
*RWM and dynamic EF control*
*RWMSC (plasma response)*
*Divertor radiation control*

***Avoidance Actuators***
*PF coils*
*2nd NBI: q, $v_\phi$, p control*
*3D fields (upgraded + NCC):*
*EF, $v_\phi$ control*
*n=1-3 feedback*
*Divertor gas injection*

Loss of Control

***Disruption Warning System***

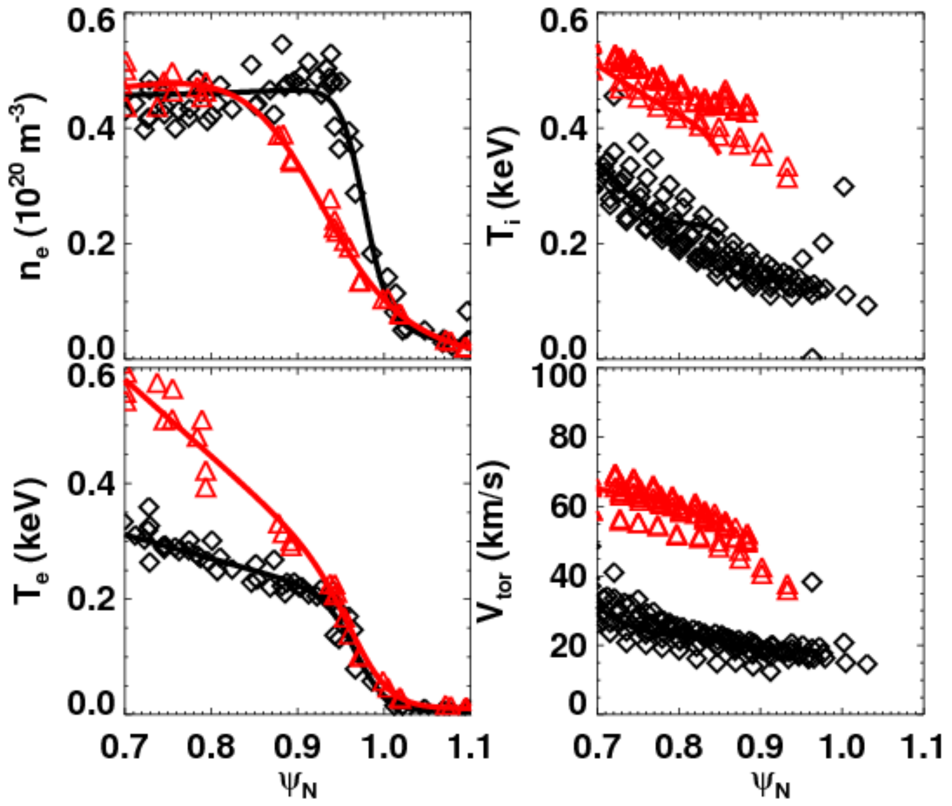
***Mitigation***
*Early shutdown*
*Massive Gas Injection*
*EPI (tbp)*



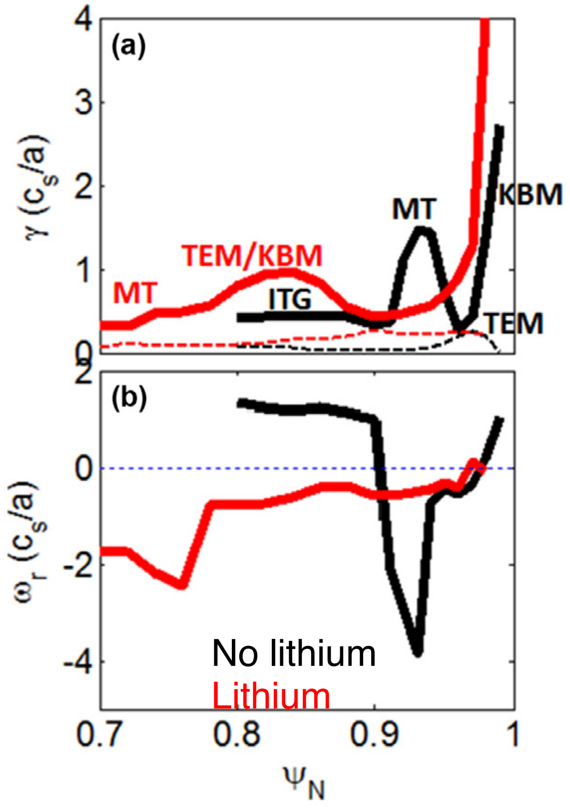
# *Lithium wall conditioning influences pedestal profiles and microstability characteristics*

