Supported by Office of Science

NSTX

National Spherical Torus Experiment

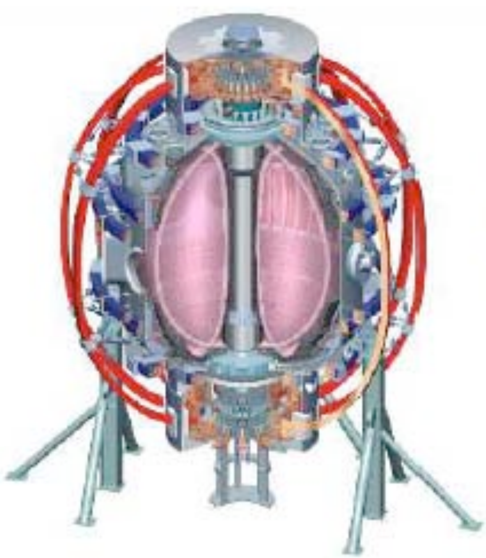
College W&M
Colorado Sch Mines
Columbia U
Comp-X
FIU
General Atomics
INL
Johns Hopkins U
Lehigh U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

Masayuki Ono

For the NSTX Research Team

Fusion Power Associate Annual Meeting

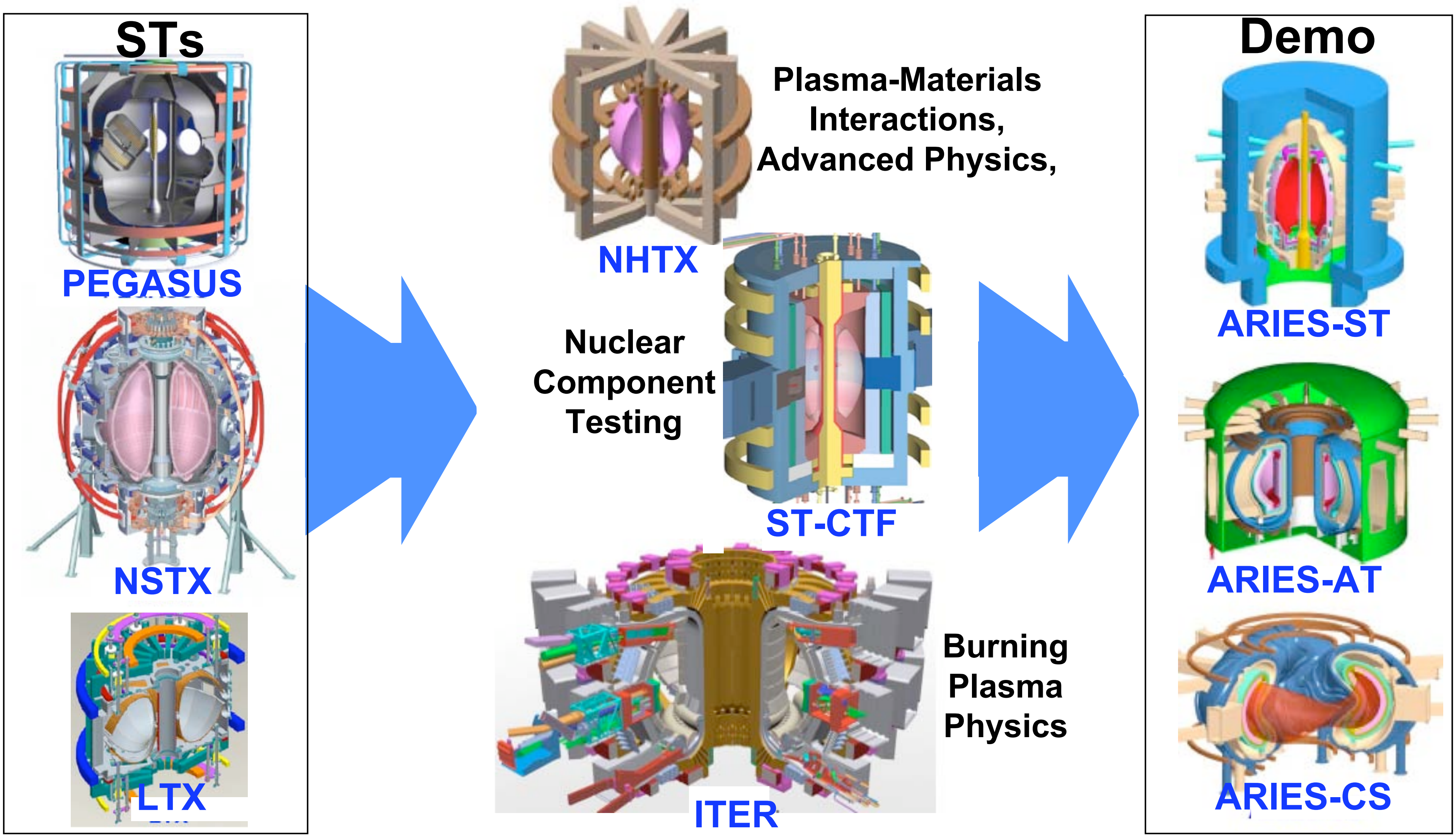
Dec. 4 - 5, 2007
ORNL



Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
IPP AS CR

NSTX Research Program Contributes Strongly to US and World Fusion Development

ST offers compact geometry + high β for attractive fusion applications



NSTX Mission Elements

NSTX

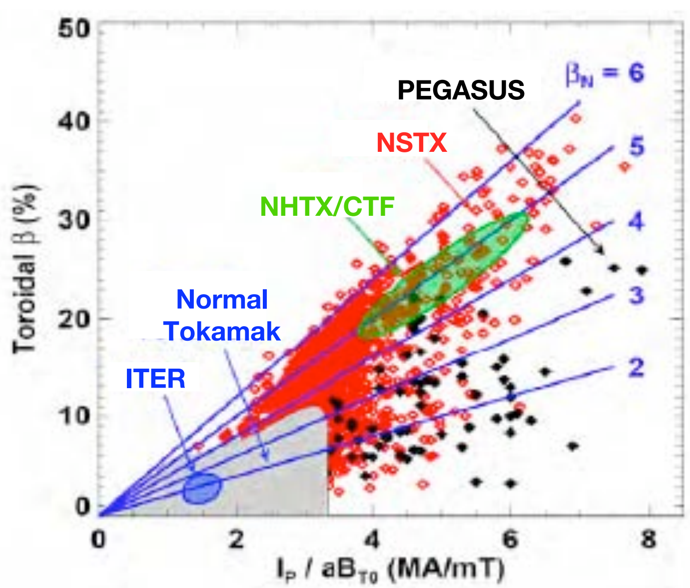
- To provide the physics basis for NHTX, ST-CTF and ST-Demo
- To broaden the physics basis for ITER, actively participating in ITPA and US BPO
- To advance the understanding of toroidal magnetic confinement

NSTX/ST Strength:

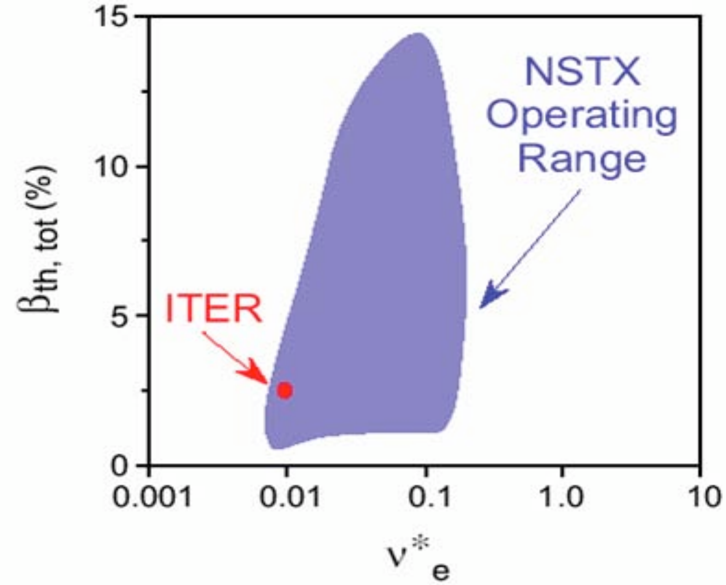
- Exceptionally wide plasma parameter space
- High degree of facility flexibility
- Highly accessible plasmas - unique diagnostics

