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NSTX

National Spherical Torus Experiment

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Masayuki Ono

For the NSTX Research Team

Fusion Power Associate Annual Meeting

September 27-28, 2006
Washington DC

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
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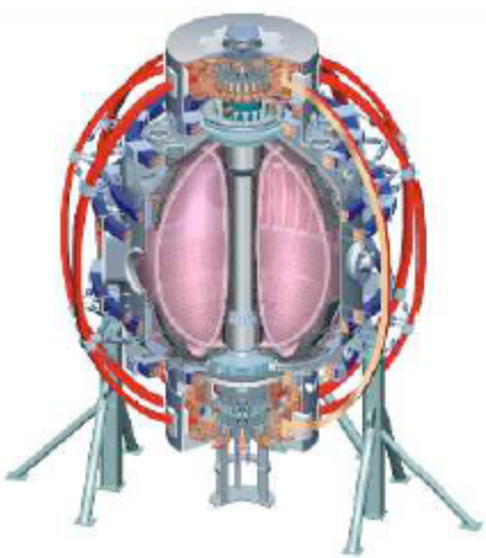
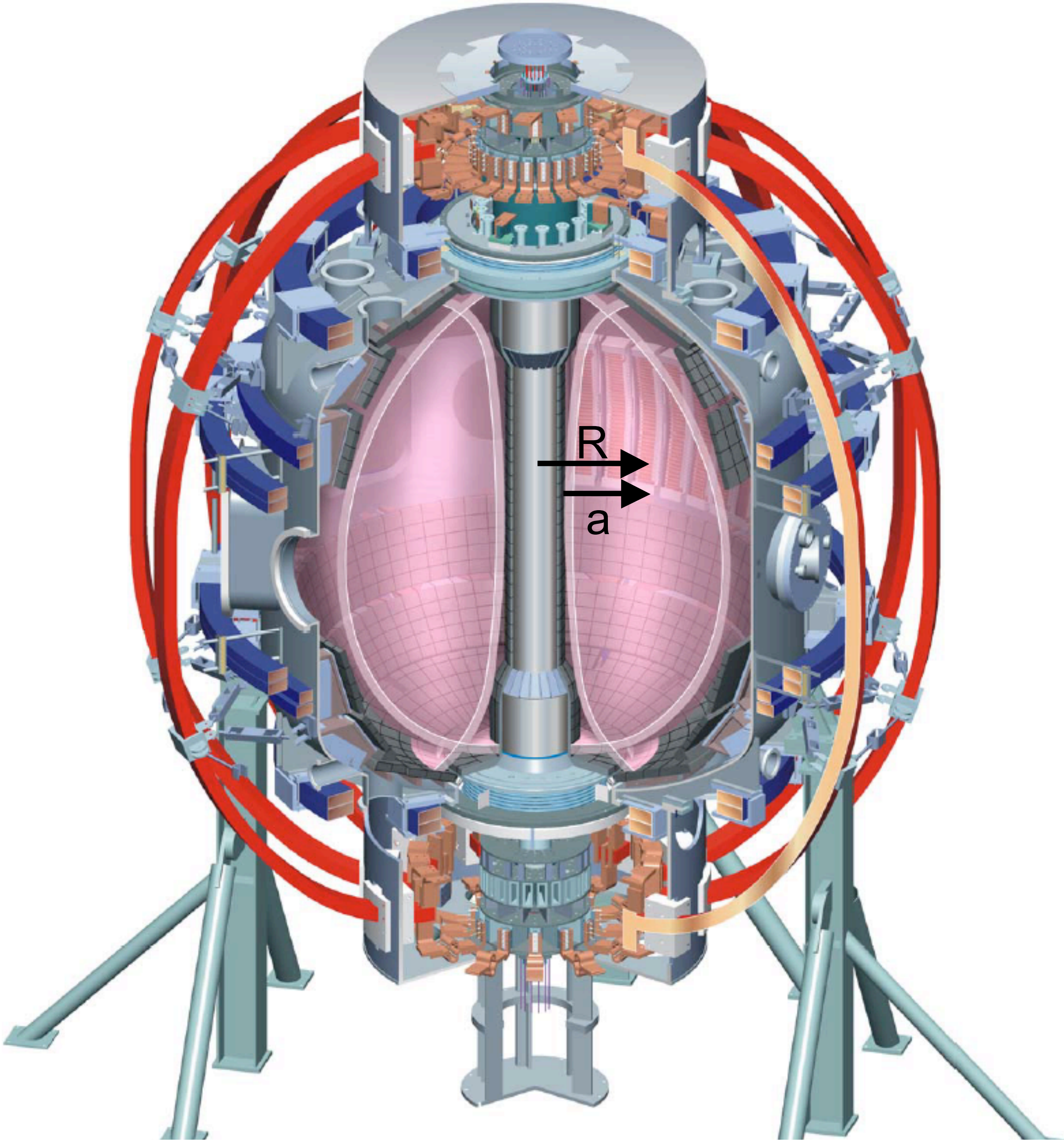
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep



