Overview of the Integrated Scenarios Science Group Status and Plans

Stefan Gerhardt, PPPL, SG Leader

R. Raman, U. of Washington, SG Deputy Leader

NSTX-U PAC 37
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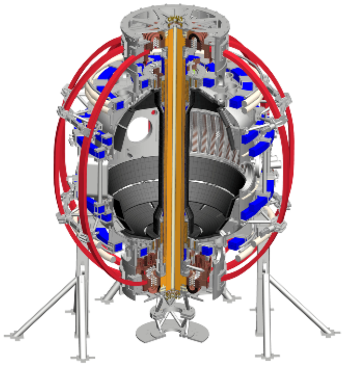

Outline

- Goals & Organization
- Milestones and the Research Forum
- Research Results, Status, and Plans
  - Advanced Scenarios and Control
  - RF Heating and Current Drive
  - Solenoid Free Start-Up
  - Two Multi-TSG Experiments + CC&E (cross cutting and enabling)
- Key Research Enabled by the Proposed Facility Enhancements
- Connection to FES Priorities and Summary

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Recall: NSTX-U Mission Elements
And How the Integrated Scenarios SG Fits In

- Explore unique ST parameter regimes to advance predictive capability – for ITER and Beyond
  - WH&CD: Advanced ICRH modeling and code validation
  - SFSU: Modeling of reconnection during CHI

- Develop Solutions for PMI Challenge
  - ASC: Closed loop control of advanced divertor geometry, divertor radiation

- Advance ST as a possible FNSF/ Pilot Plant
  - HW&CD, SFSU: Non-inductive startup and rampup
  - ASC: Fully non-inductive scenarios, profile control

Integrated Scenarios Leadership Team

- Deputy SG Leader: Roger Raman (U. of Washington)
- Advanced Scenarios and Control
  - TSG Leader: Devon Battaglia (PPPL)
  - Deputy TSG Leader: Stefan Gerhardt (PPPL)
  - Theory/Modeling Rep.: Francesca Poli (PPPL)
  - University Rep.: Egemen Kolemen (Princeton University)
- RF Heating and Current Drive
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  - University Rep. + Theory/Modeling Rep.: Fatima Ebrahimi (Princeton University)

Integrated Scenarios Members are Highly Supportive of Physics Operations

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Past, Present,
and Future
NSTX(-U)
Physics
Operators

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IS SG Supports Many NSTX-U Research Milestones

	FY2016	FY2017	FY2018
Run Weeks: Incremental	**18**	**16** 18	**12** 16
Boundary Science + Particle Control	R16-1 Assess H-mode confinement, pedestal, SOL characteristics at higher B_T, I_P, P_{NBI}	R17-1 Assess scaling, mitigation of steady-state, transient heat-fluxes w/ advanced divertor operation at high power density R17-2 Assess high-Z divertor PFC performance and impact on operating scenarios	R18-1 Assess impurity sources and edge and core impurity transport IR18-1 Investigation of power and momentum balance for high density and impurity fraction divertor operation
Core Science	R16-2 Assess effects of NBI injection on fast-ion f(v) and NBI-CD profile	R17-3 Assess τ_E and local transport and turbulence at low ν^* with full confinement and diagnostic capabilities	IR18-2 Assess role of fast-ion driven instabilities versus micro-turbulence in plasma thermal energy transport Begin ~1 year outage for major facility enhancement(s) sometime during FY2018
Integrated Scenarios	R16-3 Develop physics + operational tools for high-performance: κ, δ, β, EF/RWM	IR17-1 Assess fast-wave SOL losses, core thermal and fast ion interactions at increased field and current R17-4 Develop high-non-inductive fraction NBI H-modes for sustainment and ramp-up	R18-2 Control of current and rotation profiles to improve global stability limits and extend high performance operation R18-3 Assess transient CHI current start-up potential in NSTX-U
FES 3 Facility Joint Research Target (JRT)	C-Mod leads JRT Assess disruption mitigation, initial tests of real-time warning, prediction	DIII-D leads JRT Examine effect of configuration on operating space for dissipative divertors	NSTX-U leads JRT TBD

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The Research Forum Determined the Run Plan

- Run time allocation set to large extent by the milestones
- Significantly more days requested than allocated.
- Much discussion produced a tight research plan.
- SG structure was very valuable in setting these priorities.

TSG	Requested Days	Allocated Days
ASC	33	8
SFSU	14.5	3.5
WH&CD	9	3.5

Topic	Total Allocation
High-Beta Scenario Development	3.5
Low Current Ramp-Up	2 (1 WH&CD + 0.5 SFSU + 0.5 ASC)
Control	4
CHI	2.5
HHFW in the Flat-Top	3
Total	15
ASC+RF+SFSU	8+3.5+3.5 = 15

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ASC Research Thrusts Focus on Plasma Control and Scenario Development

#1– Scenario Develop for NSTX-U and Next-Steps

#2 - Axisymmetric Control Development

#3 - Disruption Avoidance By Controlled Discharge Shutdown

#4 - Understand Scenario Physics for Next Step Devices

Defined in the 5 Year Research Plan

For thrust sub-elements, see:

http://nstx-u.pppl.gov/program/science-groups/integrated-scenarios/advanced-scenarios-and-control

Significant Modeling Supports the ASC Research Program

- Fully relaxed non-inductive operating points have been explored with free-boundary TRANSP calculations

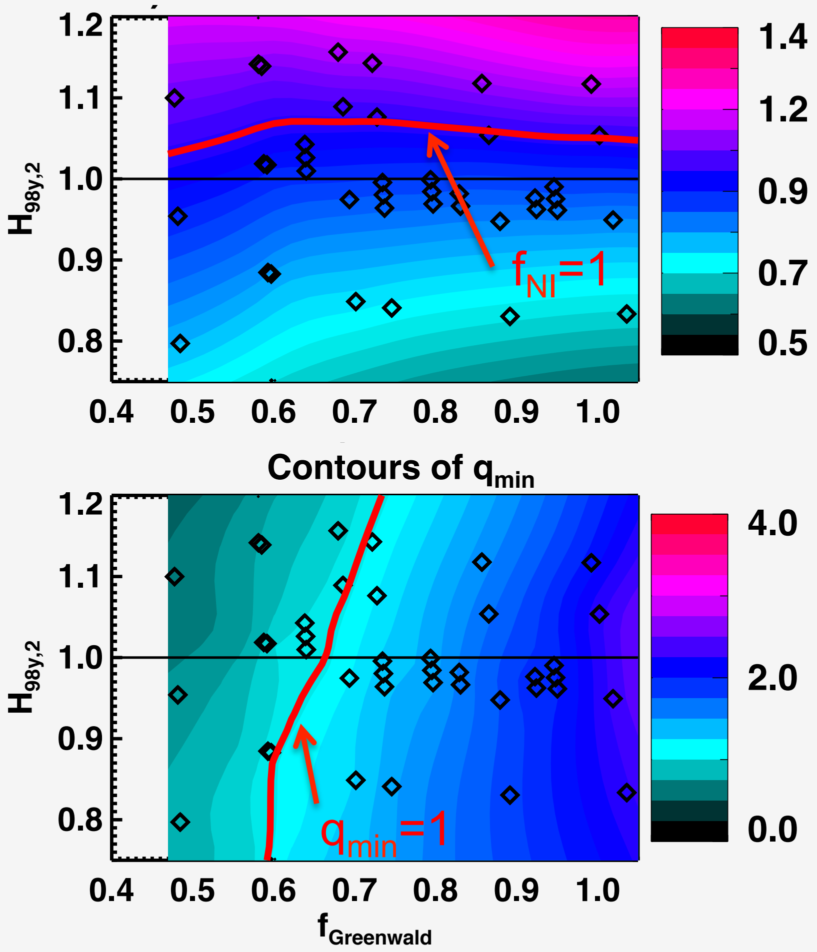
R16-3

Research Timeline for 100% Non-Inductive Scenarios

Operation Year	B_T [T]	Current Goal [kA]	Duration Goal
2016	<=0.75	~600-800	A few τ_E
2017	0.75-1.0	~600-1000	1-2 τ_R
Out-Years	1	800-1300	Up to 4.5 s at lower I_P

- These scenarios, obtained at first with an inductive ramp-up, will provide a target for non-inductive ramp-up studies
- ***See talk by F. Poli and M. Boyer for more recent modeling results.***

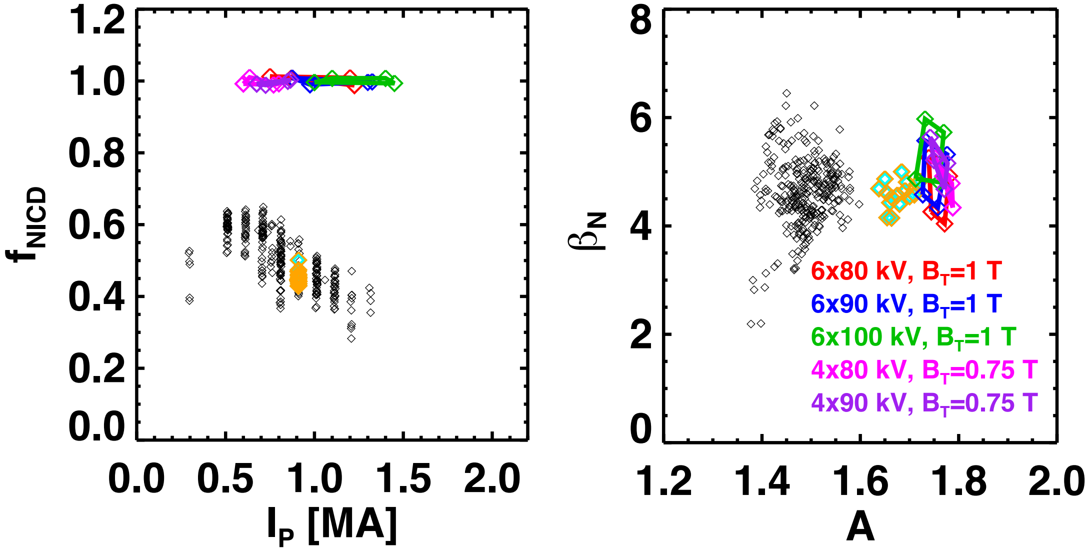
B_T=1.0 T, I_P=1 MA, P_{inj}=12.6 MW



S.P. Gerhardt, et al, Nuclear Fusion 52 083020 (2012)

Scenario Studies Will Focus on 100% NI and High-Current Long-Pulse

- *Non-Inductive Scenario Development* (XP-1507, Gerhardt, et al.)
  - **Goal:** Develop 100% non-inductive scenarios with I_P~ 600 kA.
  - **Key Issues:** Thermal transport, vertical stability at high-κ, n=1 stability
  - **Modeling/Analysis:** TRANSP



S.P. Gerhardt, et al, Nuclear Fusion 52 083020 (2012)