NSTX Offers Access to Wide Tokamak Plasma Regimes

Wide range of β_T up to ~ 40 %

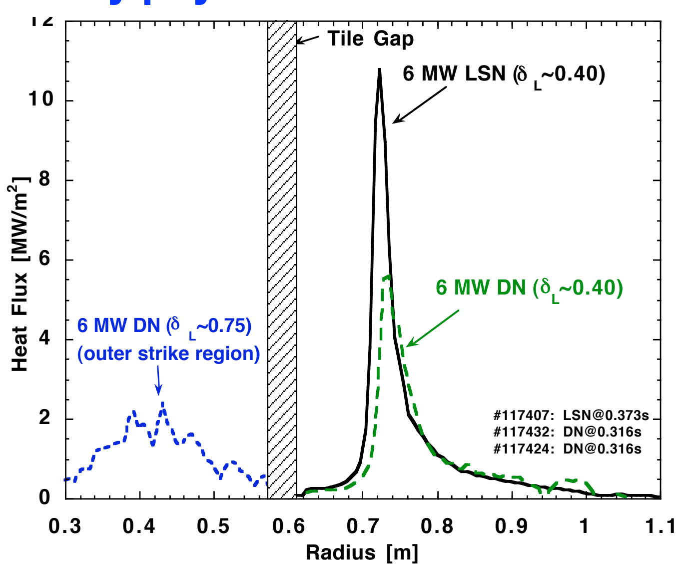


β Confinement Scaling, Electron Transport

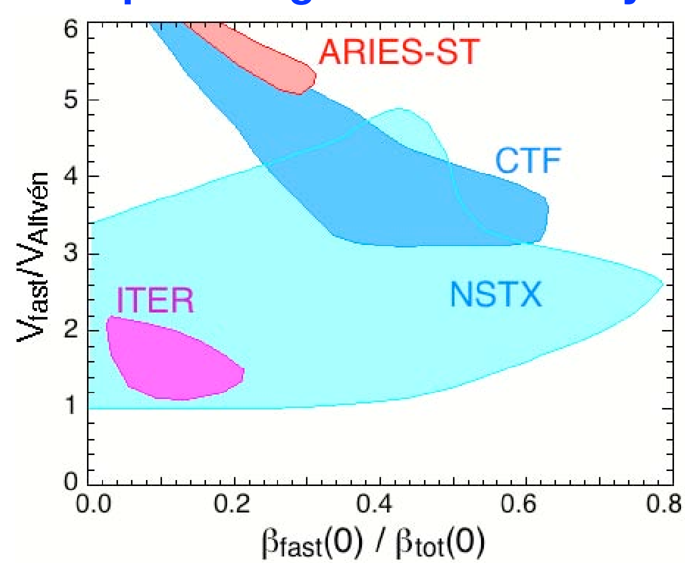


- Confinement scaling with wide range of β_T up to ~ 40 %

Boundary physics with ITER-level heat flux



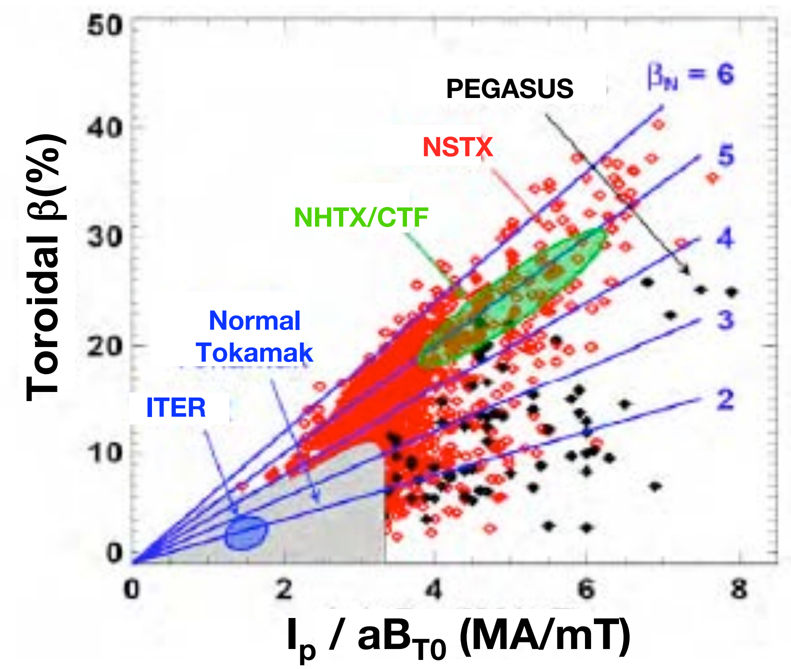
Unique Energetic Particle Physics



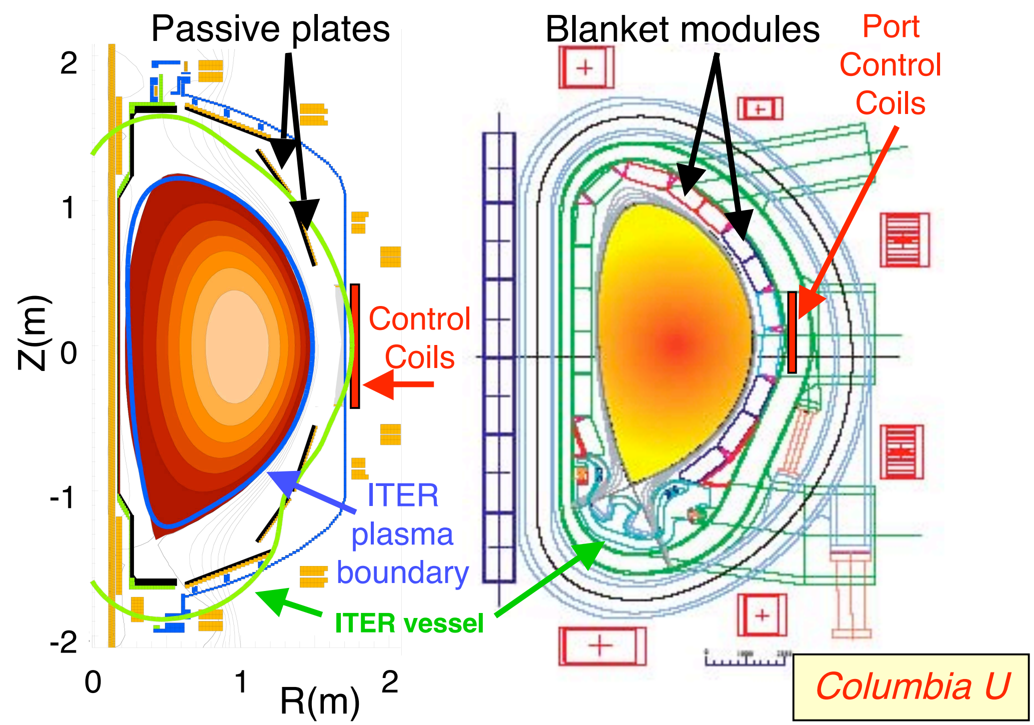
- Full set of diagnostics: including MSE for j(r)

Operation near the ideal stability limit For Advanced ST / ITER Operations

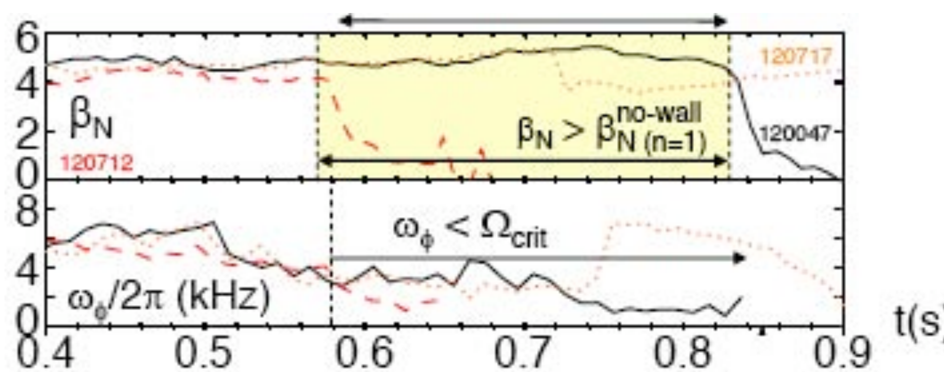
Low A, high β provides high leverage to uncover key tokamak physics



NSTX / ITER RWM control



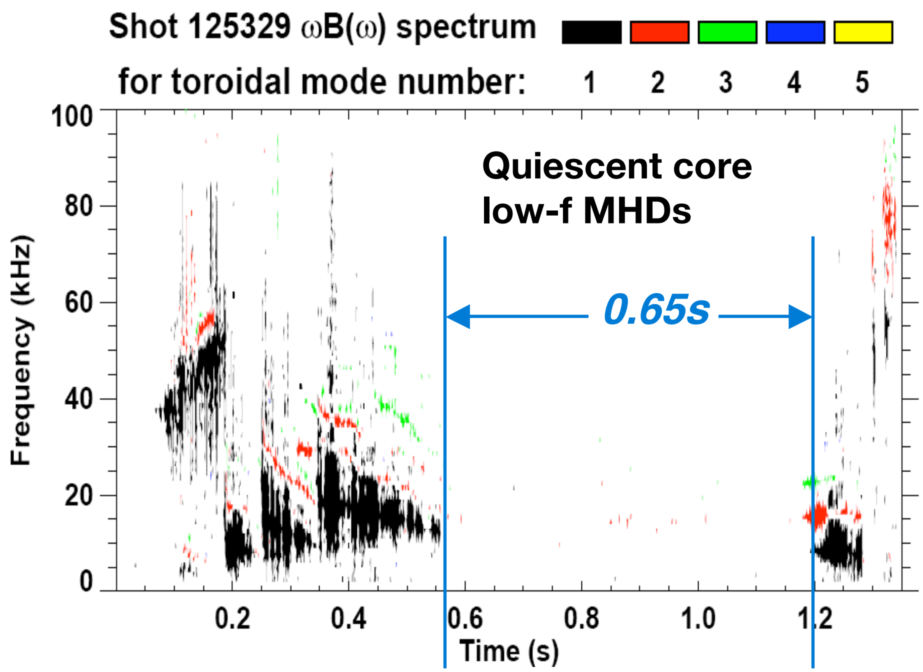
- RWM actively stabilized at ITER-relevant low rotation for ~ $90/\gamma_{RWM}$ at near ideal limit β_N~ 5.5
- Optimum phase between mode B_p and applied B_r agrees with Valen code