- Higher $T_e$, $T_i$ with lithium
- Lower pedestal density, wider $n_e$ pedestal (top moves in)

- Microtearing impt at pedestal top, TEM/KBM in gradient region (GS2)



**R. Maingi**

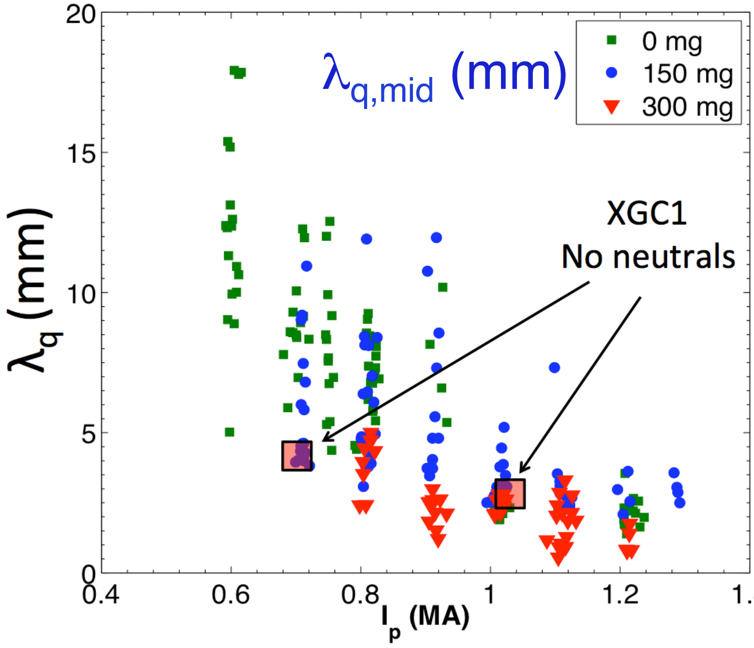


**J. Canik**

# *Both neoclassical and MHD processes important for understanding power deposition*

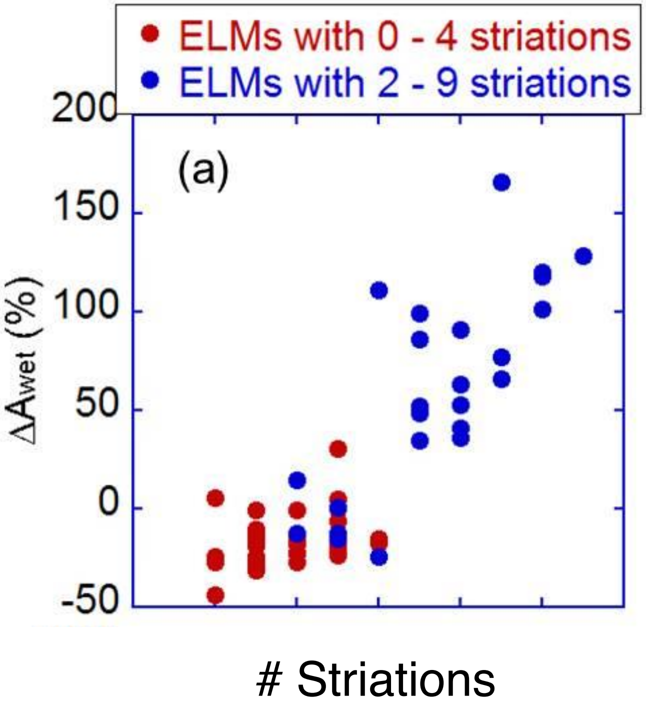
***Heat Flux***

- Heat flux widths controlled by neoclassical processes in collisionless limit, scaling as $1/I_p^{1/2}$
  - Expt scales as $1/I_p^{0.8}$