NSTX is a World Leading Low-Aspect-Ratio Spherical Tokamak Facility



Device Parameters

R = 85 cm

a = 65 cm

κ = 1.7 - 3.0

δ = 0.3 - 0.8

B_T = 5.5 kG

I_p = 1.5 MA

V_p = 14 m^3

$E_p \sim$ 430 kJ

P_{NBI} = 7.4 MW

P_{HHFW} = 6 MW

350°C bakeout

Passive Plates

EF/RWM Coils

$I_{CHI} \sim$ 400 kA

60 cm dia. ports

Wide tang. access

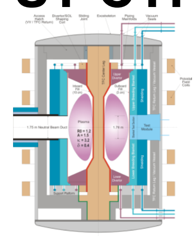
NSTX Strategy to Address Issues Important for ST-CTF and ITER through ITPA and USBPO

- Explore physics of Spherical Torus / Spherical Tokamak to provide basis for attractive U.S. Component Test Facility (CTF) and Demo.

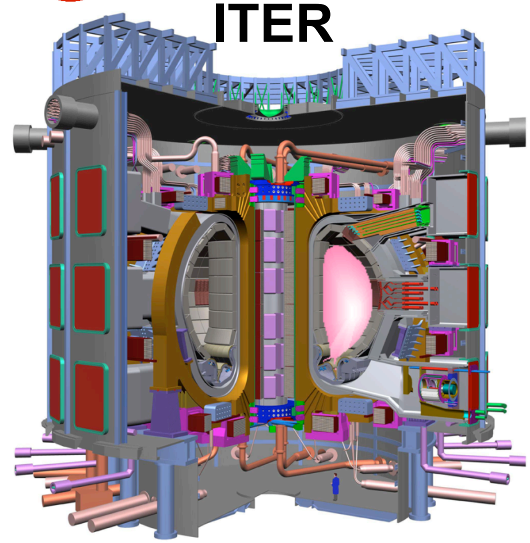
- Support preparation for burning plasma research in ITER using physics breadth provided by ST; support and benefit from "ITPA Specific" activities.

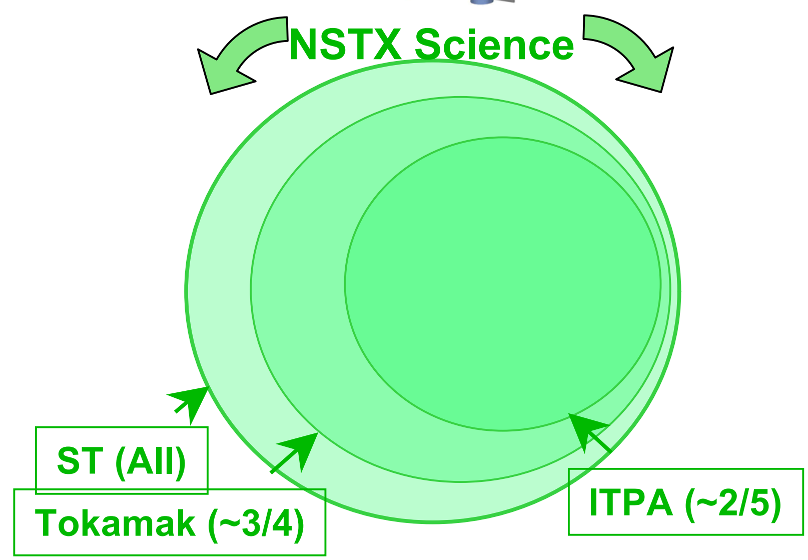
- Complement and extend tokamak physics experiments, maximizing synergy in investigating key scientific issues of toroidal fusion plasmas