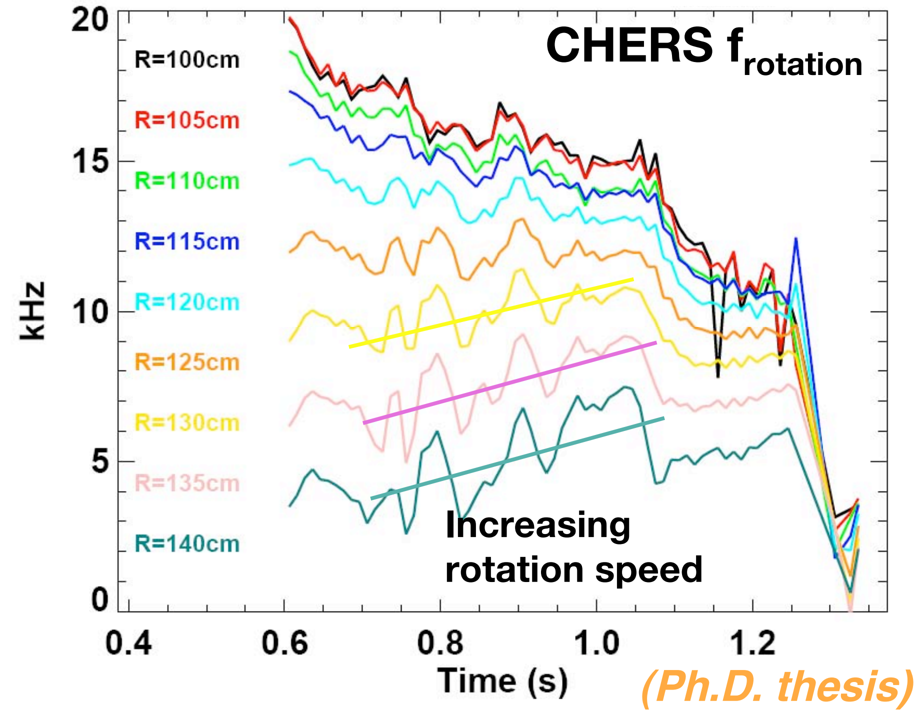


Discovered high-*n* error fields (*n*=3) important at high β_N

Lead to MHD Quiescent Plasmas and Improves Plasma Performance

NSTX





(Ph.D. thesis)

Experiments in support of near-term critical ITER design activities:

- –Vertical control
  - •Quantify controllable ΔZ, compare across devices, compare to ITER
- –ELM suppression
  - •Any demonstration of ELM suppression using a single row of coils would provide <u>very valuable data</u> for improved RMP understanding (n=1,2,&3)
- –RWM control – impact of missing control coils on feedback performance

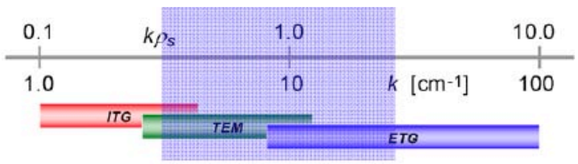
Significant Progress on Electron Heat Transport Physics

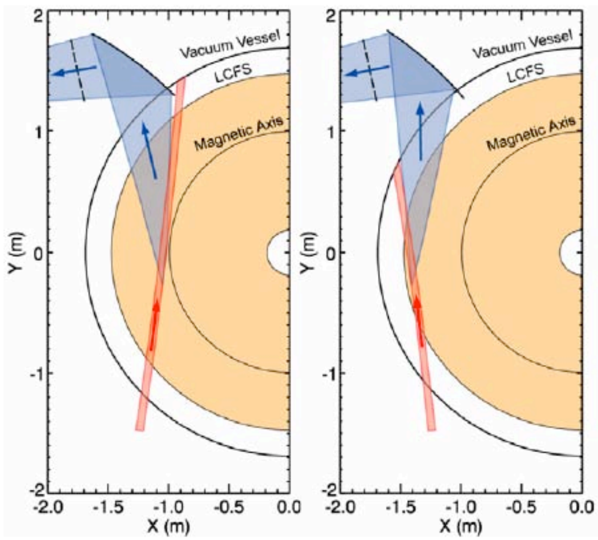
Understanding Needed for Burning Plasma Performance Prediction

ETG Causing Electron Transport? - Jenko, Doland,Hammet, PoP 8, 2001

NSTX

Tangential High-k Scattering (3 MHz)



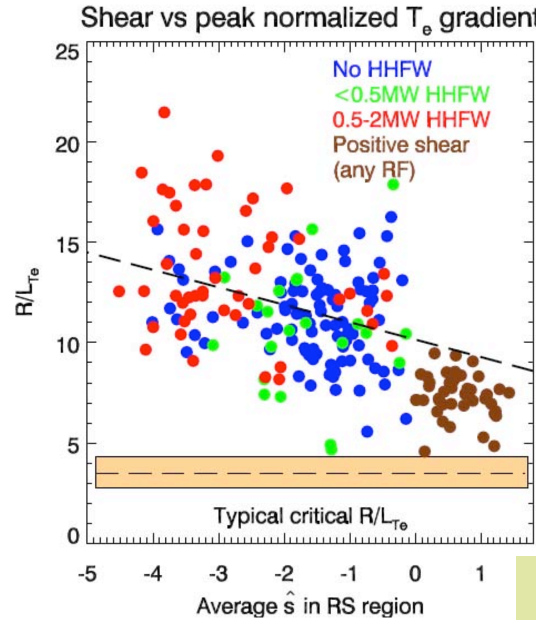


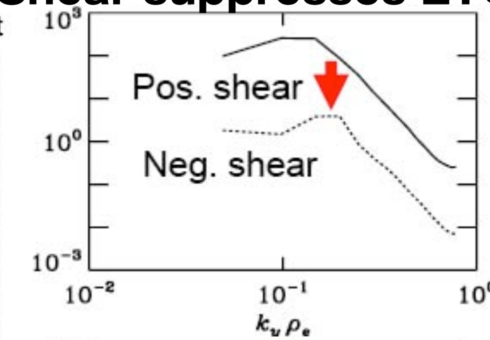
UC Davis

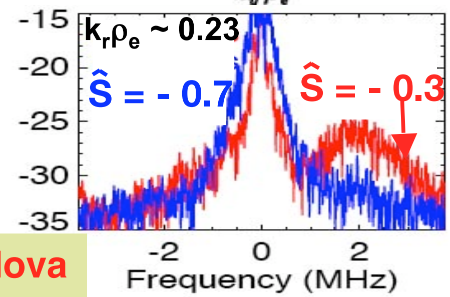
Unprecedented radial spatial resolution at electron gyro-scale turbulence (e.g., ETGs)

(Ph.D. thesis)