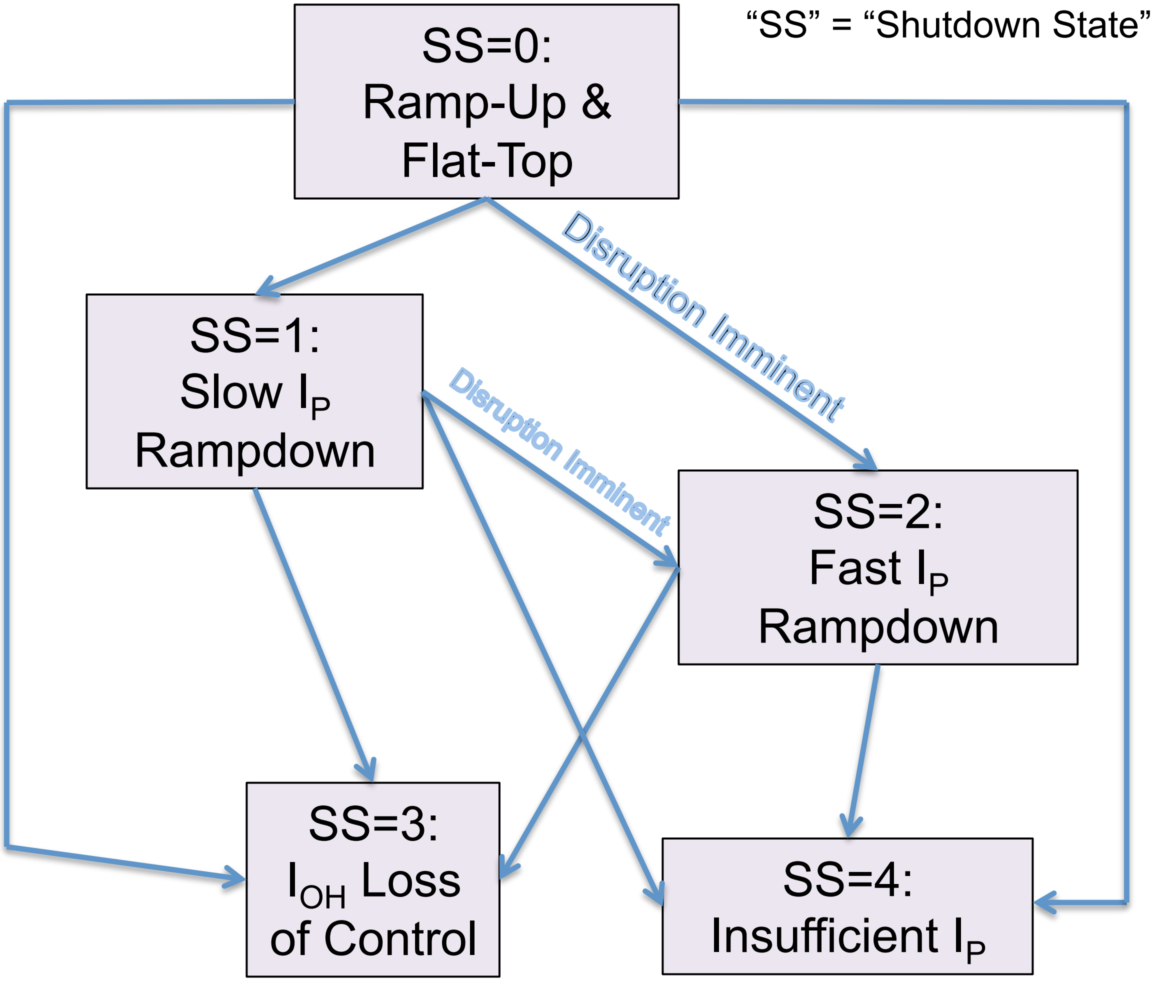
- *Long Pulse Development* (XP-1554, Battaglia et al.)
  - **Goal:** Utilize 80 kV beams, optimized OH waveform, to achieve longest possible pulse
  - **Key Issues:** fuelling optimization, preventing q_0 evolving too far, impurity control.
  - **Modeling/Analysis:** TRANSP

- *Sustained Reverser Shear* (XP-1575 H. Yuh, et al.)
  - **Goal:** Utilize off-axis NBI to sustain reversed shear
  - **Key Issues:** MHD leading to current redistribution, too-high pressure peaking.
  - **Modeling/Analysis:** TRANSP, GS2, other microstability codes pending results

These support milestones R16-2, R17-4, R18-2, & ASC thrusts #1 and #4

NSTX-U Experiments Are Already Using a Significantly Expanded Plasma Shutdown Scheme

- **NSTX PCS**: No means of detecting a disruption, or ramping down the plasma current based on events.
- **NSTX-U PCS**: State machine orchestrates the shutdown.
- Disruptions detected by:
  - Too large I_P error
  - Too large $Z_P(dZ_P/dt)$
  - Large locked n=1 modes
- Presently using "Fast I_P Rampdown" on every shot
  - waiting to use "Slow-I_P Rampdown".
  - Have not yet turned on n=1 disruption triggering.



"SS" = "Shutdown State"

SS=0: Ramp-Up & Flat-Top

SS=1: Slow I_P Rampdown

SS=2: Fast I_P Rampdown

SS=3: I_{OH} Loss of Control

SS=4: Insufficient I_P

Disruption Imminent

Disruption Imminent

Diagram of the State Machine Presently Implemented in PCS

Supports ASC thrust #3

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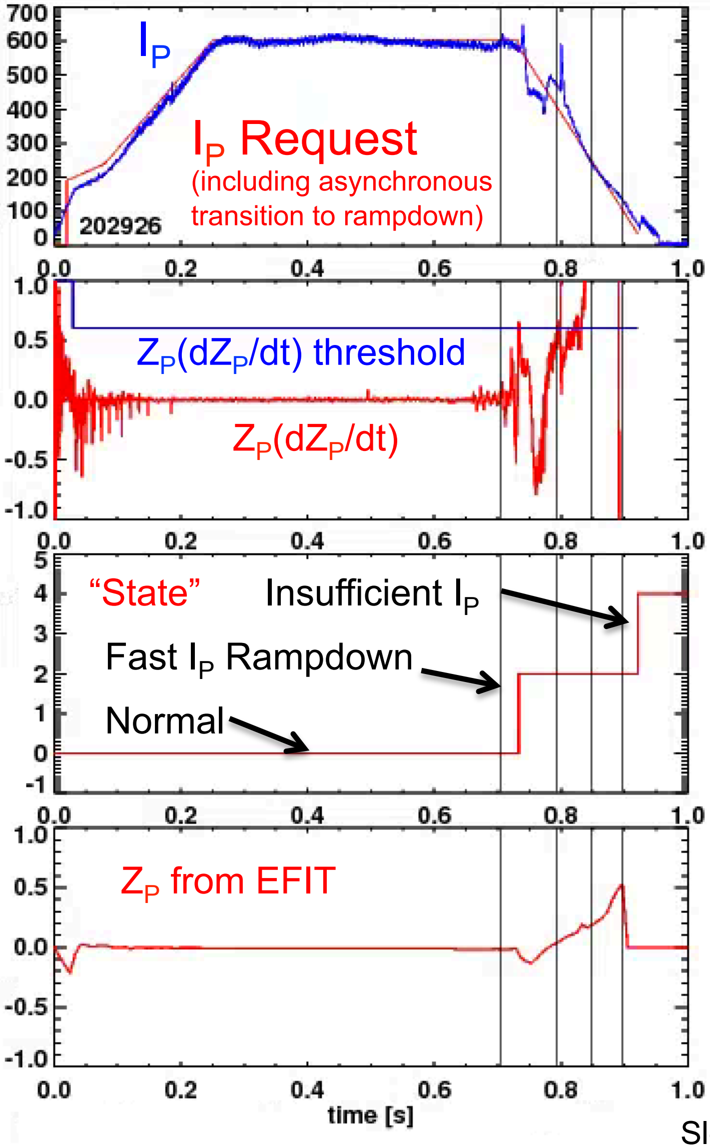
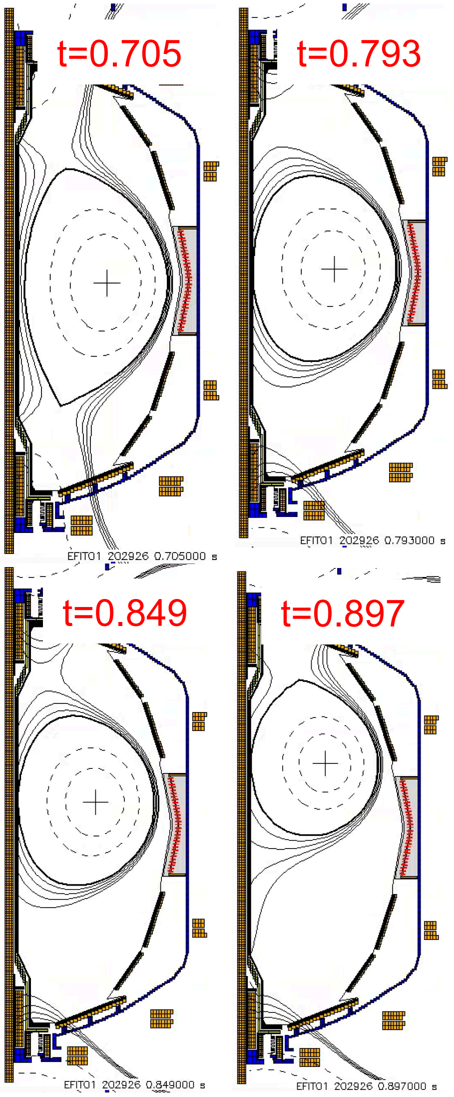
Example: This shot would have been a strong VDE in NSTX

Supports ASC thrust #3

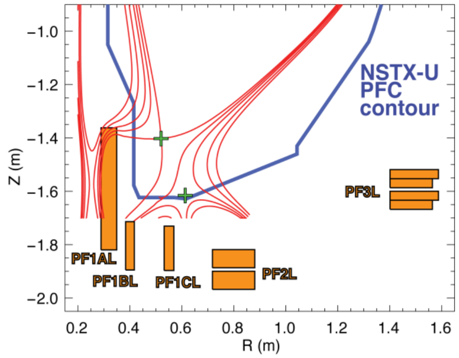




Slow Drift Up, But No VDE or Disruption

Control Experiments Support NSTX-U Program and Next Step Devices

- *β_N and l_i Control Study* (XP-1509, Boyer et al)
  - **Goal:** Demonstrate closed loop combined control of β_N and l_i.
  - **Method:** Realtime measurements with rtEFIT, control via beam, shape, maybe n=3 actuation.
  - **Key Issues**: rtEFIT quality, beam modulation effects on plasma, limited range of l_i actuation
- *Current Profile Controllability Study* (XP-1532, Boyer et al, 0.75 days)
  - **Goal:** Demonstrate closed loop control of the current profile
  - **Method:** Dedicated modulation shots for system identification type purposes, attempts at closed loop control if technically possible.
  - **Key Issues**: rtMSE availability, beam modulation effects on plasma
- *Rotation Control* [XP-1564, I. Goumiri, et al]
  - **Goal:** Demonstrate closed loop control of the rotation profile and β_N.
  - **Method:** Beam for torque and heating, NTV for breaking. State-Space control algorithm
  - **Key Issues**: rtV_ϕ availability, beam modulation effects on plasma
- *Snowflake Divertor Control* [XP-1508, Kolemen and Vail]
  - **Goal:** Demonstrate control of the unique dual X-point geometry.
  - **Method:** New PCS algorithm with dual X-point tracking based on rtEFIT flux map, PID mechanism for adjusting divertor coil currents.
  - **Key Issues**: rtEFIT quality, coil forces during control oscillations, interaction with other shape controllers



These support milestone R18-2, & ASC thrusts 1, 2, and 4

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Wave H&CD TSG Thrusts Dedicated to HHFW & EC Applications and Code Validation

- #1 Develop FW/EC heating for fully NI plasma current start-up and ramp-up
  - Joint XP with Solenoid-Free Start-Up TSG…will describe dedicated experiment later in the talk.

- #2 Validate state-of-the-art RF codes for NSTX-U and predict RF performance in future burning plasma devices.