**T. Gray, S. Ku, C.S. Chang**

- ELMs and macrostability characteristics influence heat deposition
  - Lower n MHD leads to fewer striations, narrower heat flux width

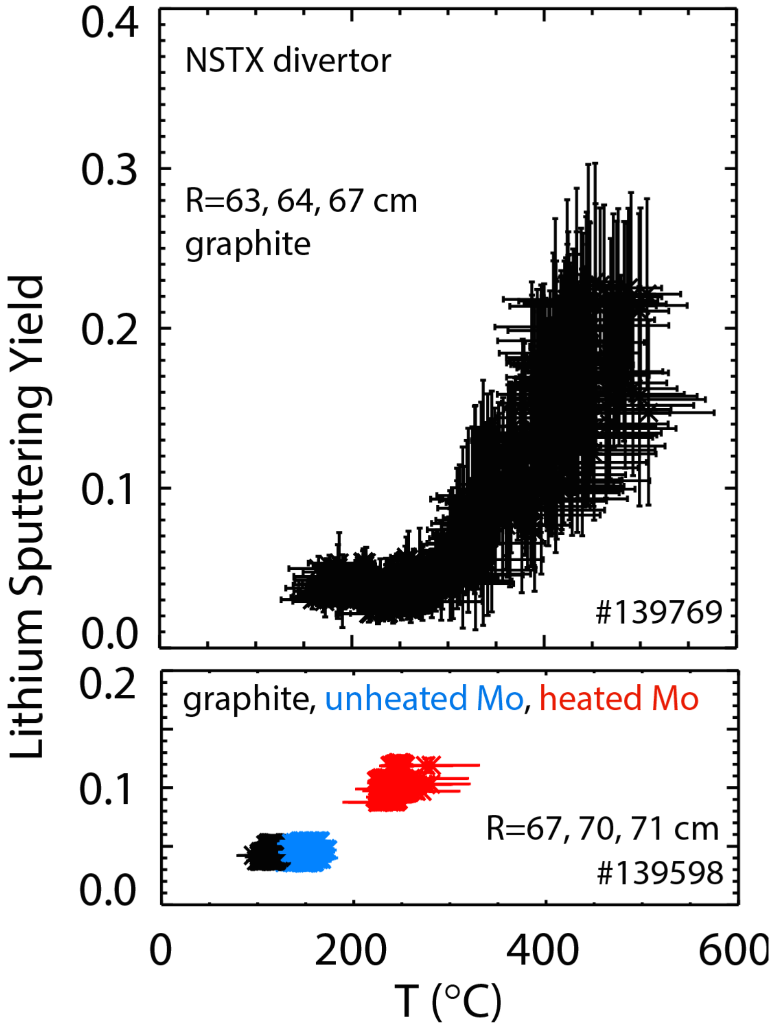


**J.-W. Ahn, EX/P6-53, Thurs. PM**

Assess edge turbulence, MHD properties for ITER for impact on heat flux

# Tokamak and test stand PMI studies support plans for metal substrates to be used on NSTX-U

- In-situ measurements indicate temperature-enhanced Li sputtering for lithiated graphite and lithiated Mo substrates
- Lithium erosion studies conducted up to 1300C on Magnum-PSI plasma device to mimic NSTX-U
  - Lithium evaporated layer
  - Deuterium plasma
- Studies find suppressed lithium emission at high temperatures
  - High D flux results in LiD mixed material
  - Results in reduced Li evap., increased D sputtering
- Lithium trapping forms stable vapor cloud up to 1000C
  - Motivates continuously vapor-shielded divertor target studies
  - Need to re-evaluate acceptable Li PFC temperature limits in NSTX-U