Increased Reversed Shear suppresses ETG

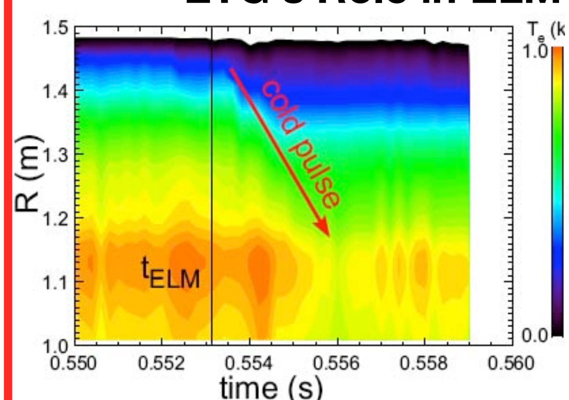


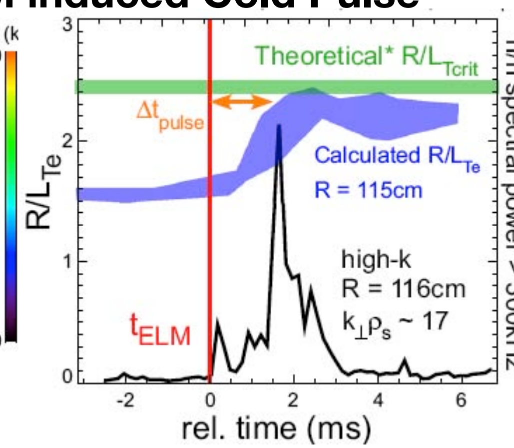




Nova

ETG's Role in ELM induced Cold Pulse





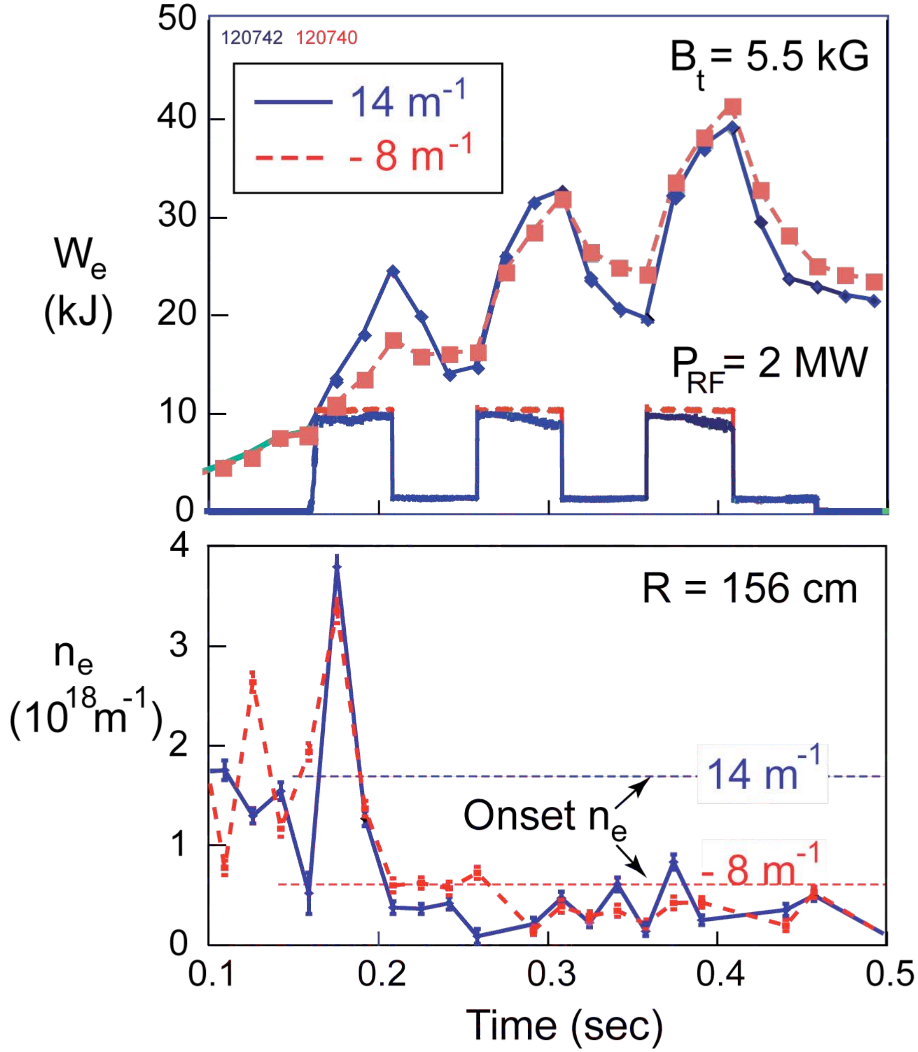
JHU

Improved High Harmonic Fast Wave Electron Heating

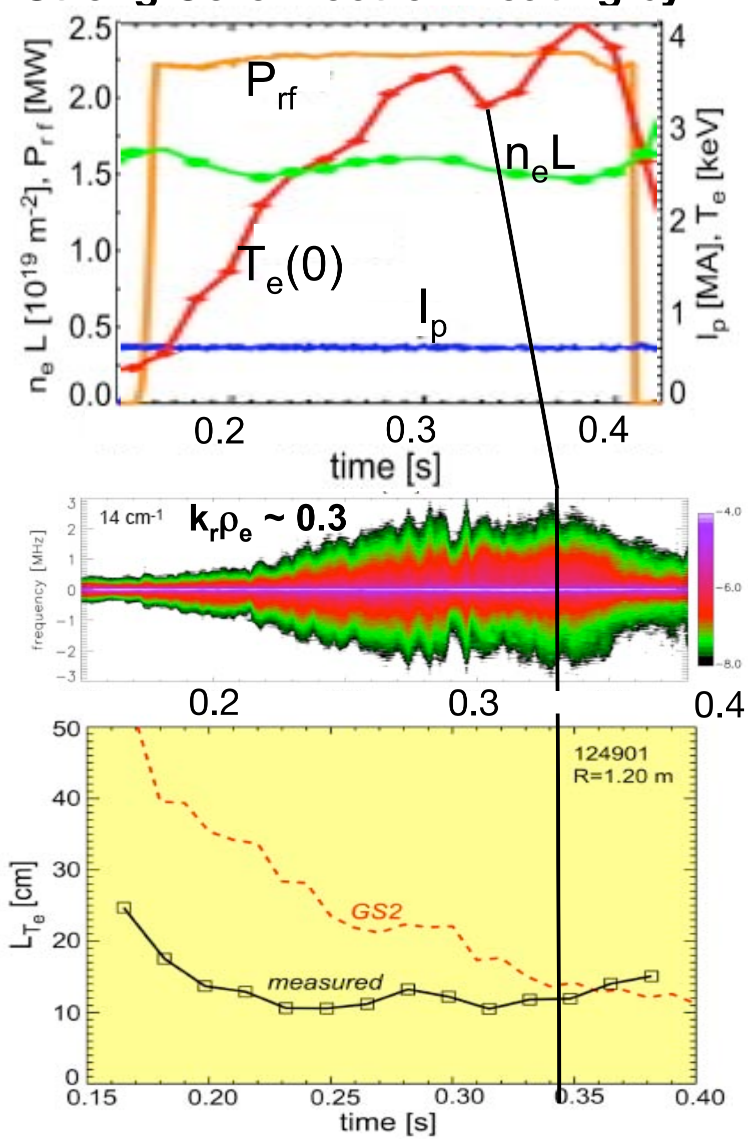
Becoming a Science Tool (e.g, Electron Transport Study with High-k)

NSTX

Importance of Edge Density in Coupling Relevant fo ITER-ICRF



Strong Core Electron Heating by HHFW

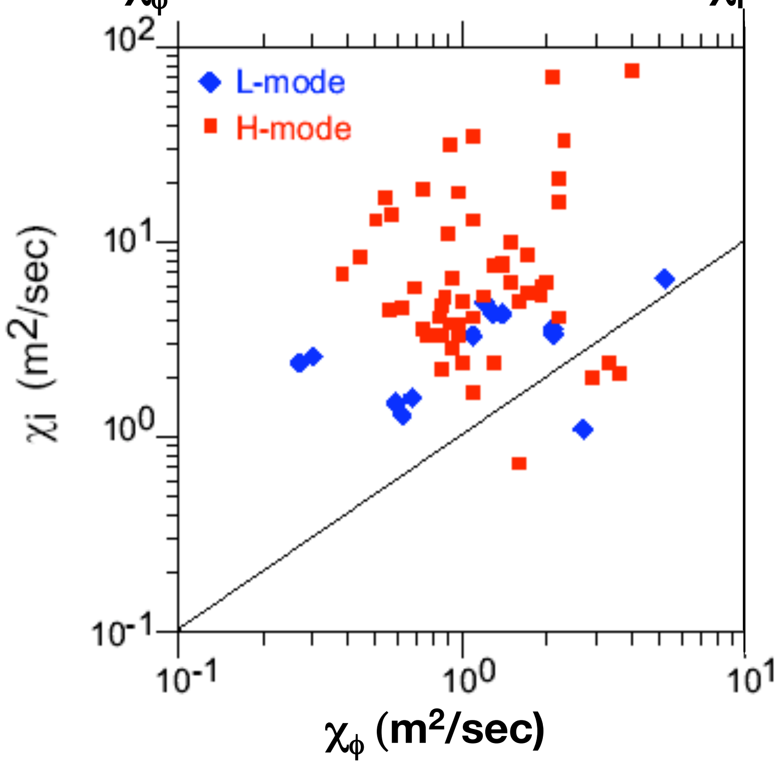


Momentum Transport Next Topic of Emphasis

Needed for Plasma Rotation Prediction for ITER and future STs

NSTX

χ_ϕ can be much less than χ_i



Shearing rates can exceed ITG / TEM growth rates by 5 to 10!

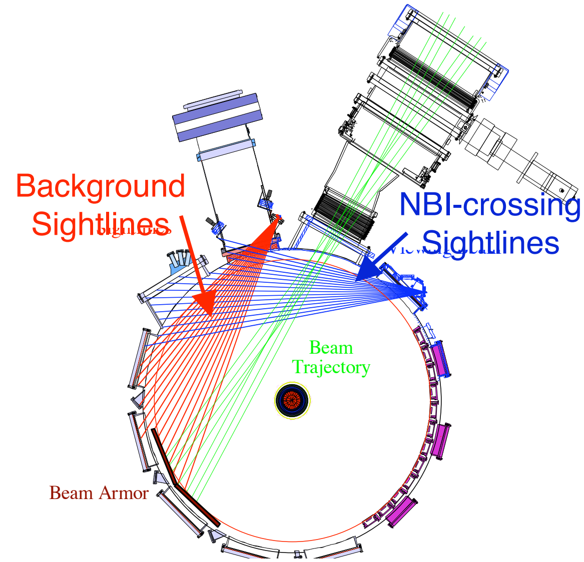
- **Due to suppression of ITG modes?**
- **What is level of $\chi_{\phi,neo}$?**
- **Does χ_ϕ scale with χ_e?**