For thrust sub-elements, see:
http://nstx-u.pppl.gov/program/science-groups/integrated-scenarios/wave-heating-and-current-drive

Modeling Is Confirming The Importance of RH Cutoff in Determining SOL Losses

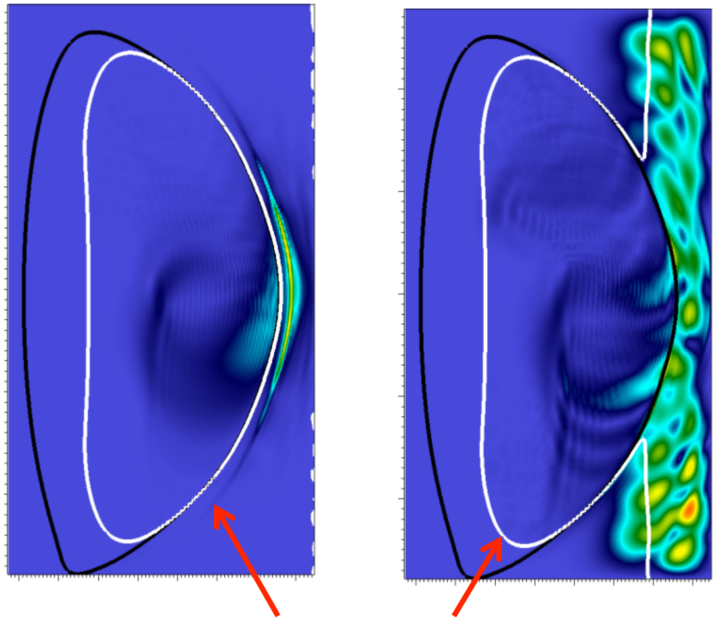
- NSTX showed a large loss of RF power in the SOL
- Modeling shows large RF field amplitude in SOL under certain conditions
  - Seen in full-wave code AORSA
    - N. Bertelli *et al.*, *Nucl. Fusion* **54** (2014) 083004.
    - N. Bertelli *et al.*, *Nucl. Fusion* **56** (2016) 016019.
  - Also seen in cylindrical cold-plasma model
    - Wave power (axial Poynting flux) confined to periphery, only gradually penetrating the core
    - R. J. Perkins *et al.*, 41th EPS Conference on Plasma Physics P-1.011.
- RF fields in divertor cause RF sheath; potentially large enough to account for SOL losses
  - Increased sheath voltage and electron current predicted to substantially increase heat flux to tiles
    - R. J. Perkins *et al.*, *Phys. Plasma* **22** (2015) 042506.

$k_\phi = 13\ \mathrm{m}^{-1}$

Heating phasing

Lower SOL density ($n_{ant} = 1\mathrm{x}10^{12}\ \mathrm{cm}^{-3}$)

Higher SOL density ($n_{ant} = 2\mathrm{x}10^{12}\ \mathrm{cm}^{-3}$)



Cutoff layer

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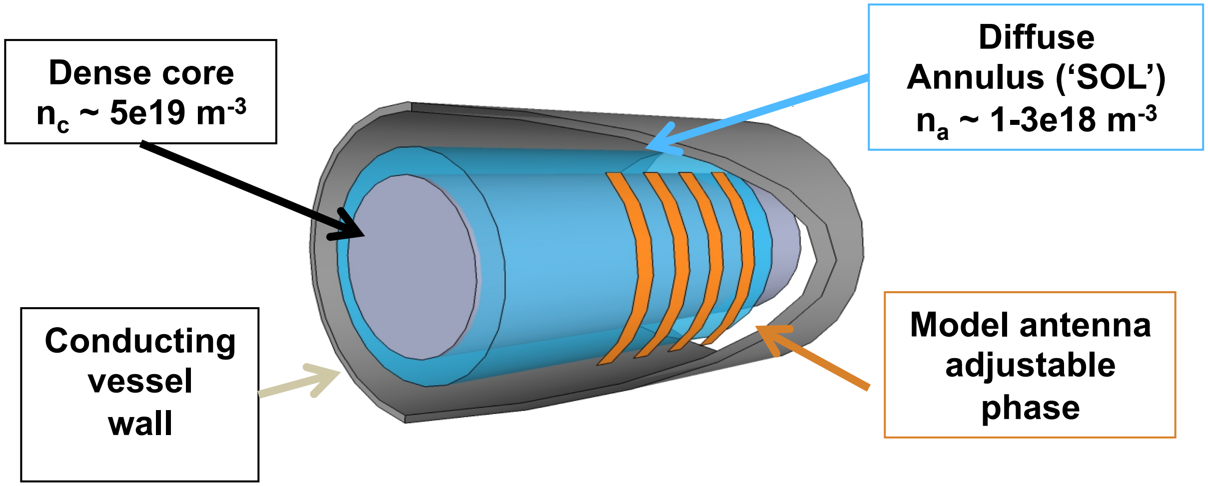


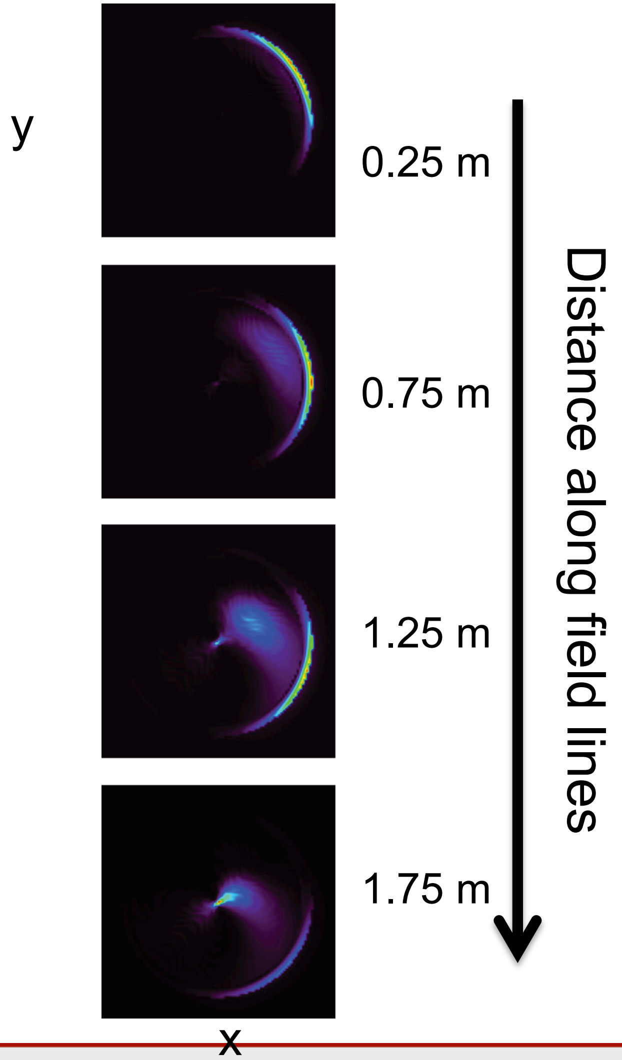
Dense core
n_c ~ 5e19 m^{-3}

Diffuse Annulus ('SOL')
n_a ~ 1-3e18 m^{-3}

Conducting vessel wall

Model antenna adjustable phase

Axial poynting flux only gradually penetrates core



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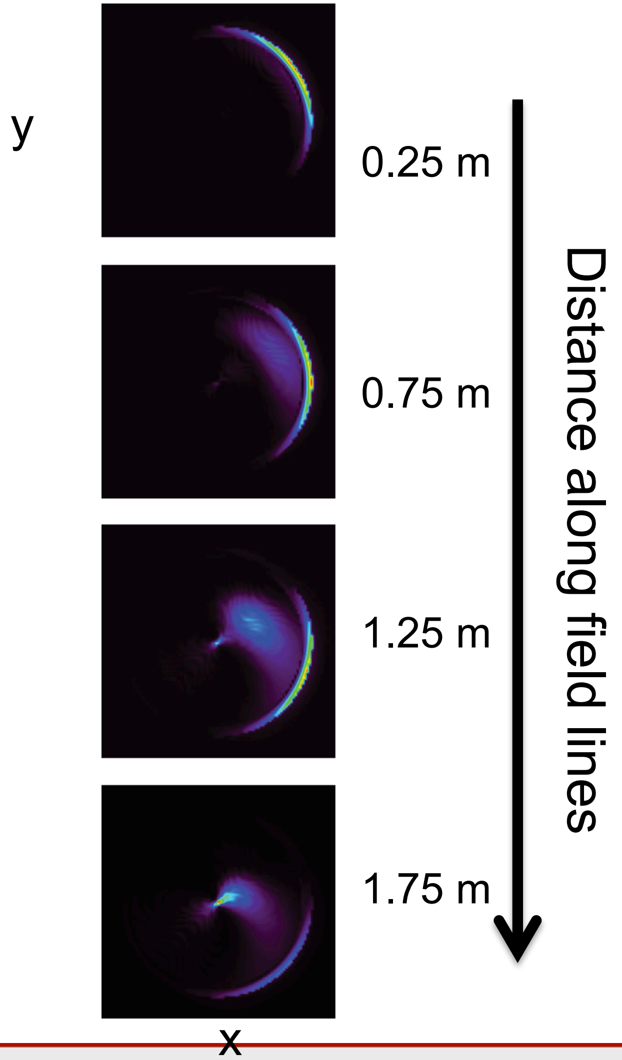
Axial poynting flux only gradually penetrates core

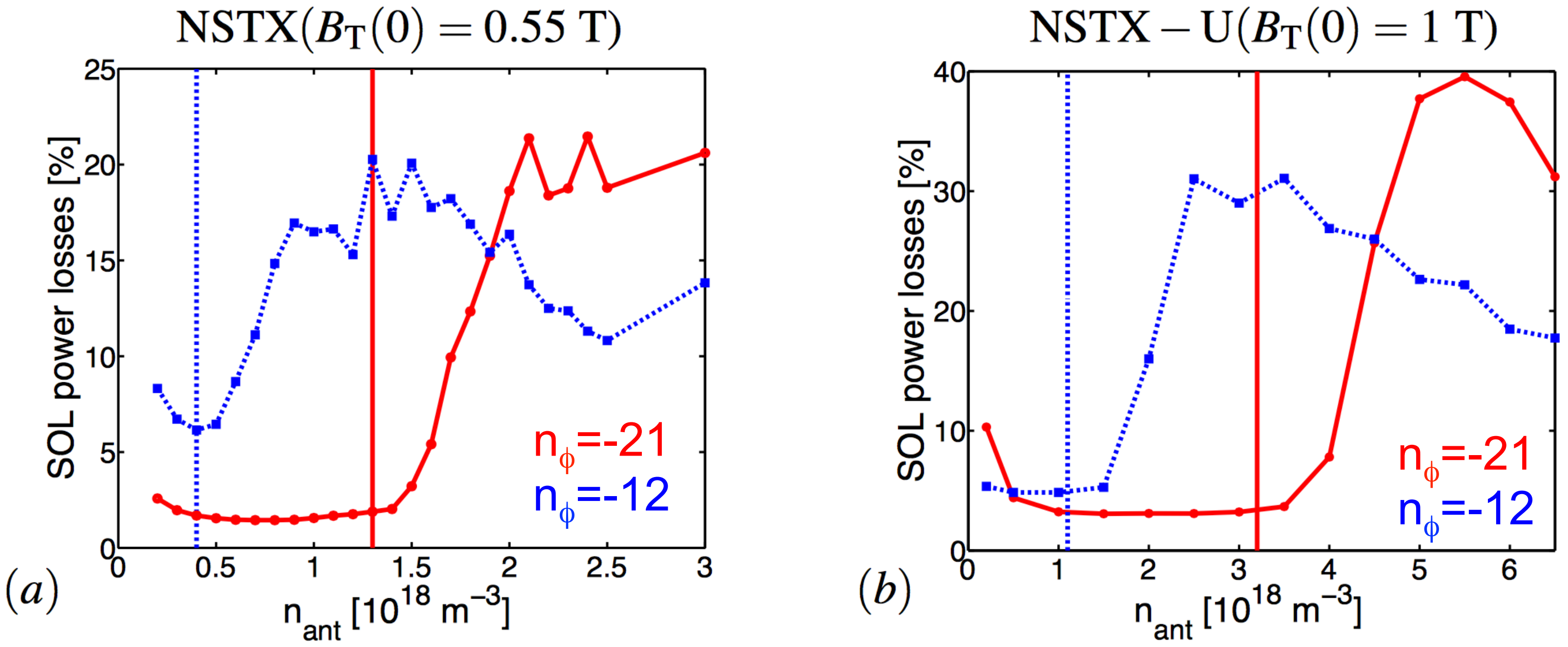


NSTX-U Prospect: Higher Toroidal Field May Reduce These SoL Losses

- Right-hand cutoff density proportional to B:
  - – Larger cutoff density may reduce losses.

$$n_{\mathrm{e,FWcut-off}} \propto \frac{k_{\parallel}^{2} B}{\omega}$$

- AORSA modeling confirms this expectation.
  - – Using NSTX discharge data and NSTX-U TRANSP scenarios.