ST CTF



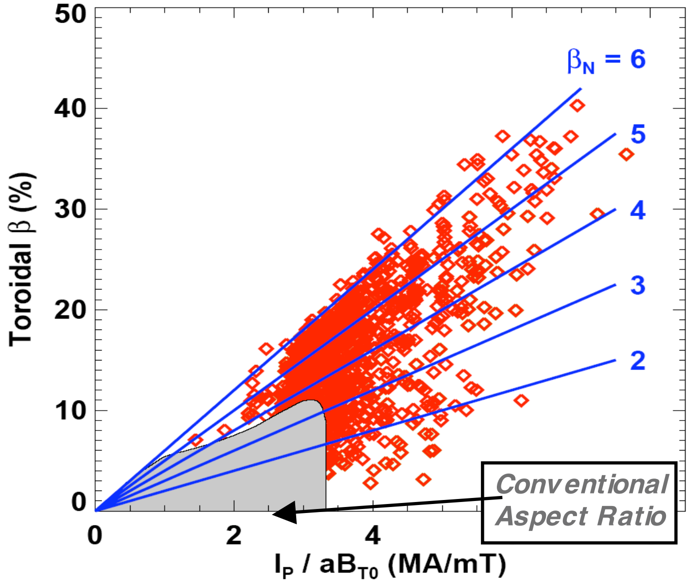
ITER



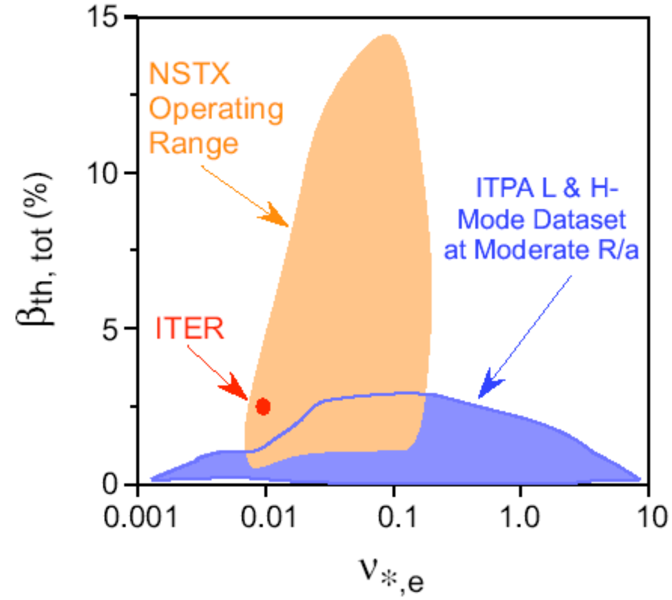


NSTX Offers Access to Wide Tokamak Plasma Regimes

Wide range of β_T up to ~ 40 %.