Beam Emission Spectroscopy planned

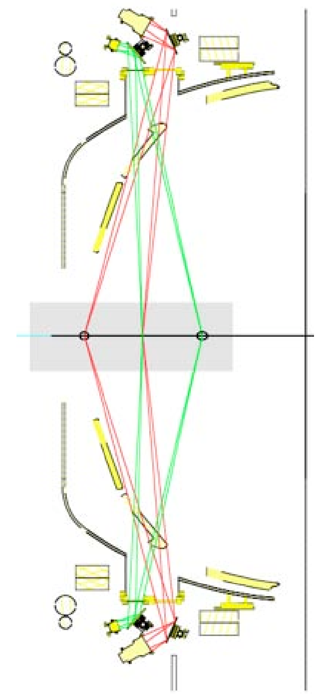
U Wisconsin

Momentum Transport Diagnostics Readied

Resolves structure to ion gyro-radius



51 Ch CHERS for $T_i(r)$, $V_\phi(r)$



70 Ch P-CHERS for $V_p(r)$

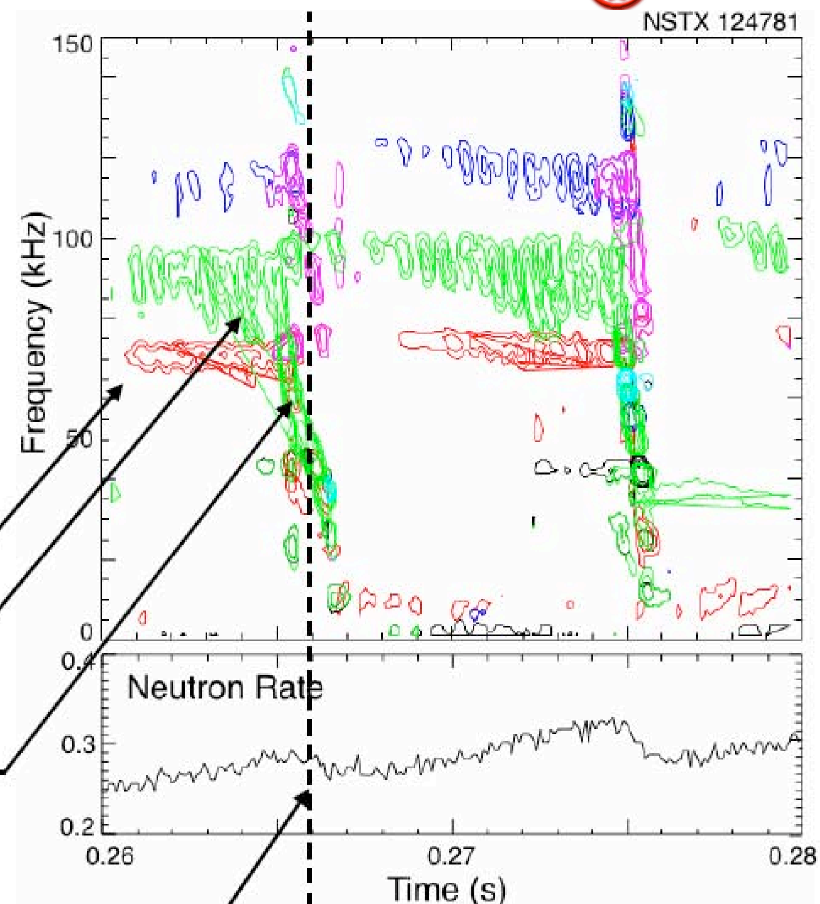
Near-term T&T Plan:

- **Determine relationship between local turbulence and electron/ion heat transport**
- **Investigate momentum transport physics**
- **Investigate particle transport physics**

Fast Ion Loss on ITER Expected from Multiple Nonlinearly Interacting Modes, Currently being Studied on NSTX

NSTX

In 2007, entire AE stability space - from no AE modes to AE avalanche threshold – has been mapped and comprehensively diagnosed for in NSTX.

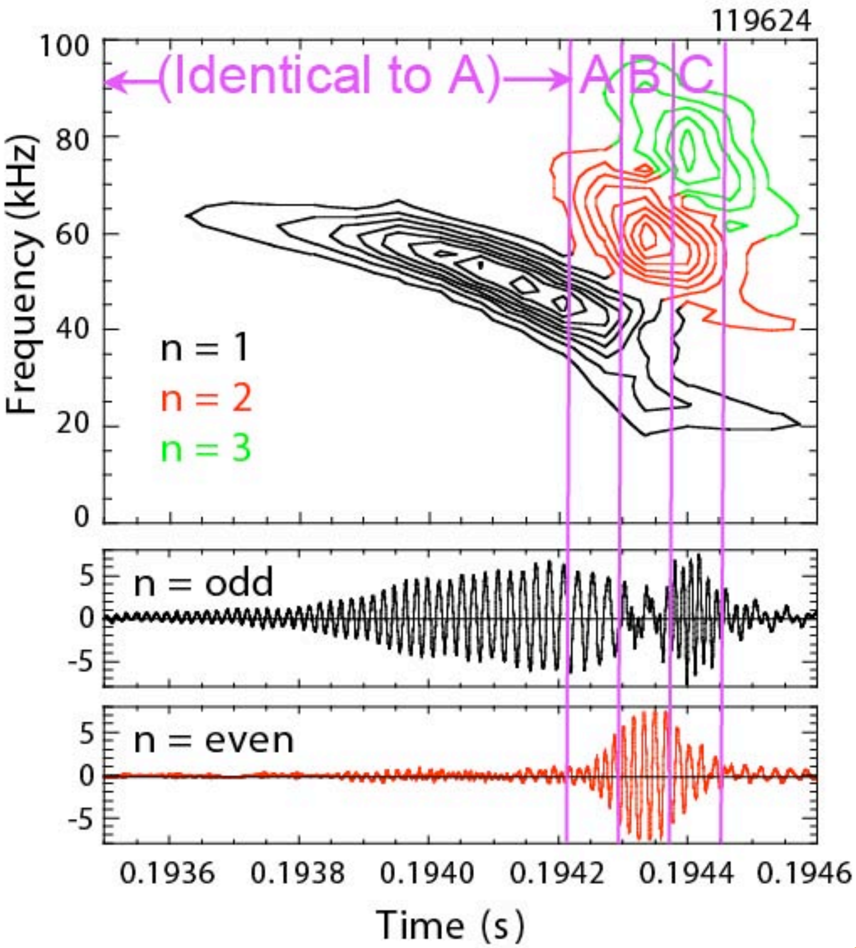


- As power is raised, first see TAE
  - then chirping TAE
  - then avalanches, multi-mode transport
- Avalanches are strong bursts of multiple TAE modes ($2 \le n \le 6$), with weak or no n=1 fishbone modes, and correlated with neutron drops

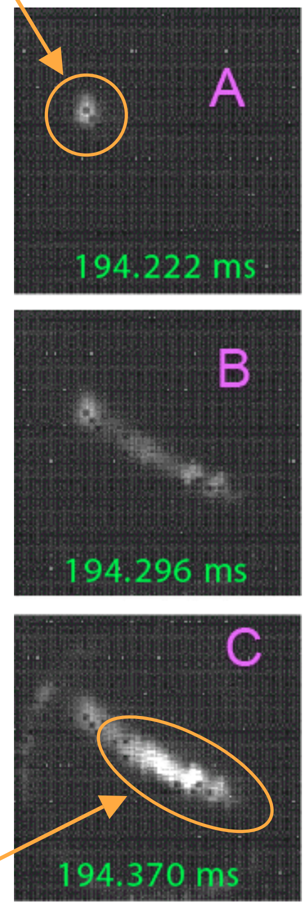
UCLA

Fast Ion Loss of from Multiple Nonlinearly Interacting Modes Measured and Simulation Effort is Underway