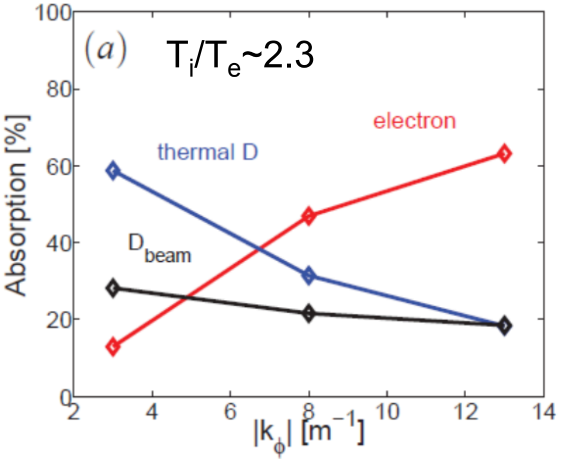


NSTX-U Prospect: Wide Range of Possible Partitions for HHFW Power Absorption

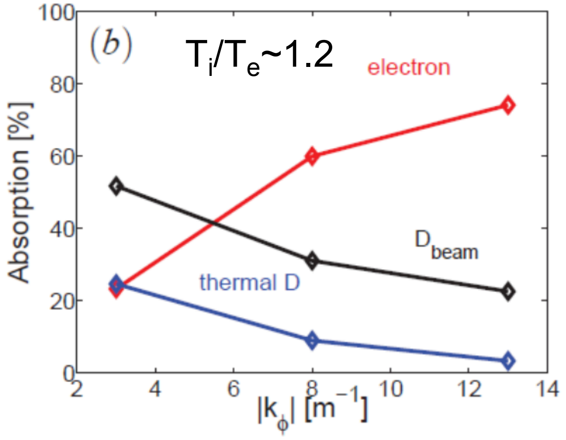
- Increased B_T may increase the thermal and fast ion absorption
  - Decreased ion cyclotron harmonic number, increased cyclotron absorption

- AORSA predictions for NSTX-U :
  - greater deuterium heating when $T_i > T_e$
  - Ion heating increases and electron heating decreases as k_φ decreases

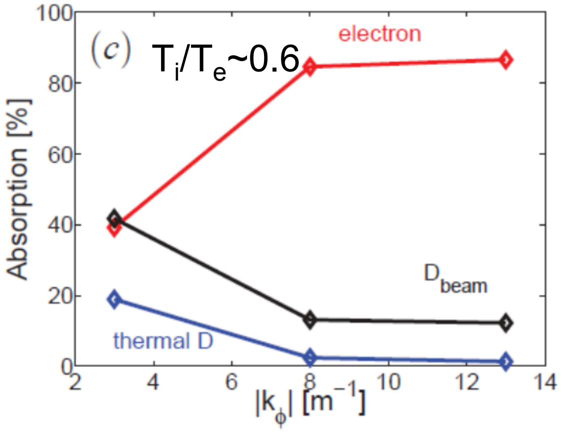
Ti = 2.86 keV, Te = 1.22 keV



Ti = 1.43 keV, Te = 1.22 keV



Ti = 1.43 keV, Te = 2.44 keV

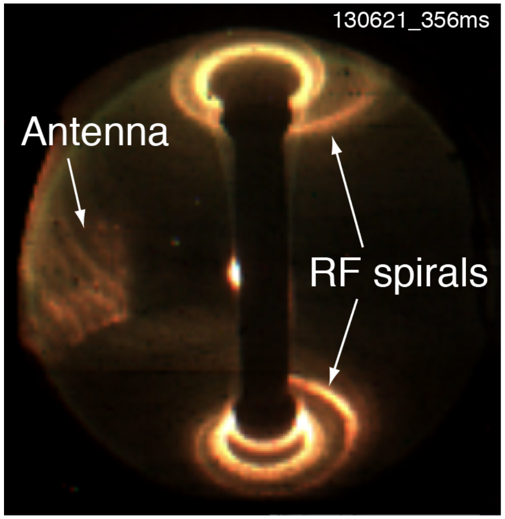


N. Bertelli, et al AIP Conference Proceedings 2014

- This work will benefit from including non-Maxwellian effects in TORIC v.5
  - Bertelli et al. APS 2015

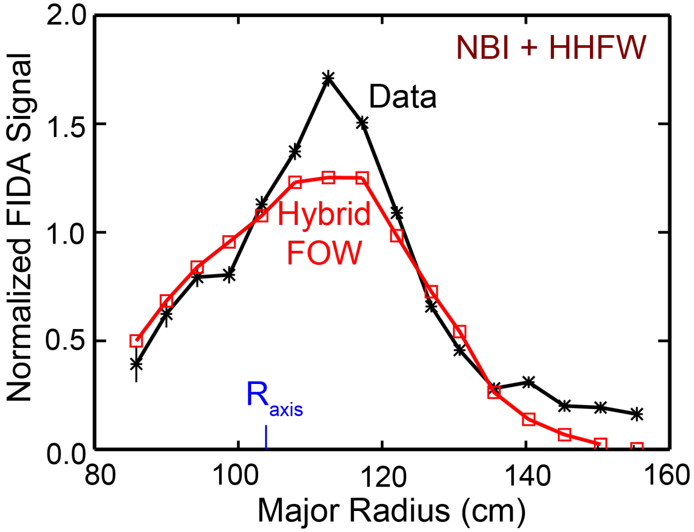
SoL Propagation and Core Absorption Physics Will be Addressed in Two XPs

- *Characterize SoL Losses of HHFW Power in H-Mode* (XP-1510, Perkins, et al.)
  - Goal: Assess scaling of SoL losses as a function of edge parameters, B_T
  - Diagnostics:
    - fraction of HHFW power lost & spiral intensity along length of spiral
    - RF voltage at the most intense portion of the spiral,
    - SOL density profiles in front of antenna.
  - – Modeling/Analysis: TRANSP, AORSA



R. Harvey et al., 56th APS-DPP 2014

- *HHFW Absorption in NB Heated Plasmas* (XP-1533, Bertelli, et al)
  - Goal: Characterize RF absorption as a function of RF phase, toroidal field
  - Analysis/Modeling
    - GENRAY/CQL3D, TORIC, AORSA, AORSA +CQL3D, ORBIT-RF
    - Continue validation of CQL3D with fast ion diagnostic (FIDA) data.



These support milestone IR17-2 , WH&CD Thrusts #2

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SFSU Research Thrusts Are Synergistic with Other IS TSGs, Address Key Issues for a low-A FNSF

#1 – Establish and Extend Solenoid-Free Plasma Start-up

#2 - Test NBI Current Ramp-Up

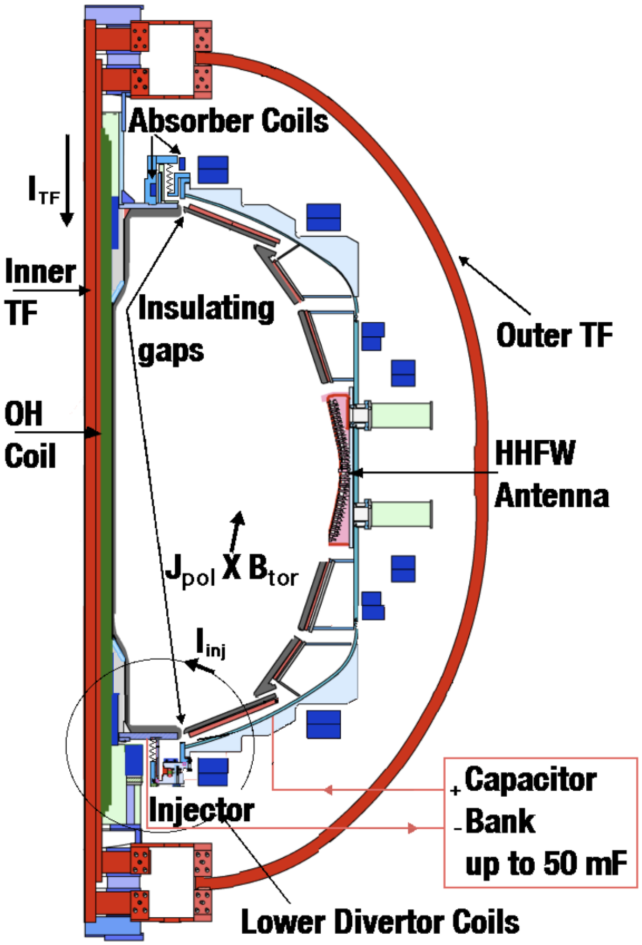
#3 - Ramp-up CHI plasma discharges using ECH, HHFW and NBI and test plasma gun start-up

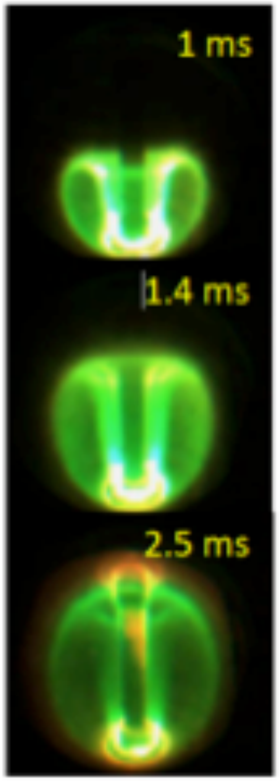
For thrust sub-elements, see:

http://nstx-u.pppl.gov/program/science-groups/integrated-scenarios/solenoid-free-start-up-and-ramp-up

NSTX & NSTX-U Design Incorporates Features for Coaxial Helicity Injection

CHI in NSTX/NSTX-U

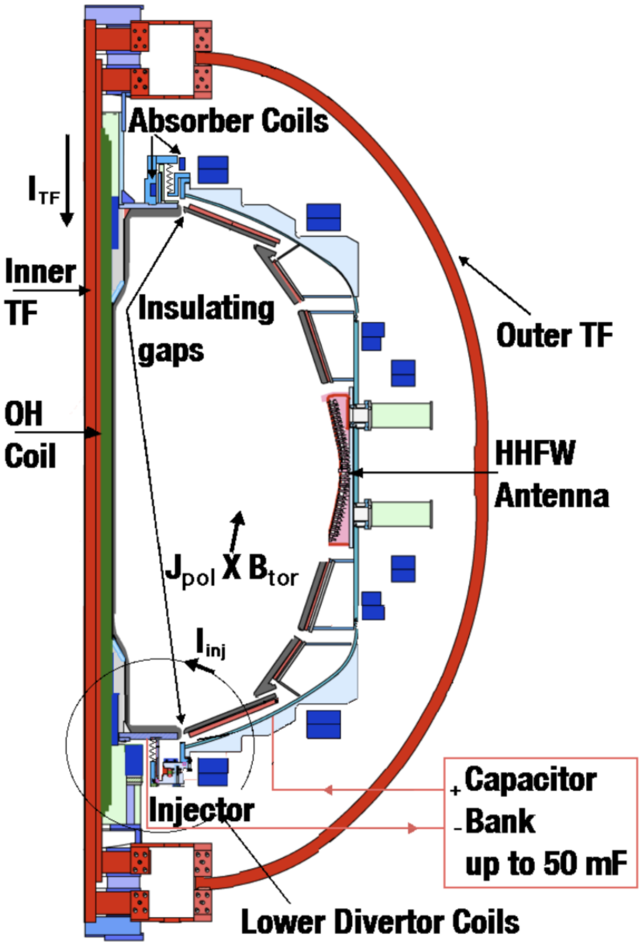


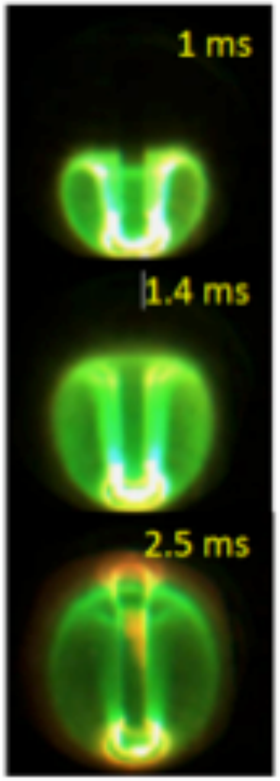


- Inner and outer vacuum vessels
- Injector and absorber regions
- Injector coils & TF
- Capacitor bank
  - 2kV, 50 mF
- JxB force drives the plasma into the main chamber.
- Closed surfaces form when the injector (bank) current dies away or is crowbarred.