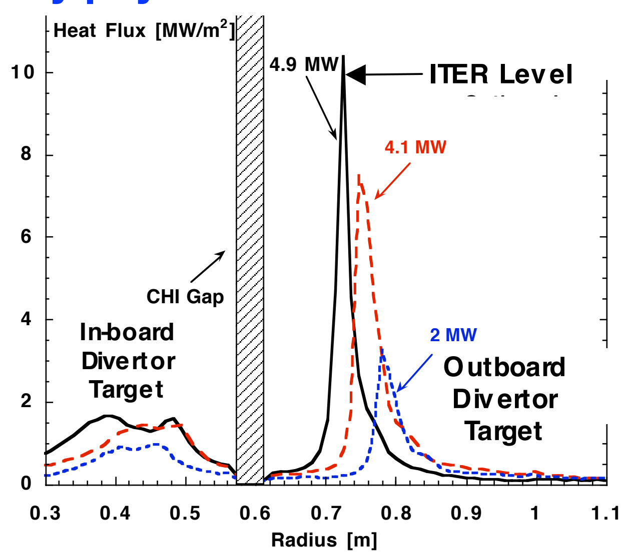


β Confinement Scaling, Electron Transport

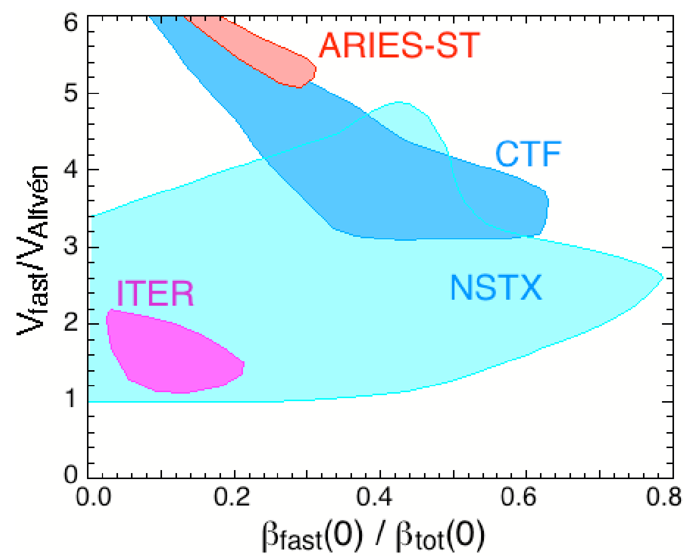


- **Confinement scaling with wide range of β_T up to ~ 40 %**

Boundary physics with ITER-level heat flux



Unique Energetic Particle Physics Capability

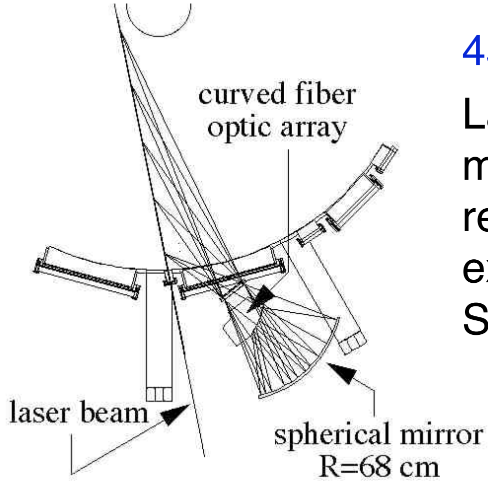


- **Full set of diagnostics: including MSE for j(r)**

State-of-the-Art Profile Diagnostics with Excellent Tangential Access Enable In-depth Research

NSTX

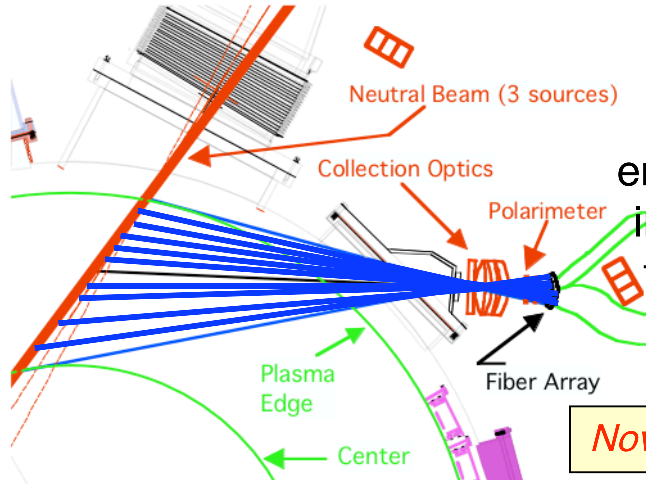
30 Ch, 60Hz MPTS for $T_e(r)$, $n_e(r)$



45 ch, 90 Hz planned

Large collection mirror and low readout noise gives exceptionally high S/N ratio

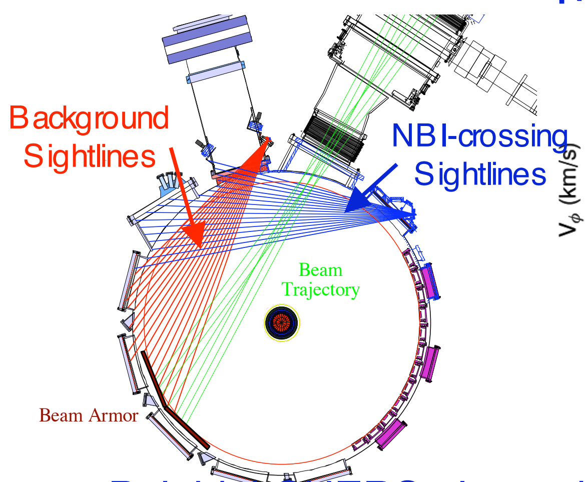
12 Ch MSE for q(r) (19 ch planned)