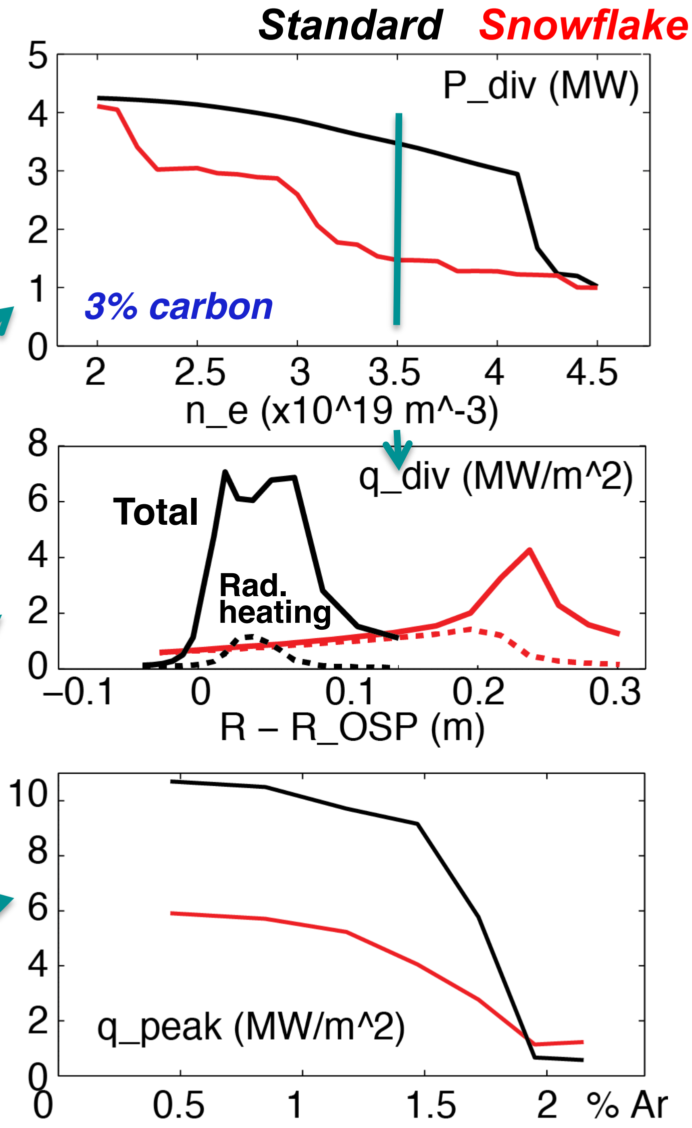
Scotti

# *Modeling supports snowflake and impurity-seeded radiative divertors as heat flux mitigation candidates in NSTX-U*

***Heat flux mitigation***

- Multi-fluid UEDGE code
  - $B_T$=1 T, $I_p$=2 MA, $P_{SOL}$=9 MW
  - NSTX-like transport: $\chi_{i,e}$=2–4 $m^2/s$, D=0.5 $m^2/s$
- **Standard** and **snowflake** divertor configurations achievable using NSTX-U divertor coils
- Radiative snowflake operational densities as low as $n_e/n_{GW}$~0.4 (~$2x10^{19}$ $m^{-3}$)
- Peak heat flux reduced by 50% over standard radiative divertor
- Less impurity seeding (argon or neon) needed in snowflake for lower peak heat flux