NSTX-U Upgrades that Facilitate CHI Start-up

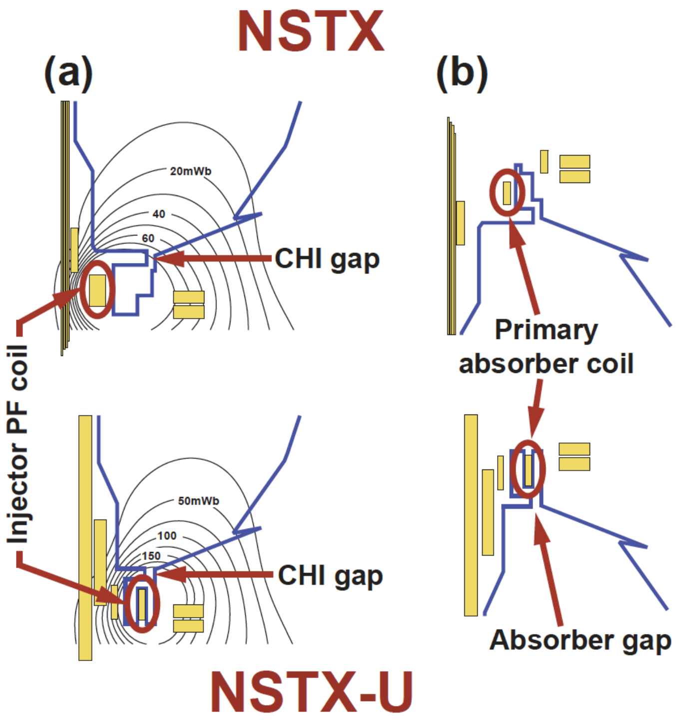
CHI in NSTX/NSTX-U





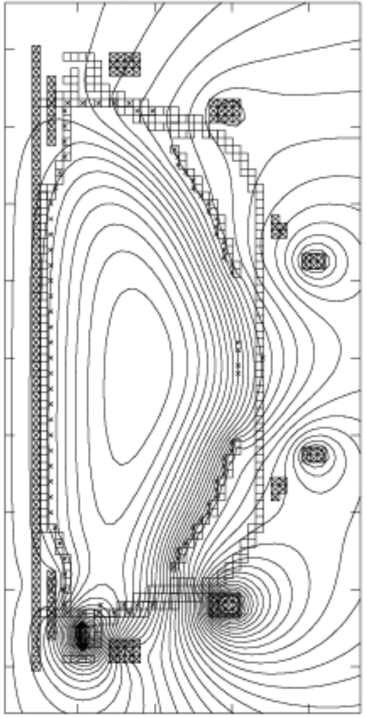
NSTX-U Machine Enhancements for CHI

- > 2.5 x Injector Flux (proportional to I_p)
- About 2 x higher toroidal field (reduces injector current requirements)

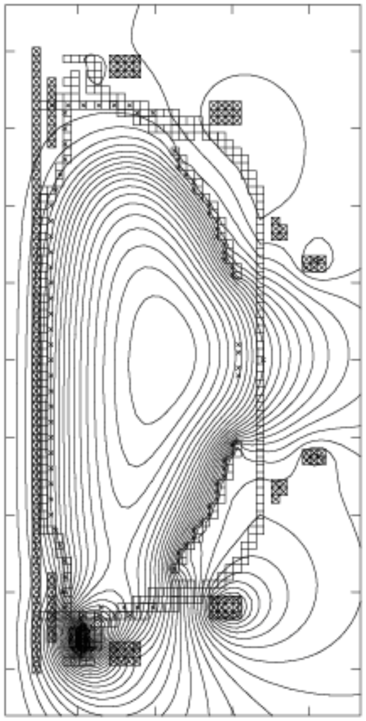


TSC Simulations in the NSTX-U Geometry support up to 400kA Current Start-up Capability in NSTX-U

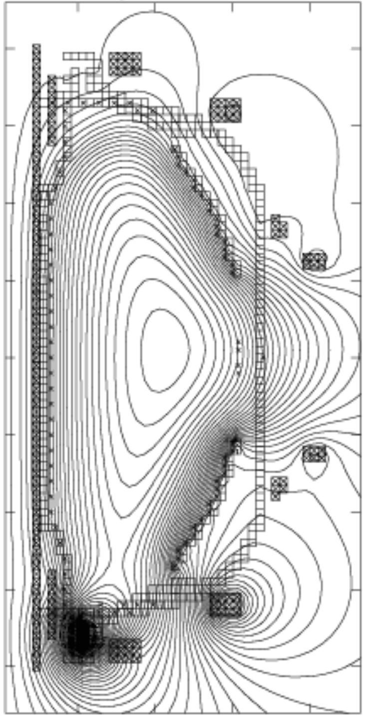
Poloidal Flux at 15 ms
2 kA in Injector Coil



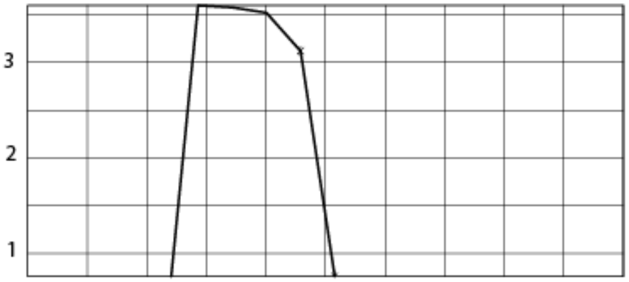
4 kA in injector Coil



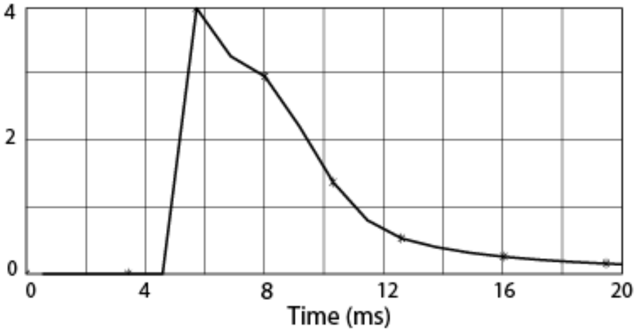
8 kA in Injector Coil



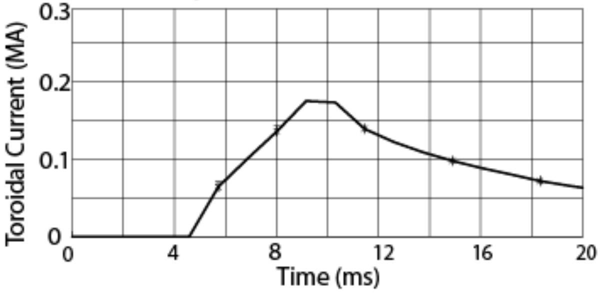
Representative Injector Volatge Waveform (Arbitrary Units)



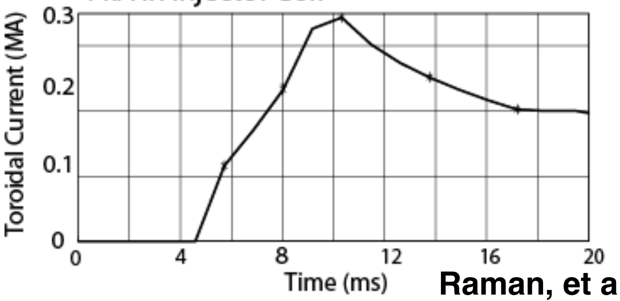
Representative Injector Current Waveform (Arbitrary Units)