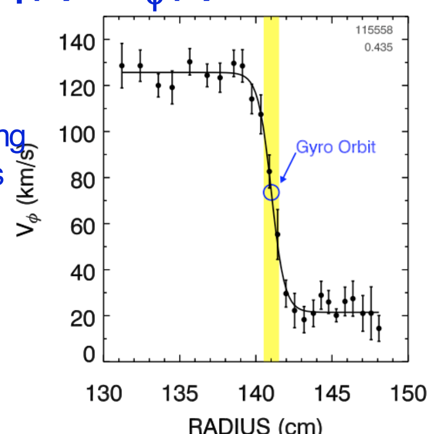
Innovative design enables MSE in kG range for the first time

Nova Photonics

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

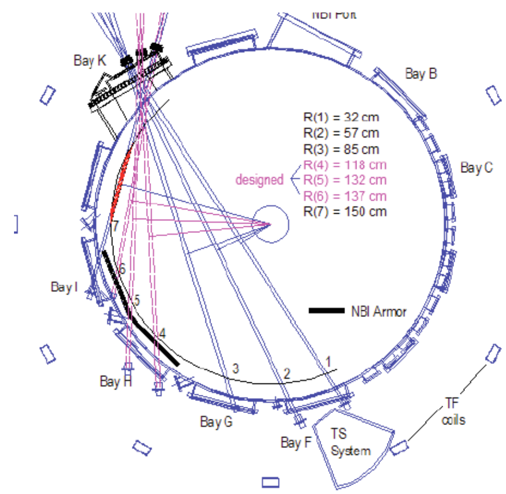


Poloidal CHERS planned



Resolves structure to ion gyro-radius

Tangential FIR Int-Pol (600 kHz)