Prompt loss of 90keV D^+



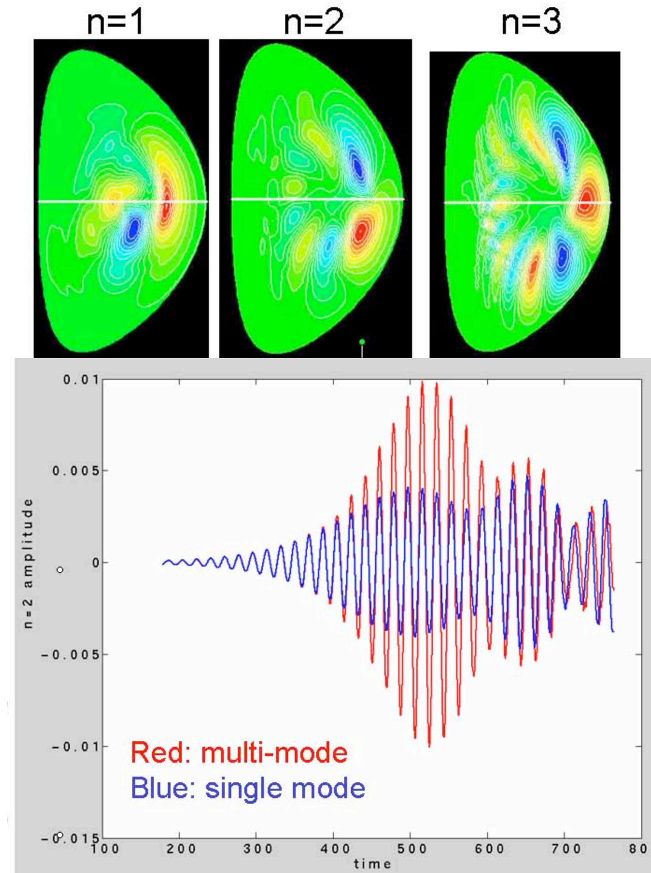
Fast Lost Ion Probe



Mode-induced loss of 90keV D^+

FIDA Energetic Particle Diagnostic Installed UCI

M3D simulations of non-linear mode-mode interactions can impact mode amplitudes

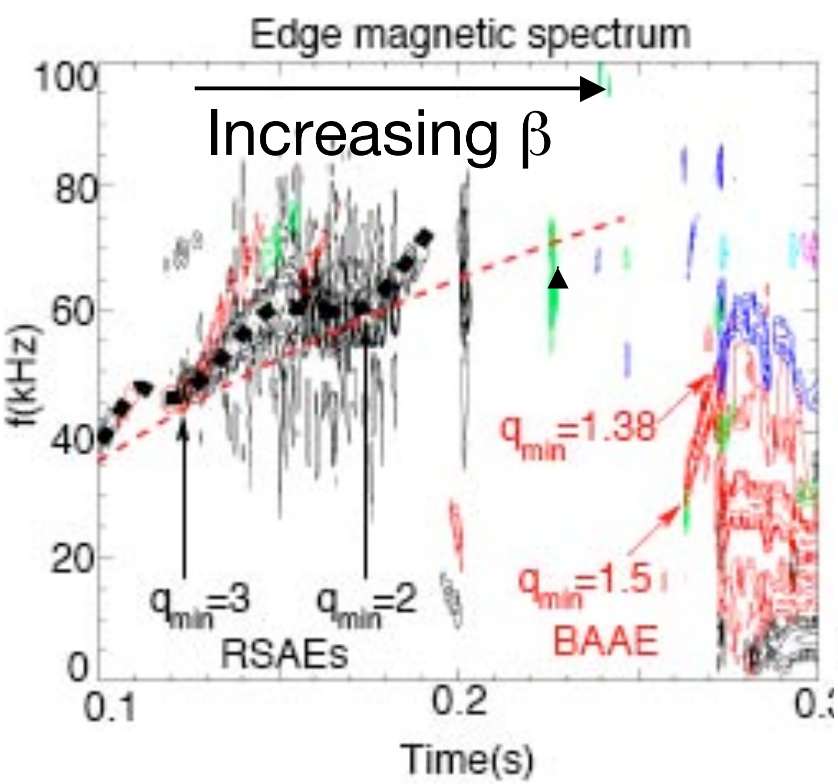


n=2 amplitude: ***multi-mode amplitude higher than for single mode treatment***

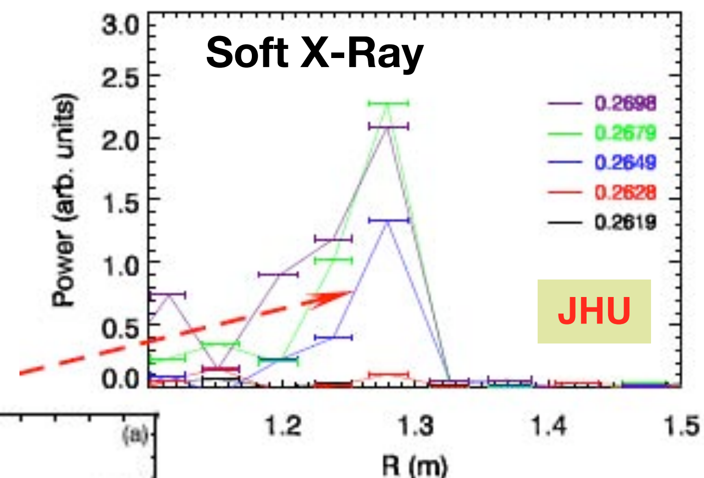
At high β ($\geq$ 15%), Alfven Cascades are suppressed, and NBI can excite Beta-induced Alfven Acoustic Eigenmode (BAAE)

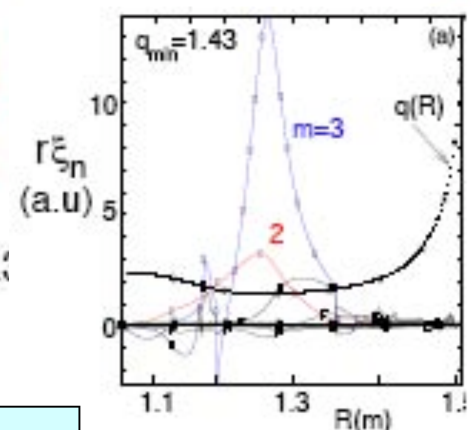
BAAE can couple directly to thermal ions (α-channeling)

NSTX



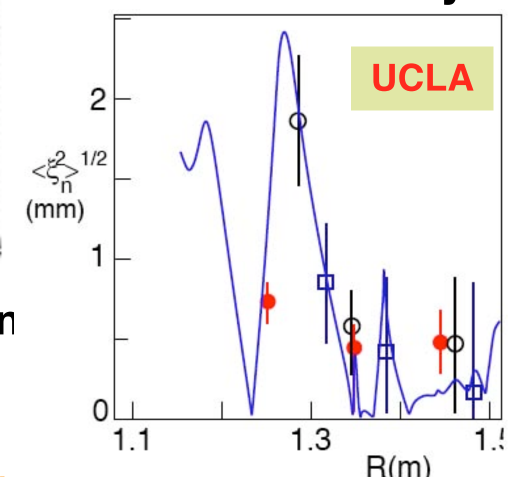
BAAE Identified by Internal Measurements





Nova-k Simulation

Reflectometry



Near-term Energetic Particle Plan:

- **Develop predictive capability of energetic particle mode excitations and related energetic particle transport for ITER and CTF**

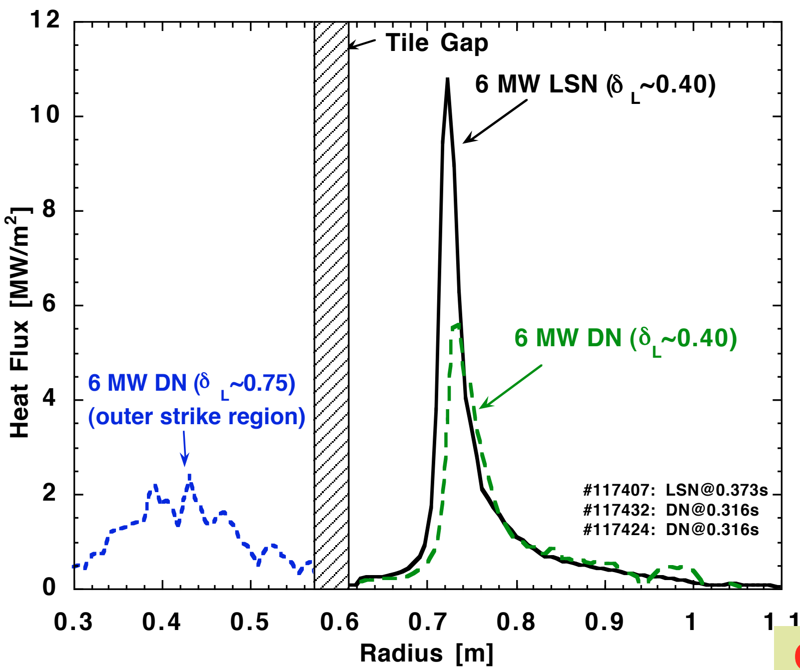
(N. Gorelenkov

Studying Physics of Divertor and Detachment - Needed for NHTX and ST-CTF Design

NSTX

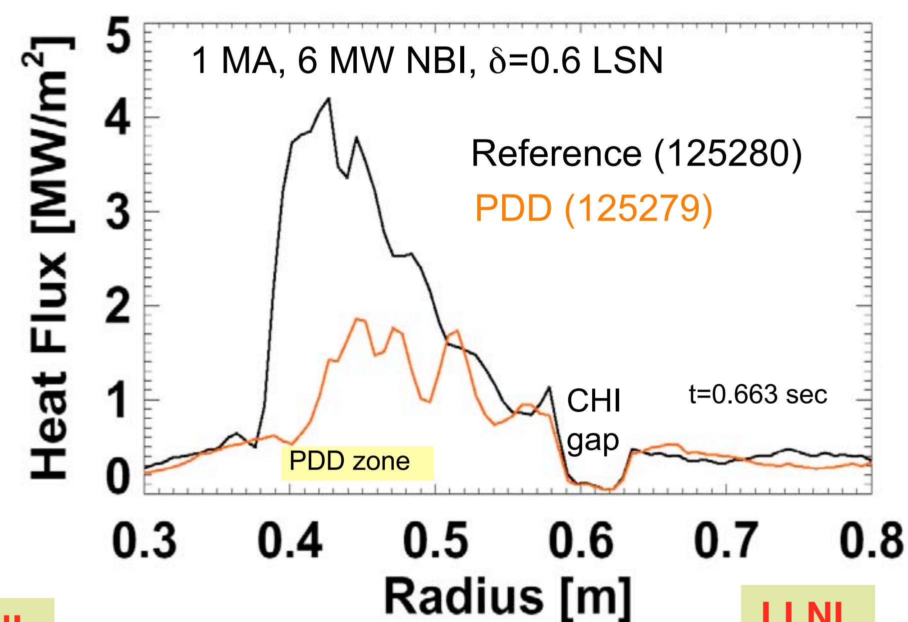
Power management through flux expansion and detachment

Boundary physics with ITER-level heat flux
Heat Flux Reduction with higher triangularity



ORNL

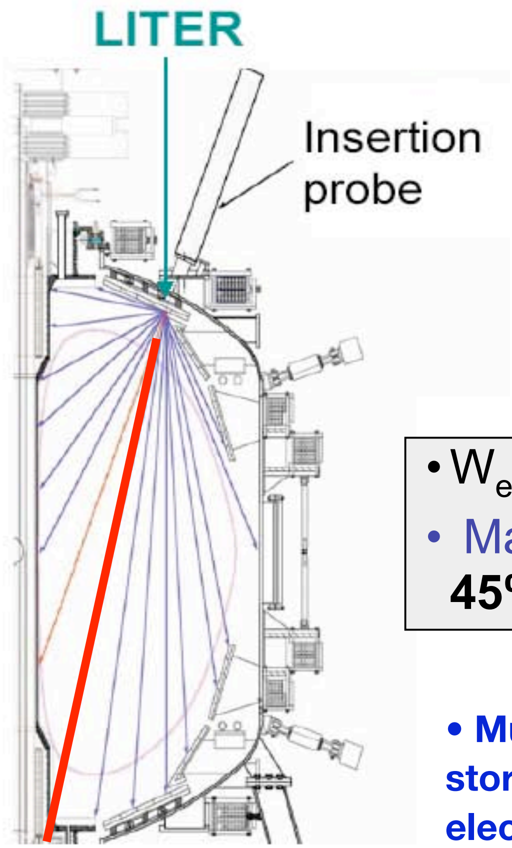
Partially Detached Divertor significantly reduce heat flux without reducing H-mode performance