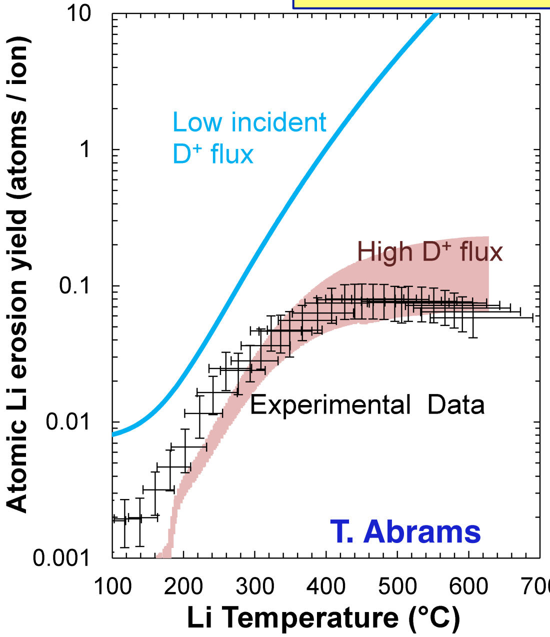
**E. Meier, TH/P6-50, Thurs. PM**

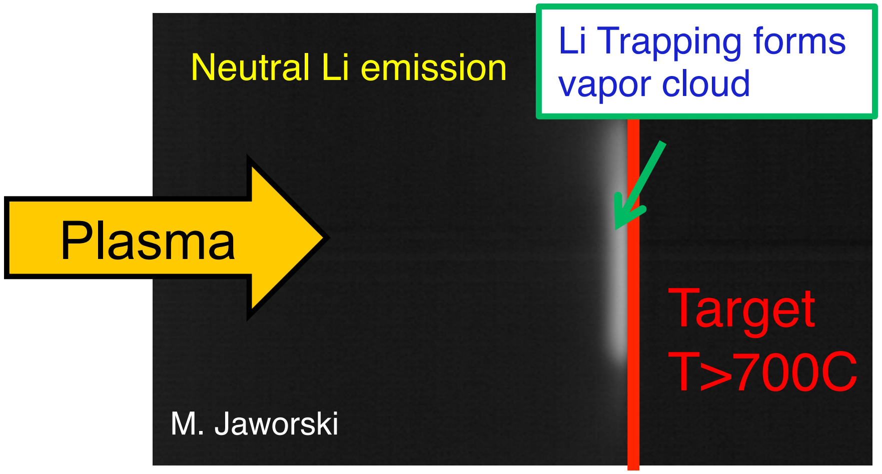


# *Test stand PMI studies support plans for Li-coated metal substrates to be used on NSTX-U*

***Surface Physics***

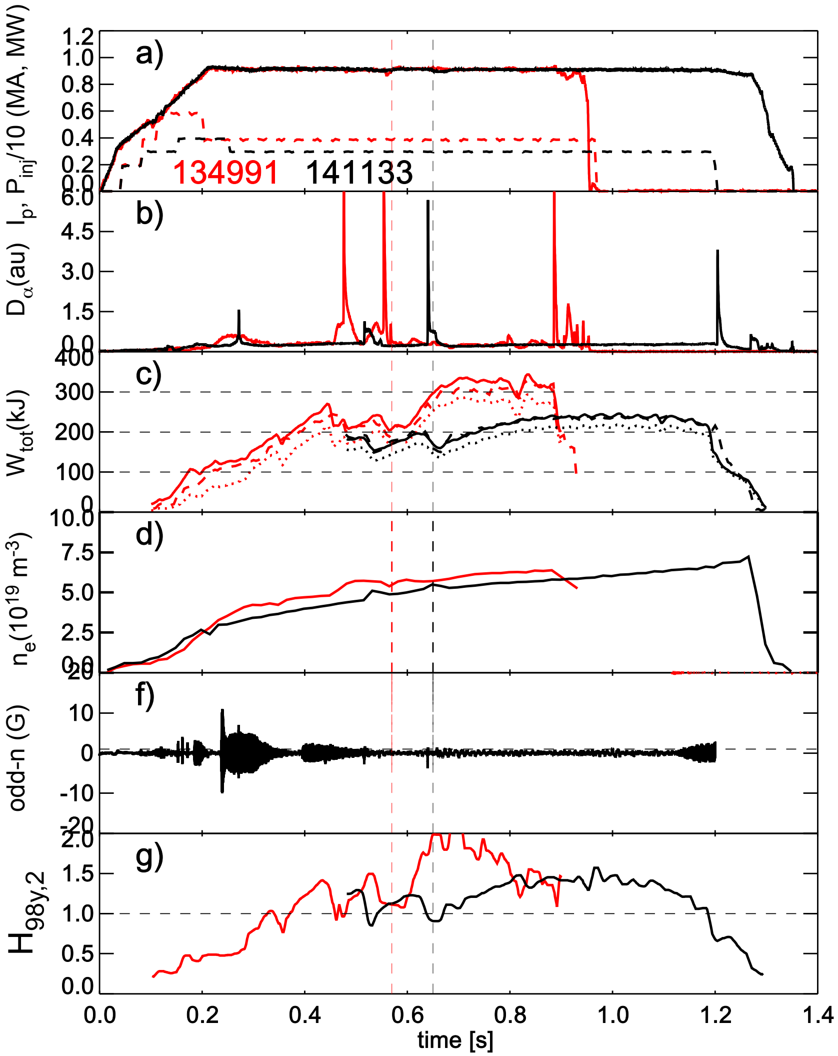
- Lithium erosion studies conducted up to 1300C on Magnum-PSI plasma device to mimic NSTX-U
  - Lithium evaporated layer on Mo
  - Deuterium plasma
- Studies find suppressed lithium emission at high temperatures
  - High D flux results in LiD mixed material
    - Expected in NSTX-U divertor
  - Results in reduced Li evap., increased D sputtering