Installed 6 ch

7 ch, 2MHz planned

Spans plasma cross-section

UC Davis

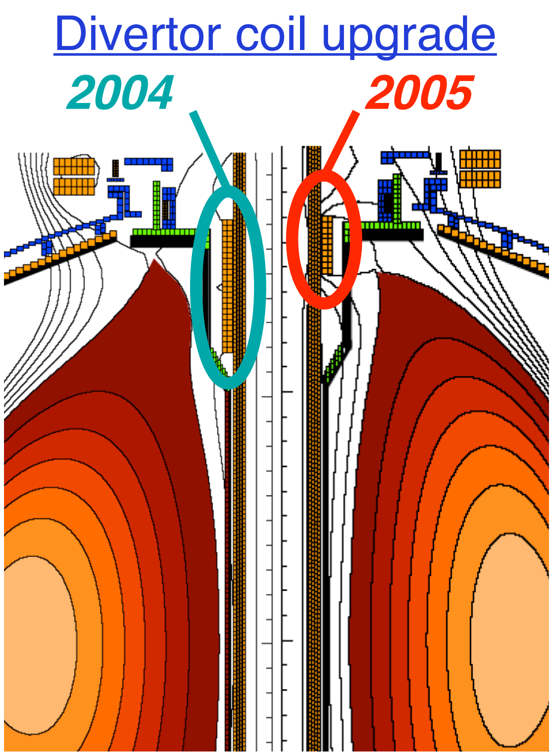
UCD

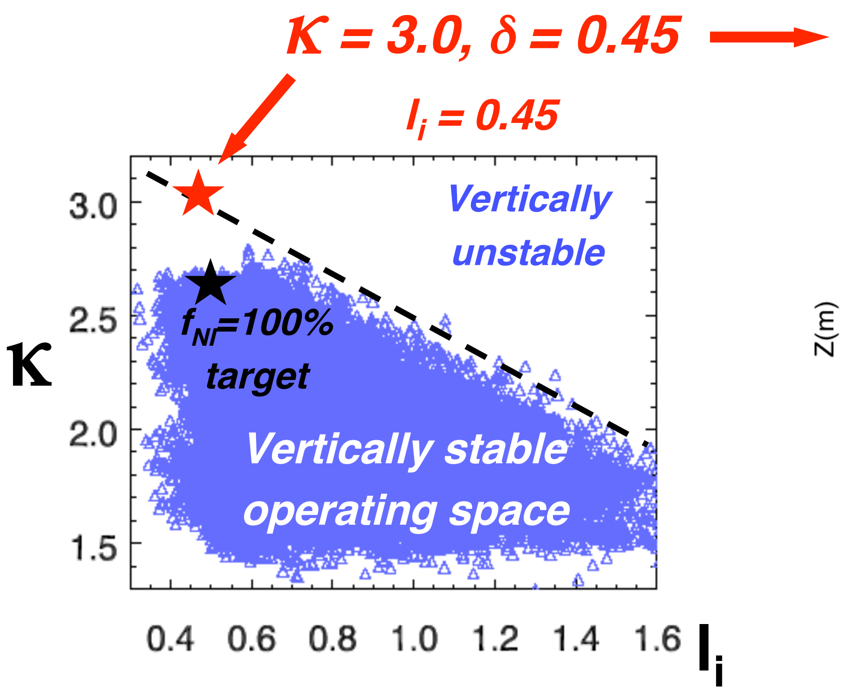
Extreme Elongation at Low l_i Opens Possibility of Higher β_P, f_{BS} Operation at High β_T

NSTX

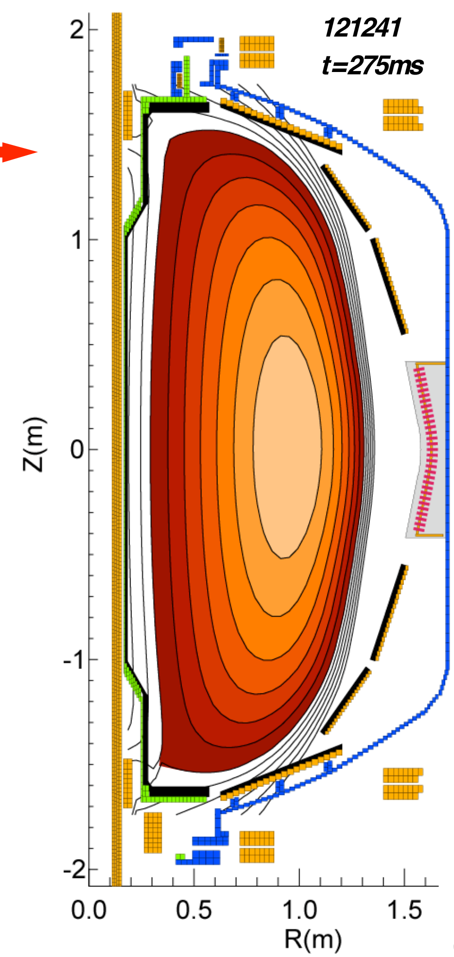
- Sustained $\kappa \geq 2.8$ (reached $\kappa = 3$) for many τ_{WALL} using rtEFIT isoflux control
  - Allowed by divertor coil upgrade in 2005, **no** in-vessel vertical position control coils
- High κ research important for CTF design studies