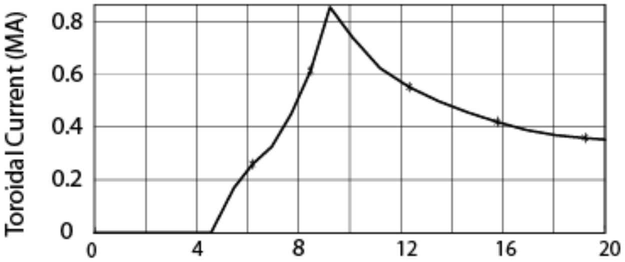
2 kA in Injector Coil



4 kA in injector Coil

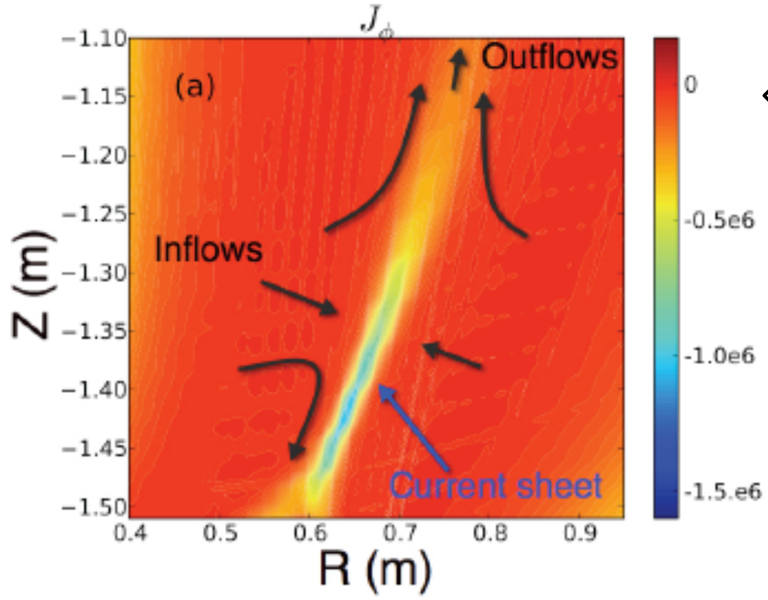


8 kA in Injector Coil

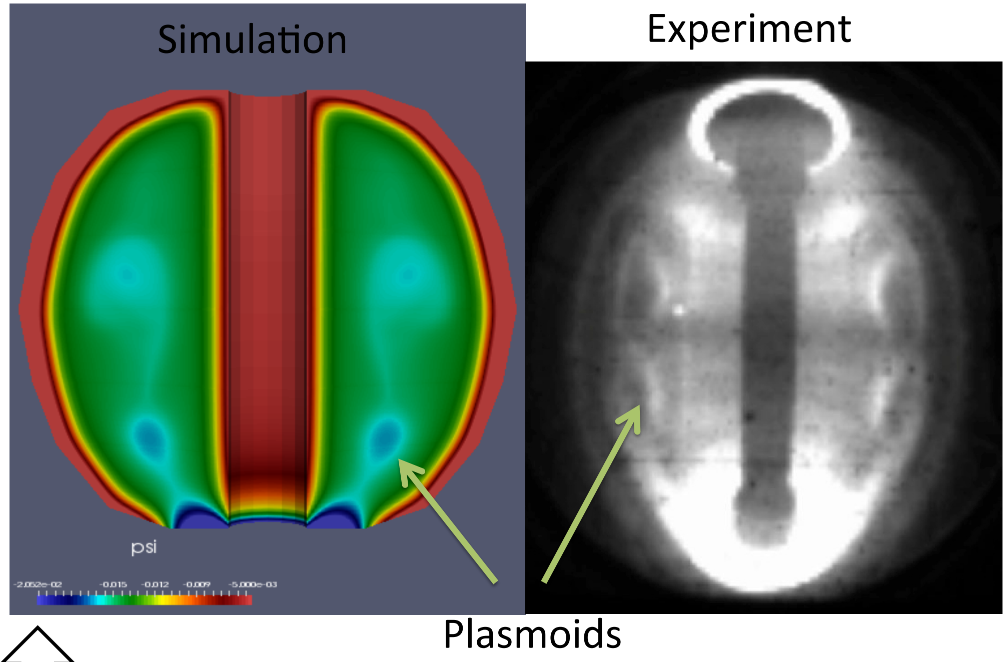


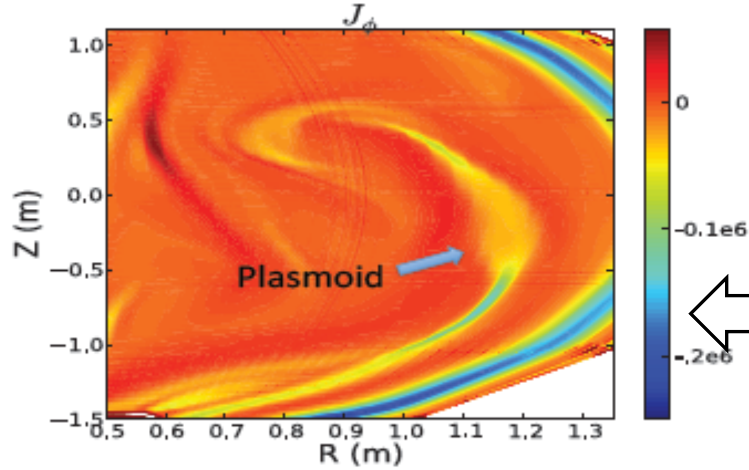
Raman, et al., IEEE Trans. Plasma Sci. (2014)

At High Lundquist Number, Plasmoid Mediated Reconnection Identified as Assisting in Flux Closure



- **Sweet Parker (S-P) reconnection in the injector region at low Lundquist number**





- At high Lundquist number the S-P current sheet is plasmoid unstable
- Plasmoids seen in NSTX CHI

NIMROD Simulations **F. Ebrahimi, et al., PRL (2015)**

Two FY-16 Experiments Will Exploit the New Upgrade Capabilities, Target Coupling to Induction

- *Transient CHI Startup in NSTX-U* (XP-1432. R. Raman).
  - **Motivation**: New geometry of CHI gap, PF coils, PFCs mandate experiments to establish transient CHI.
  - **Goal**: Establish reliable flux closure in the NSTX-U geometry.
  - **Method**: Start at NSTX-level fields and currents, then increase B_T and injector flux once reliable discharges have been formed.
  - **Key Issues**: Breakdown with new narrow gap, tailoring the flux-footprint with new coils, electrode conditioning.
  - **Modeling/Analysis**: NIMROD + Utilize the extensive suite of cameras to assess plasmoid formation and effects.
- *Inductive Flux Savings of Inductively-driven Transient CHI Plasmas* (XP-1535, B. Nelson)
  - **Motivation**: Coupling transient CHI to induction is a step towards demonstrating compatibility of CHI with subsequent ramp-up schemes.
  - **Goal**: Establish transient CHI discharge and ramp it up with induction
  - **Key Issues**: Persistent enough CHI plasma for good coupling, hand-off to position and I_P control.

These support milestone R18-3 , SFSU goal #1

Outline

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- Key Research Enabled by the Proposed Facility Enhancements
- Connection to FES priorities and Summary

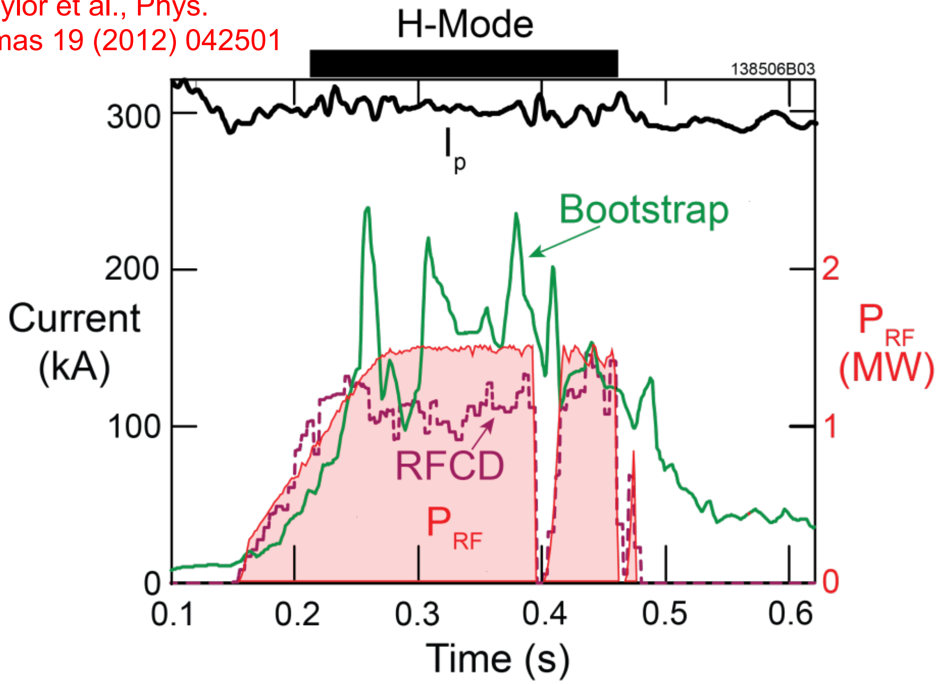
See talk by F. Poli for modeling/theory motivation for these two joint XPs

Effective Heating of Low-I_P Plasmas Will Be Further Developed

Low Plasma Current, Fully Non-Inductive, HHFW H-Mode Plasmas
(XP-1534, Taylor)

300 kA inductive NSTX target heated to 3keV using ~1 MW HHFW

G. Taylor et al., Phys. Plasmas 19 (2012) 042501



See talk by Poli for how this type of heating fits into the full ramp-up scheme

Motivation:

- Critical to heat low-I_P plasmas to the levels needed for NBI CD.
- Very efficient heating of a low current plasma was demonstrated on NSTX
  - Bootstrap current dominant when ITB forms

Goal

- Re-establish ~300 kA, high-f_{NI}, HHFW heated scenarios in NSTX-U
- Attempt overdrive.

Key Issues:

- Shape control and ELMs impact on the RF coupling.
- ITB formation

Analysis/Modeling

- TRANSP, TRANSP+TORIC
- AORSA

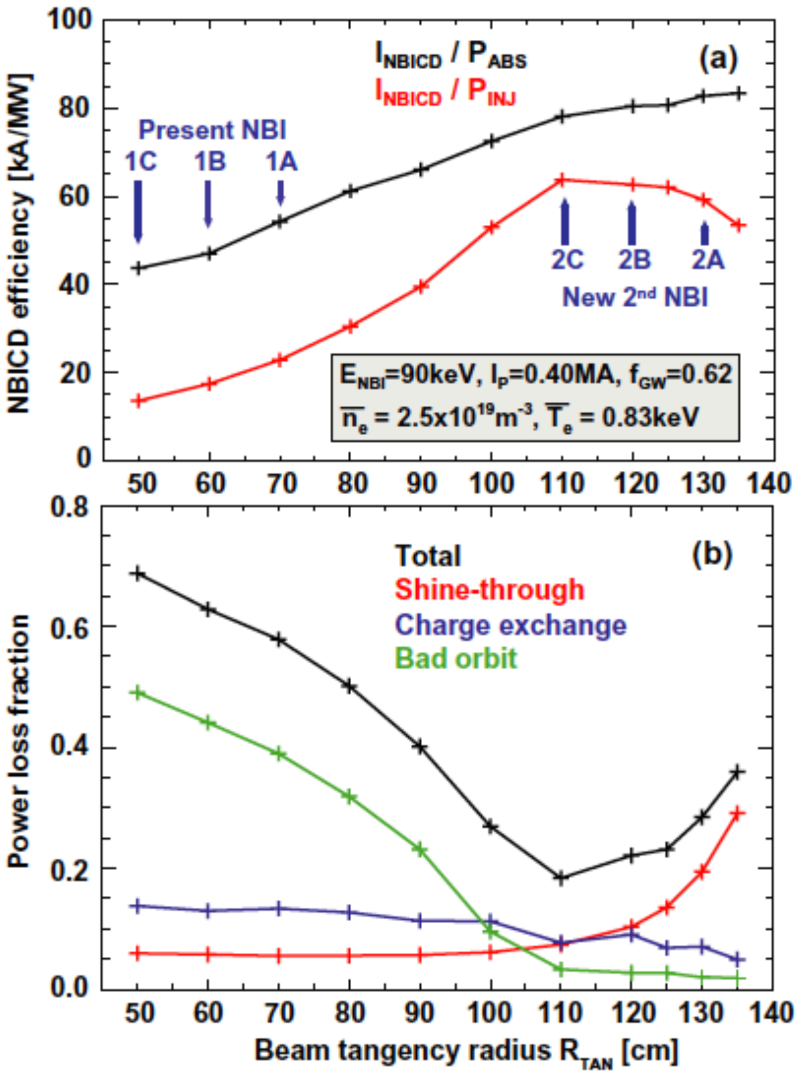
These support SFSU thrust #3, WH&CD thrusts #1 & 2

Ability of Large Tangency Radius Beam to Couple Power/Current at Low Current Will Be Assessed

NB Ramp-Up Studies (XP-1567, F. Poli)

- Motivation
  - Calculations predict high current drive efficiency at low I_P for large tangency radius sources
- Goal:
  - Assess lowest I_P (& therefor n_e, T_e) for NB coupling as a function of tangency radius
- Key Issues:
  - Shine through losses vs. bad orbit losses
  - FI pressure peaking
  - Confinement & plasma control at low I_P
- Method
  - High B_T, $300<I_P<500$ kA, 80-90 kV beams.
  - FI diagnostics and comparison to TRANSP predictions
  - HHFW may be used to increase T_e
- Analysis/Modeling
  - TRANSP/NUBEAM

These support milestone SFSU thrust #2, ASC thrust #1



J. Menard, et al., Nuclear Fusion **42**, 083015 (2012)

IS SG Also Supports Cross-Cutting and Enabling XPs & XMPs

- *Optimization of the Vertical Control Algorithm* (XP-1501, Boyer)
  - **Goal:** Optimize control observer parameters, feedback gains, and then push to higher elongation.
  - **Analysis**: TOKSYS, TRANSP-ISOLVER
- *Tuning of Automated Rampdown Software* (XP-1502, Gerhardt)
  - **Goal**: Tune shutdown algorithm for the more challenging H-mode rampdown.
  - **Key Issues**: Shape handoff using ISOFLUX, position transients during H->L.
- *HHFW Antenna Conditioning* (XMP-026, Hosea)
  - **Goal**: Antenna conditioning under plasma conditions, after successful antenna conditioning
- *Commissioning CHI System* (XMP-126, Raman)
  - **Goal**: Commission CHI capacitor bank and dedicated instrumentation, make first CHI discharges.
  - **Key Issues**: Noise reduction on new instrumentation, DCPS configuration during CHI, noise on magnetic diagnostics.
- LGI Control (XMP-130, Lunsford)
  - **Goal**: Commission Lithium Granule Injector, including PCS algorithms

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Proposed Facility Enhancements Will Be a Dramatic Step Forwards for SFSU and WH&CD Research

- 28 GHz gyrotron system is largely motivated by the need to connect CHI to HHFW and NB heating.
  - See talk by F. Poli for details on how SFSU research will be fundamentally enhanced.