- Lithium trapping forms stable vapor cloud up to 1000C target temperature
  - Motivates continuously vapor-shielded divertor target studies
  - Need to re-evaluate acceptable Li PFC temperature limits in NSTX-U



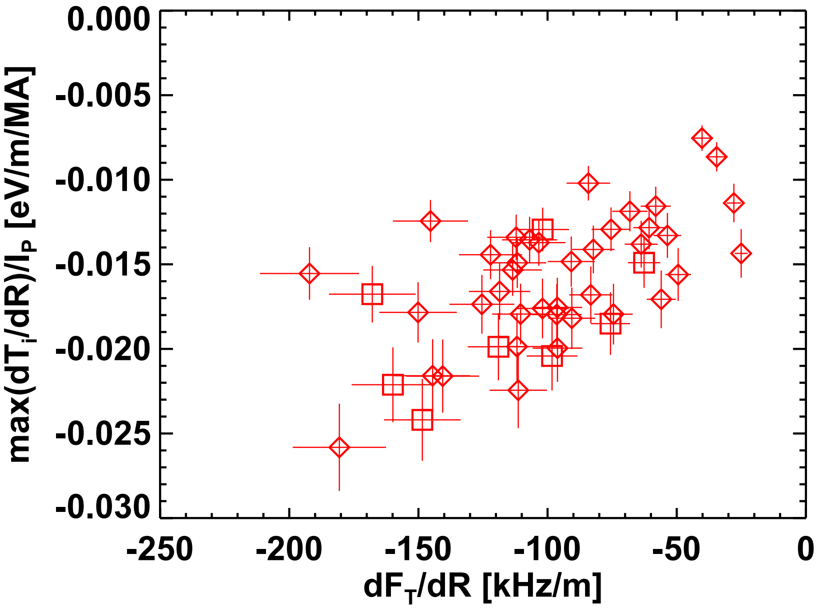


# *Enhanced Pedestal H-mode offers opportunity for high-performance ($H_{98y,2}$~1.5 to 2)*

***High performance***



- Spontaneous trigger from H-phase
- MHD quiescent, confinement at levels necessary for FNSF
- Strong edge velocity shear may provide reliable trigger for mode
  - Through 3D fields?



**S. Gerhardt**