LLNL

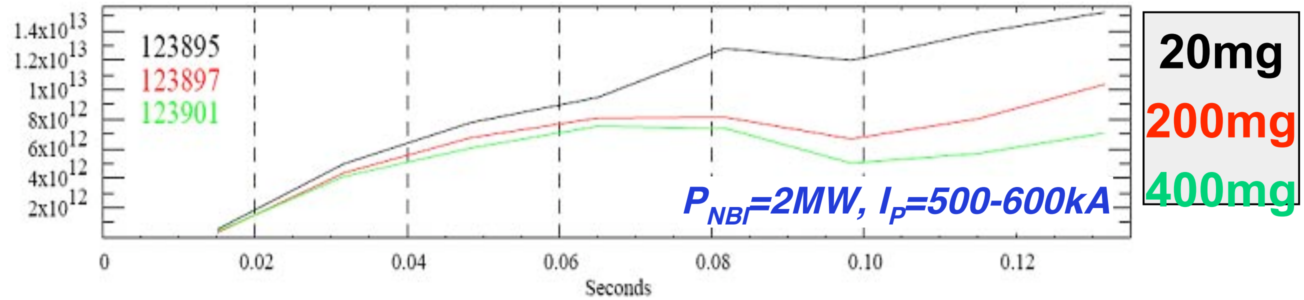
Lithium Evaporator (LITER) has demonstrated that Li can increase τ_E and pump D ◊ Li is tool for advanced scenarios

NSTX



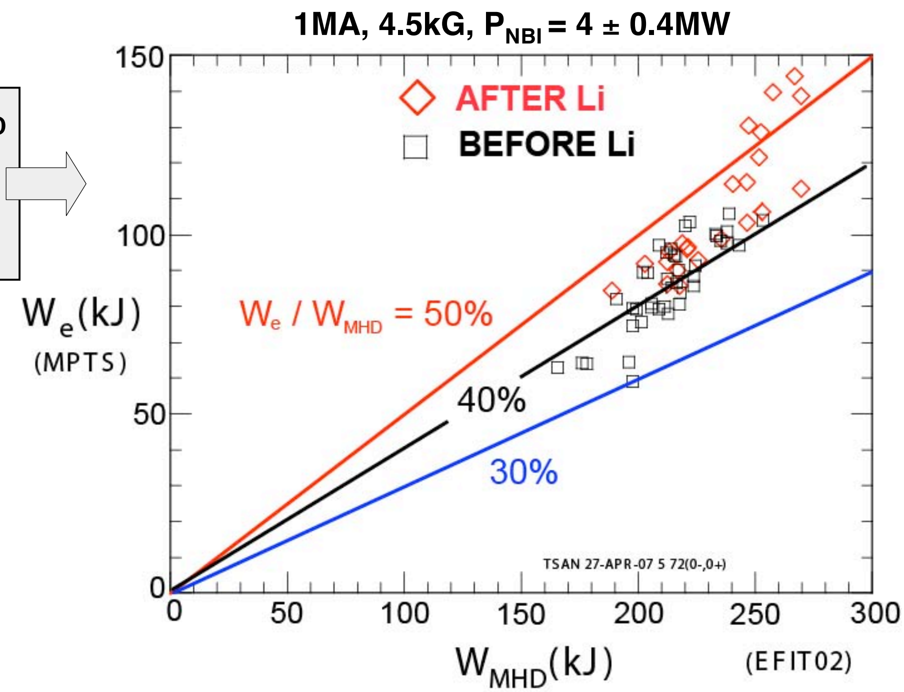
2nd LITER for complete toroidal coverage for 2008

Density decreases with increased Lithium deposition



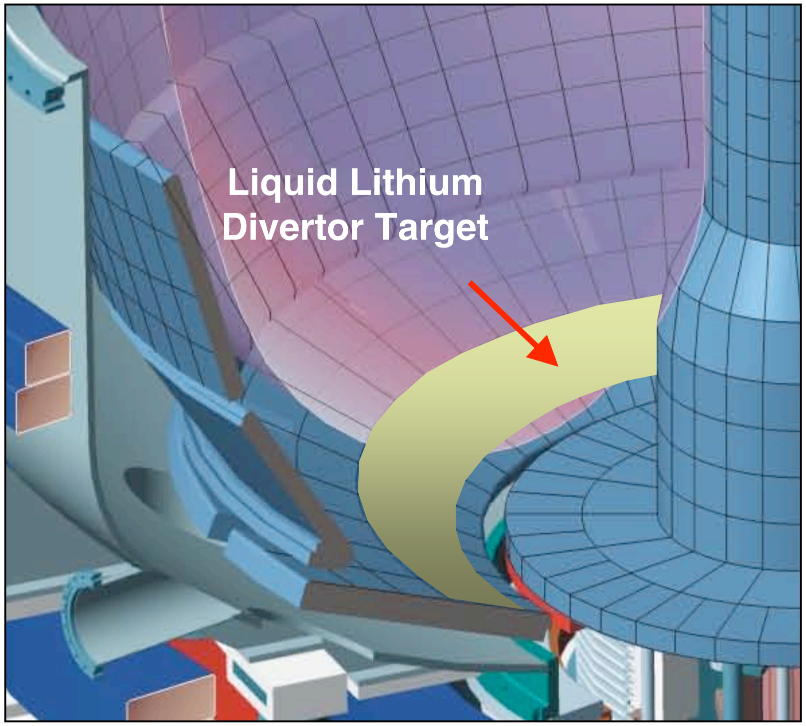
- W_e increases up to 40%
- Max. (W_e / W_{MHD}) = **45% ◊ 55%**

- **Much of increase in stored energy comes from electrons (broader Te)**
- **Edge hydrogenic neutral density and recycling also decreased**



Next Step in Innovative Liquid Lithium PFC Research

- **Liquid Lithium Divertor for D pumping**
  - Control density rise for long-pulse
  - Improve H-mode performance
  - Increase non-inductive current fraction