- 28 GHz gyrotron will also allow EBW heating studies to move forward, following a launcher upgrade.

- High-Z PFC upgrade will provide metal electrode surfaces, which will likely prove advantageous for CHI once properly conditioned (reduced low-Z impurities, radiation).

Exciting Opportunities for ASC Research Will Come out of the Facility Enhancements

- Cryo-pump should resolve a long-standing, legitimate criticism of NSTX scenario research…lack of density control.
  - Will likely be a key capability in exploiting the full NSTX-U magnet and heating systems.
  - Will facilitate targeted scenario and physics studies.
  - Refer to talks by R. Maingi, M. Ono for more details.
- High-Z PFC enhancement will introduce critical, exciting challenges to scenario and control development.
  - May make active heat flux management as critical as other control loops, as will be the case in ITER and other next steps.
  - See talk by M. Jaworski for details.
- NCC will provide an additional key actuator for profile control.
  - Closed loop pedestal height control will be assessed as an ELM mitigation strategy.
  - More flexible rotation control strategies will be developed, which may be important for scenario optimization

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IS SG Research Supports FES Priorities

- Advancing predictive capability, model validation
  - Control oriented modeling, start-up modeling, RF code validation
    - See also talks by Boyer, Poli, in addition to these slides.
- Mitigating / avoiding transients
  - Disruption avoidance via i) advanced profile control and ii) discharge shutdown studies
- Taming the PMI
  - Closed-loop control of advanced divertors (magnetic geometry and radiation)
- Establishing physics basis for FNSF
  - *Non-inductive start-up, ramp-up, and sustainment*
  - RF Physics
- Supporting discovery science, basic plasma physics
  - Reconnection physics during CHI

This SG Works to Solve Scenario Physics Problems for the NSTX-U Program, ITER, and Next-Step Devices

- Strong support for the non-inductive startup, ramp-up, and sustainment across the three TSGs.
- Active modeling efforts in all areas support the NSTX-U programmatic goals and FES priorities
- Developing the H&CD actuator physics and closed loop control techniques for next step devices.
- We have an exciting research program planned for the FY16 run and are ready to go!

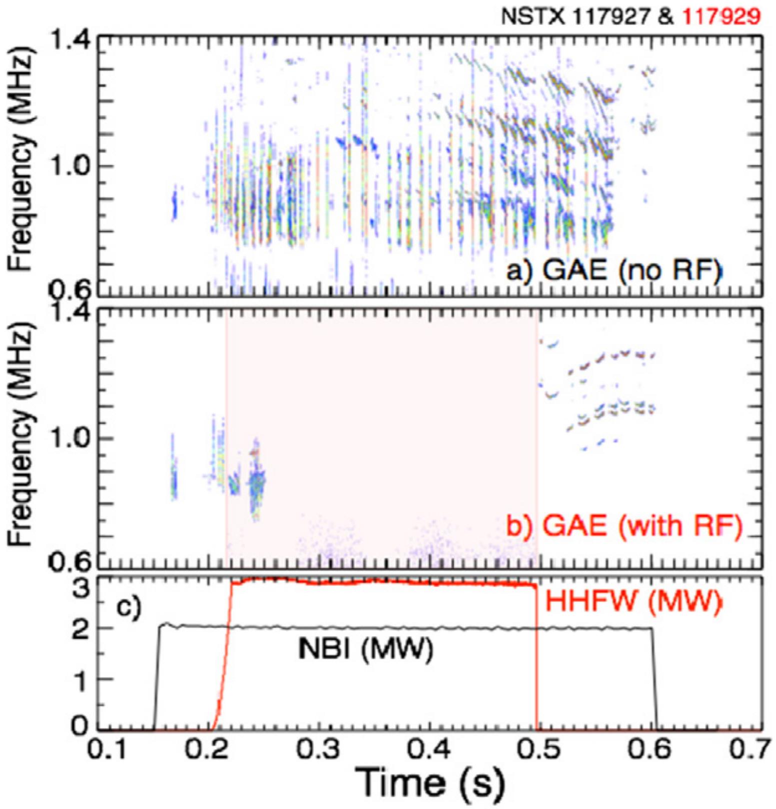
Backup

Ion Absorption of HHFW Power Has Potential Benefits and Disadvantages

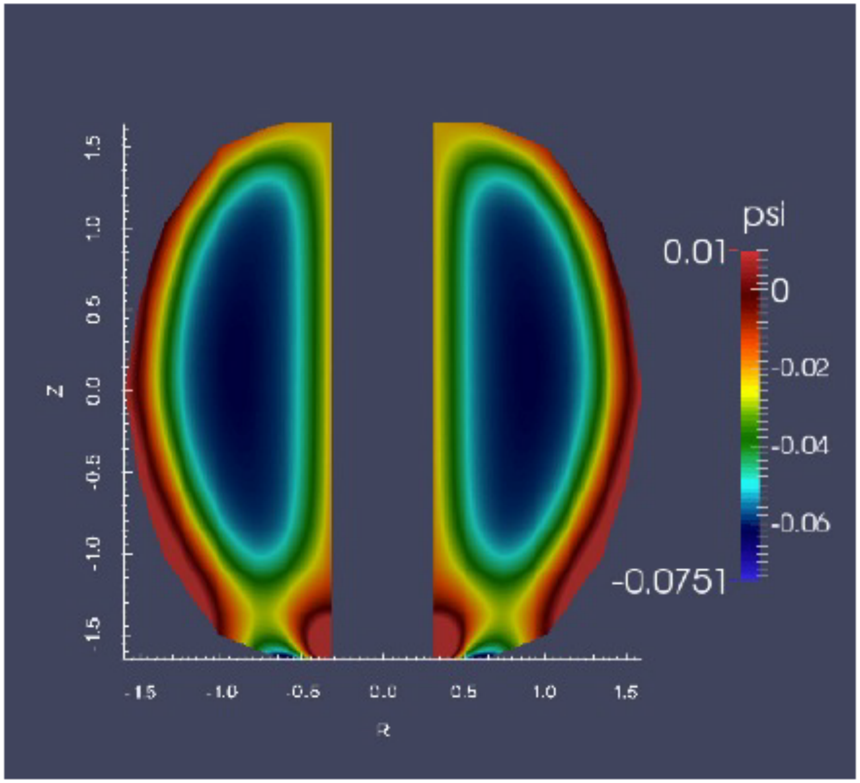
- In NSTX, a significant fraction of (core) HHFW power absorbed by fast ions.
  - Seen in neutrons, NPA spectrum, FIDA.

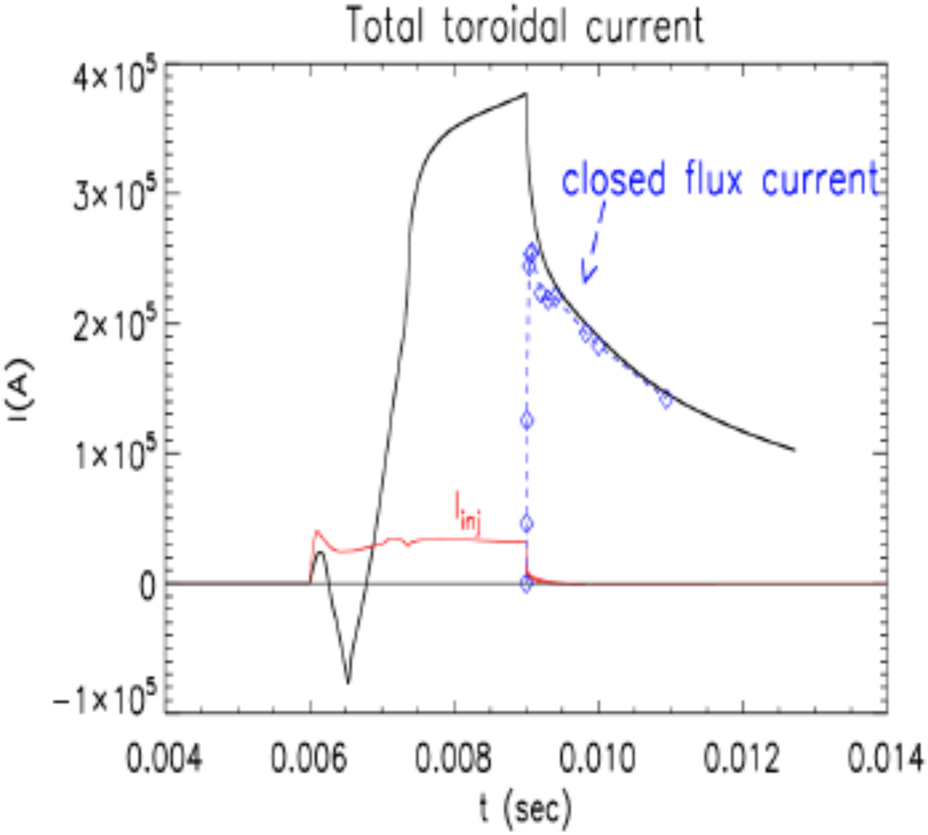
- Ion acceleration to loss orbits can be a strong loss mechanism
  - detrimental heat loads to the PFCs.

- FW interactions with beam ions could be useful for influencing energetic particle modes [EP TSG]
  - Modification of fast-ion distribution
    - D. Liu *et al.*, *Plasma Phys. Control. Fusion* **52** (2010) 025006.
  - Suppression of energetic-particle driven modes
    - E. D. Frederickson *et al.*, *Nucl. Fusion* 55 (2015) 013012.



High fraction of open flux conversion to closed flux seen in simulations with narrow injector flux footprint





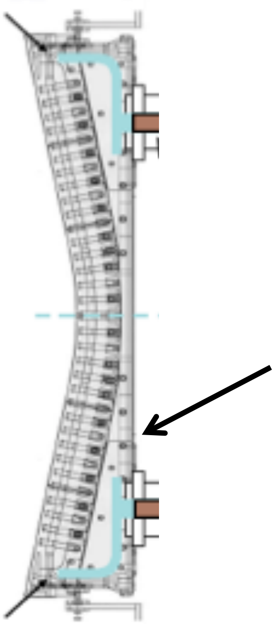
- CHI in NSTX-U configuration naturally has a narrower injector flux footprint due to improved Injector coil positioning
- Due to higher Lundquist number in NSTX-U CHI simulations, closed flux surfaces form even during the actively injected phase

NIMROD Simulations **F. Ebrahimi, et al., submitted to NF-Lett.**

Hardware Upgrades Support HHFW Operations and Physics Studies

- Twelve-strap antenna re-installed
  - New compliant, bellowed feedthrough used to withstand disruptions at I_P=2 MA
  - Additional grounding points added to raise voltage standoff
- Six RF sources recommissioned; conditioning started
  - Recent breaker failure being investigated; replacement parts are ready to go
- New color fast camera and infrared camera will monitor antenna
- New sets of divertor Langmuir probes
  - RF-suitable electronics have been designed, reviewed, and tested

Compliant Feedthroughs



Poloidal Cut of Antenna Strap

Additional grounding to between antenna box and vessel

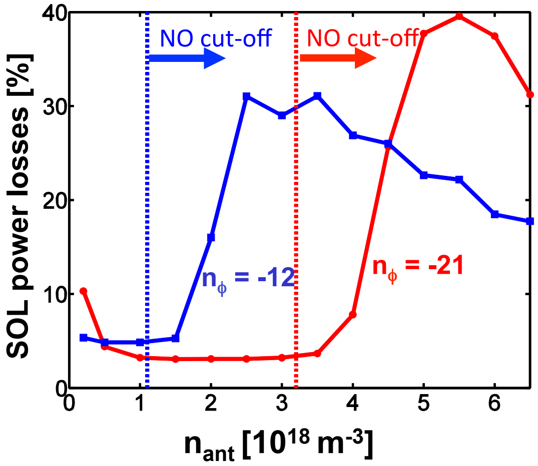
Distribution of First Authors (not including CC&E, XMPs)
~12 First Authors

Author	XP	Run Days	Area
Gerhardt	100% non-inductive	2 (ASC)	Scenario Development (3.5 Days)
Battaglia	Longest Possible Pulse	1 (ASC)	
Yuh	Reversed Shear	0.5 (ASC+0.5 T&T)	
Kolemen	SFD Control	1.5 (ASC)	Control Development (4 Days)
TBD	Rotation Control	0.5 (ASC)	
Boyer	Current profile control, β_N + l_i control	2.0 (ASC)	
Bertelli	Absorption in NB plasmas	1.0 (RF)	HHFW at Higher Current (3 Days)
Perkins	SOL Losses in H-mode	1.75 (RF)	
D. Smith	Measure Density Perturbation with BES	0.25 (RF)	
Poli	NBI Coupling to Low-Current Plasmas	1 (0.5 ASC+ 0.5 SFSU)	Ramp-Up (2.0 Days)
Taylor/Poli	Low Current, high f_{NI}, HHFW	1 (0.5 RF+ 0.5 SFSU)	
Raman	Transient CHI startup	2.0 (SFSU)	CHI (2.5 Days)
Nelson	Inductive Rampup	0.5 (SFSU)	

AORSA show different behavior of SOL power losses between HHFW and IC minority heating regimes

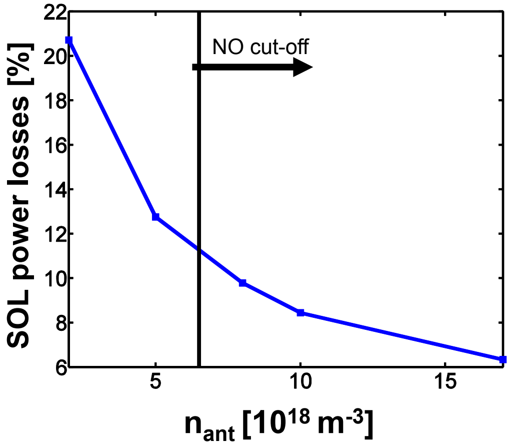
HHFW

NSTX-U scenario
B_T = 1 T
f = 30 MHz
ν/ω = 0.01



VS.

IC minority



C-mod
n_ϕ = 10
f = 80 MHz
ν/ω = 0.01

- SOL RF field amplitude increases when FW can propagate in the SOL
- Direct correlation between SOL RF field amplitude , FW cut-off location , and SOL power losses behavior
- Agreement with DIII-D sim./exp.
- Larger evanescent region predicted at higher fields achievable in NSTX-U, favorable for future experiments
- Possible aspects: cavity modes & magnetic pitch angle

- Alcator C-Mod & EAST results show a decreasing of E field amplitude outside LCFS with increasing n_{ant}
- No transition to higher SOL power losses
- Results perhaps more intuitive w.r.t. the NSTX/NSTX-U/DIII-D

  increase SOL density ⇨ enhances antenna-plasma coupling ⇨ lower fraction of power lost to the SOL region
- Consistent with the C-Mod/ASDEX-U exp.

N. Bertelli et al., Nucl. Fusion 56 (2016) 1

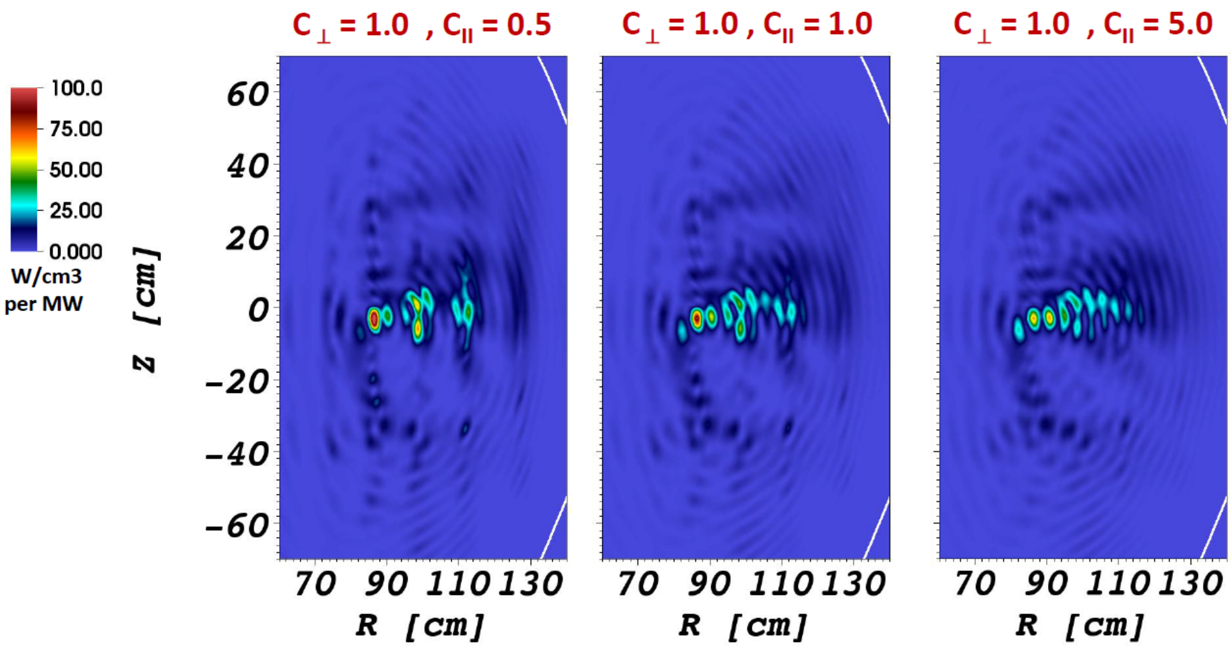
Extended TORIC v.5 to include non-Maxwellian effects both in HHFW and IC minority heating regimes

- implementation of the bi-Maxw. and slowing down analytical distributions
- Capability to read a numerical fast ion distr. func. from NUBEAM is underway

Non-Maxwellian effects, generally, result in finite changes in the amount and spatial location of absorption.

$$f_{\rm D}(v_\parallel, v_\perp) = (2\pi)^{-3/2}(v_{{\rm th},\parallel} v_{{\rm th},\perp}^2)^{-1}\exp[-(v_\parallel/v_{{\rm th},\parallel})^2 - (v_\perp/v_{{\rm th},\perp})^2]$$

with $v_{{\rm th},\parallel} = \sqrt{2C_\parallel T(\psi)/m_{\rm D}}$, $v_{{\rm th},\perp} = \sqrt{2C_\perp T(\psi)/m_{\rm D}}$, with constants $C_\parallel$ and $C_\perp$



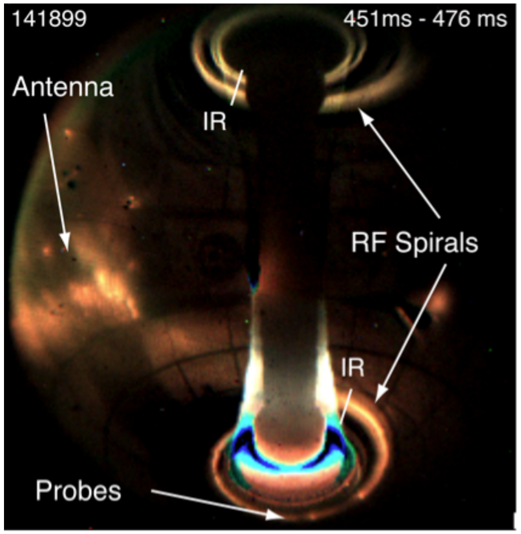
$C_\perp = 1.0$, $C_\parallel = 0.5$ $C_\perp = 1.0$, $C_\parallel = 1.0$ $C_\perp = 1.0$, $C_\parallel = 5.0$

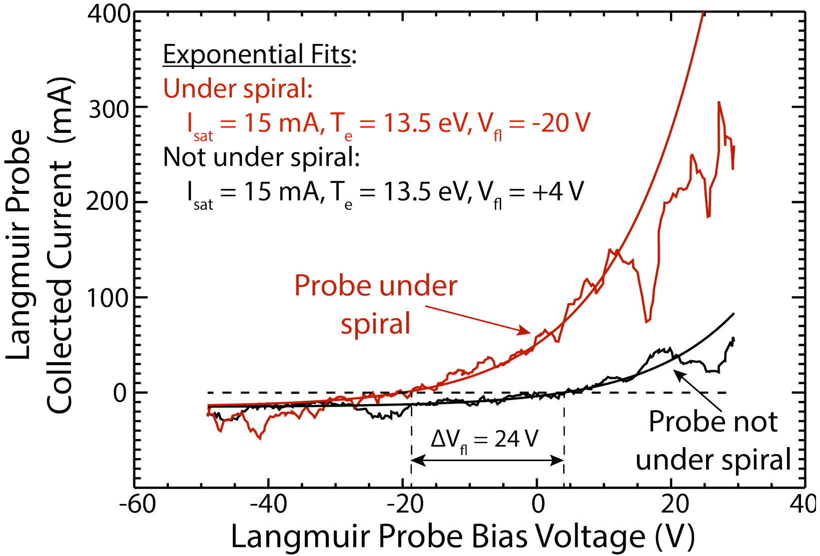
Fast ion absorption assuming a bi-Maxw distr. func. in NSTX

Bertelli et al. APS 2015

Modeling Is Confirming The Importance of RH Cutoff in Determining SOL Losses

- NSTX showed a large loss of RF power in the SOL
- Modeling shows large RF field amplitude in SOL under certain conditions
  - Seen in full-wave code AORSA
    - N. Bertelli *et al*., *Nucl. Fusion* **54** (2014) 083004.
    - N. Bertelli *et al*., *Nucl. Fusion* **56** (2016) 016019.
  - Also seen in cylindrical cold-plasma model
    - Wave power (axial Poynting flux) confined to periphery, only gradually penetrating the core
    - R. J. Perkins *et al*., 41th EPS Conference on Plasma Physics P-1.011.
- RF fields in divertor cause RF sheath; potentially large enough to account for SOL losses
  - Rectified sheath voltage and e^- current predicted to substantially increase heat flux to tiles
    - R. J. Perkins *et al*., *Phys. Plasma* **22** (2015) 042506.





ASC (and Broader NSTX-U) Research Facilitated by Numerous Upgrades to the Plasma Control System

- Hardware:
  - New control computers, reduced latency links to the power supplies
  - realtime V_{phi} in final testing, realtime MSE measurement in development.
- Methods:
  - Complete prose documentation of all physics algorithms within PCS.
  - Control design with full-physics models in TRANSP
    - See talk by Dan Boyer
- Algorithms:
  - Reviewed every line of code in every control algorithm
  - New shape control capabilities during the ramp-up and ramp-down
  - New automatic discharge shutdown system
  - More modular beam control, vertical control, ISOFLUX shape control algorithms.
  - In final development:
    - Snowflake divertor control
    - Rotation/Current profile control