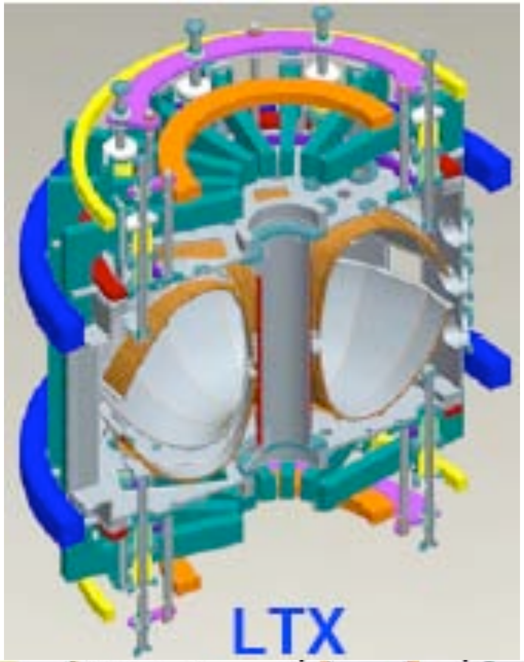


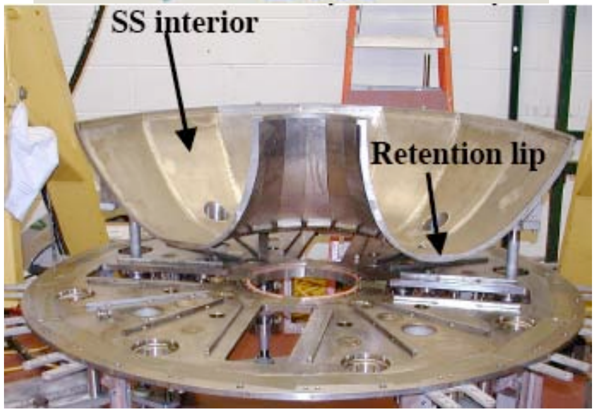
Initial LLD operational FY09

Second LLD in FY10

SDNL

LTX to test ultra-low recycling with thin liquid li wall surface





Lithium Evaporation Improved EBW H-mode Coupling

Efficient Off-Axis CD needed for Advanced ST Operations

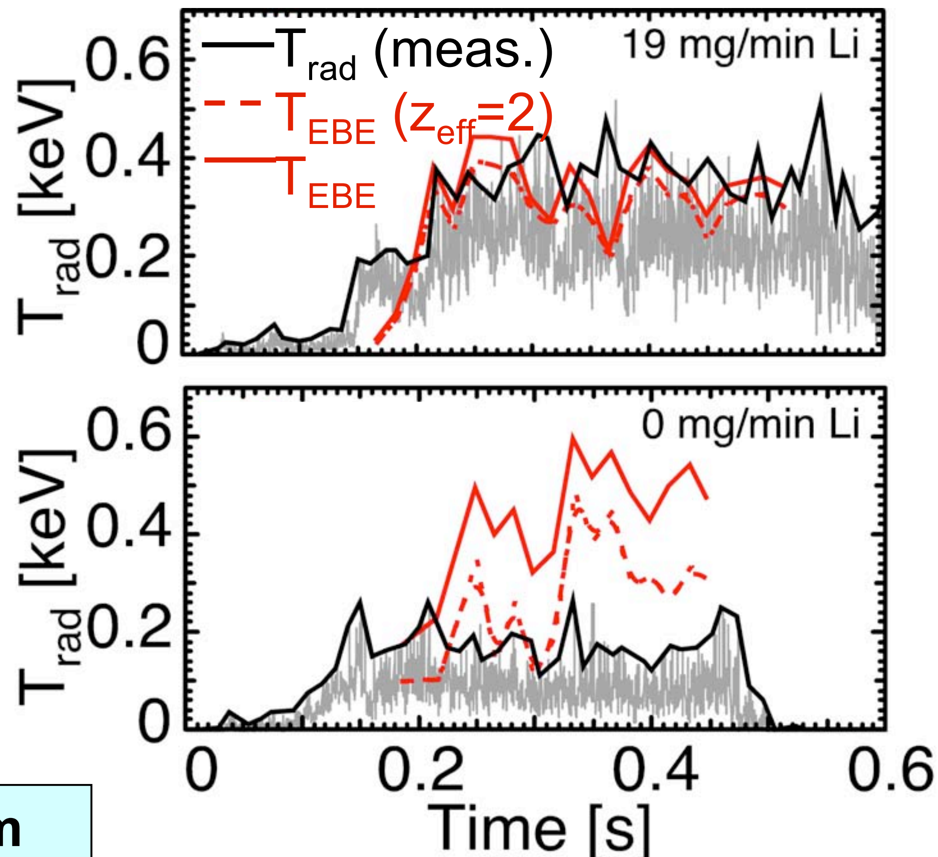
NSTX

Modeling shows adding 1 MA of off-axis EBWCD to ST-CTF plasma significantly increases stability: *Y-K. M. Peng, et al., PPCF, 47 (2005)*

- β_n increases from 4.1 to 6.1 (β_t increases from 19% to 45%)

Good 28 GHz EBW Emission Observed with LITER in H-mode

- **For highest Li evaporation rate, 19 mg/min:**
  - Measured and simulated T_{rad} with collisional damping agree
  - Lithium conditioning increases T_e and reduces L_n near B-X-O mode conversion layer
- **For no Li:**
  - Measured T_{rad} is much less than simulated
  - For T_e < 20 eV, EBW collisional damping becomes significant



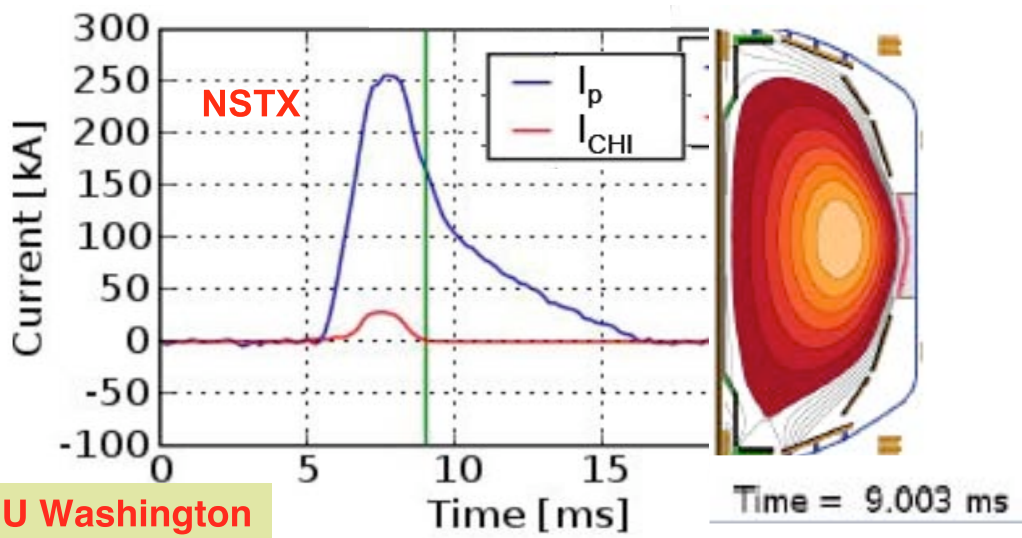
28 GHz 350 kW ECH/EBW system planned in 2009 ORNL

(Ph.D. thesis)

Startup & Ramp-up for ST-CTF and Demo
A number of options being developed

NSTX

CHI drove 160 kA of closed-flux current



U Washington

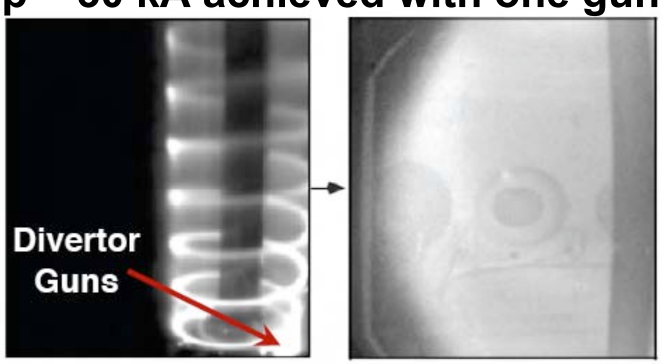
CHI to be optimized toward ~ 300 kA

High-β_N plasmas

7 MW of NBI Heating & CD

6 MW of HHFW Heating & CD

PEGASUS Gun Start-up
Ip ~ 30 kA achieved with one gun



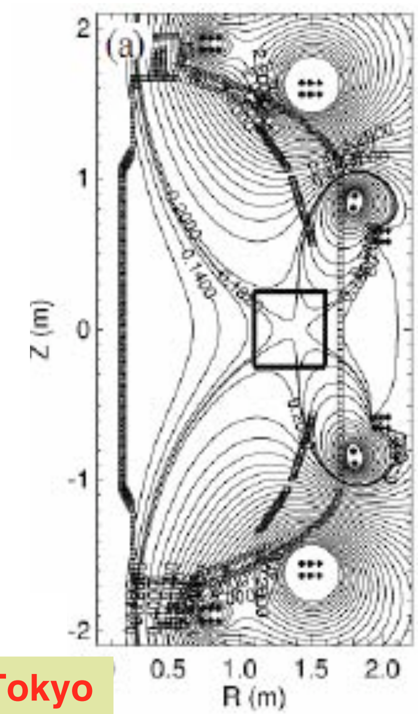
Further improvements with improved/multiple guns

U Wisconsin

Start-up with CHI, Plasma Gun, and/or Outer PF Flux

ECH Preionization

CTF compatible Iron core provides limited high quality OH flux



KAIST, U Tokyo

NSTX participation in International Tokamak Physics Activity (ITPA) benefits both ST and tokamak/ITER research

NSTX

Actively involved in 18 joint experiments – contribute/participate in 25 total

Boundary Physics
- PEP-6 Pedestal structure and ELM stability in DN
- PEP-9 NSTX/MAST/DIII-D pedestal similarity
- PEP-16 C-MOD/NSTX/MAST small ELM regime comparison
- DSOL-15 Inter-machine comparison of blob characteristics
- DSOL-17 Cross-machine comparison of pulse-by-pulse deposition

Macroscopic stability
- MDC-2 Joint experiments on resistive wall mode physics
- MDC-3 Joint experiments on neoclassical tearing modes including error field effects
- MDC-12 Non-resonant magnetic braking
- MDC-13: NTM stability at low rotation

Transport and Turbulence
- CDB-2 Confinement scaling in ELMy H-modes: b degradation
- CDB-6 Improving the condition of global ELMy H-mode and pedestal databases: Low A
- CDB-9 Density profiles at low collisionality
- TP-6.3 NBI-driven momentum transport study
- TP-8.1 NSTX/MAST ITB similarity experiments
- TP-9 H-mode aspect ratio comparison

Wave Particle Interactions
- MDC-11 Fast ion losses and redistribution from localized Alfvén Eigenmodes

Advanced Scenarios and Control
- SSO-2.2 MHD in hybrid scenarios and effects on q-profile
- MDC-14: Vertical Stability Physics and Performance Limits in Tokamaks with Highly Elongated Plasmas

NSTX contributes strongly to fundamental toroidal confinement science in support of ITER, NHTX, ST-CTF

- **Most capable ST in world for developing high-non-inductive fraction, high β plasmas**
- **High-k + MSE + $\chi_i = \chi_{i\text{-}neo}$ + BES (future) = understand ST transport & turbulence**
- **Only ST in world with advanced mode stabilization tools and diagnostics**
- **Unique Li research (Liquid Li + divertor + H-mode) + broad ST boundary research**
- **Uniquely able to study multi-mode fast-ion instability effects with full diagnostics**
- **Developing unique heating and current drive tools essential for ST, useful for AT**
- **Developing unique plasma start-up and ramp-up research crucial to ST concept**
- **ST offers compact geometry + high β for attractive fusion applications:**
  - NHTX for plasma-material interface (PMI) and advanced physics
  - ST-CTF with reduced electrical and tritium consumption
  - More attractive fusion reactor - simpler/cheaper magnets, simplified maintenance