GA



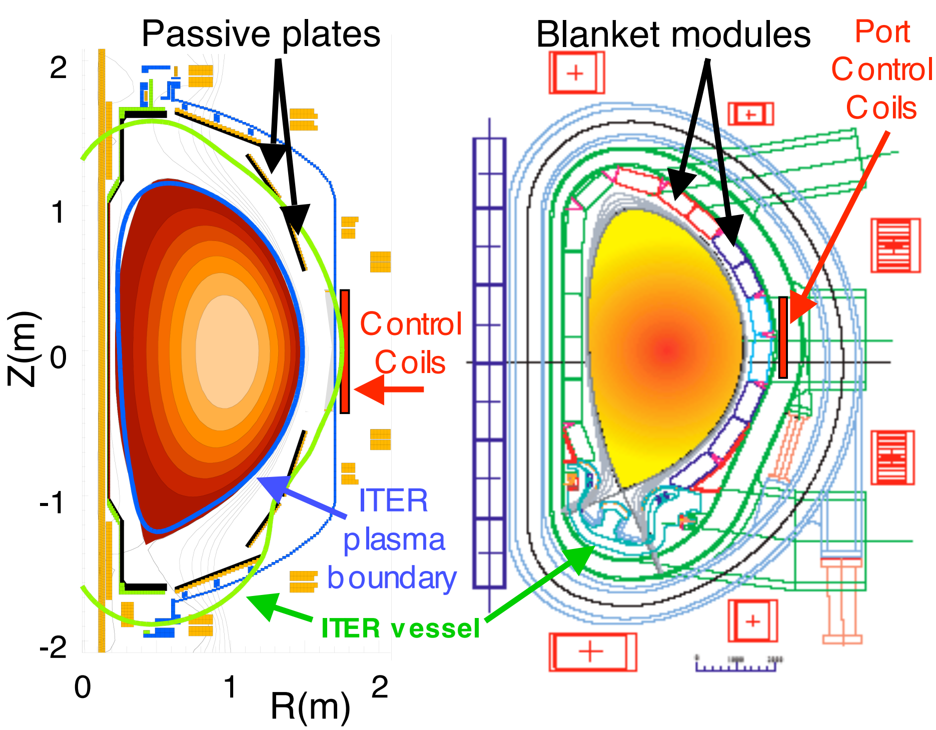


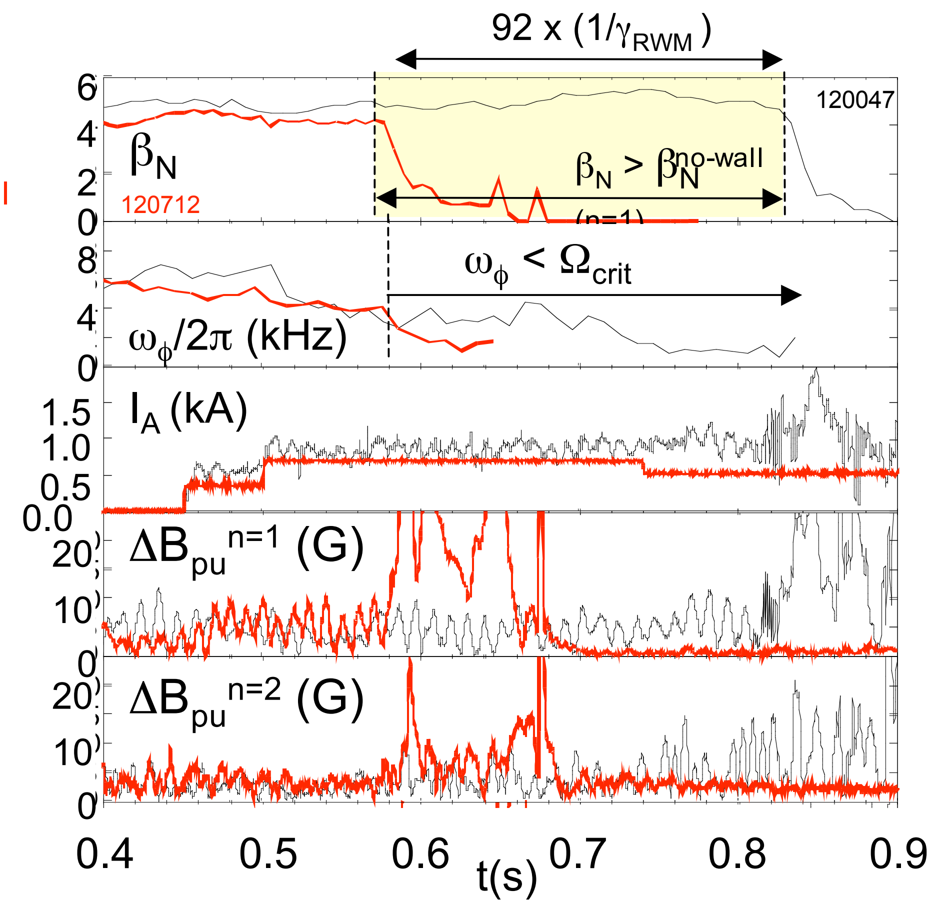
(Gates, et al., PoP **13** (2006) 056122.)



Low aspect ratio, high β provides high leverage to uncover key tokamak physics (e.g. RWM control, rotation damping, high elongation)

NSTX / ITER RWM control





Addressing relevant physics for ITER, CTF, KSTAR

RWM actively stabilized at ITER-relevant rotation for ~ 90/γ_{RWM}

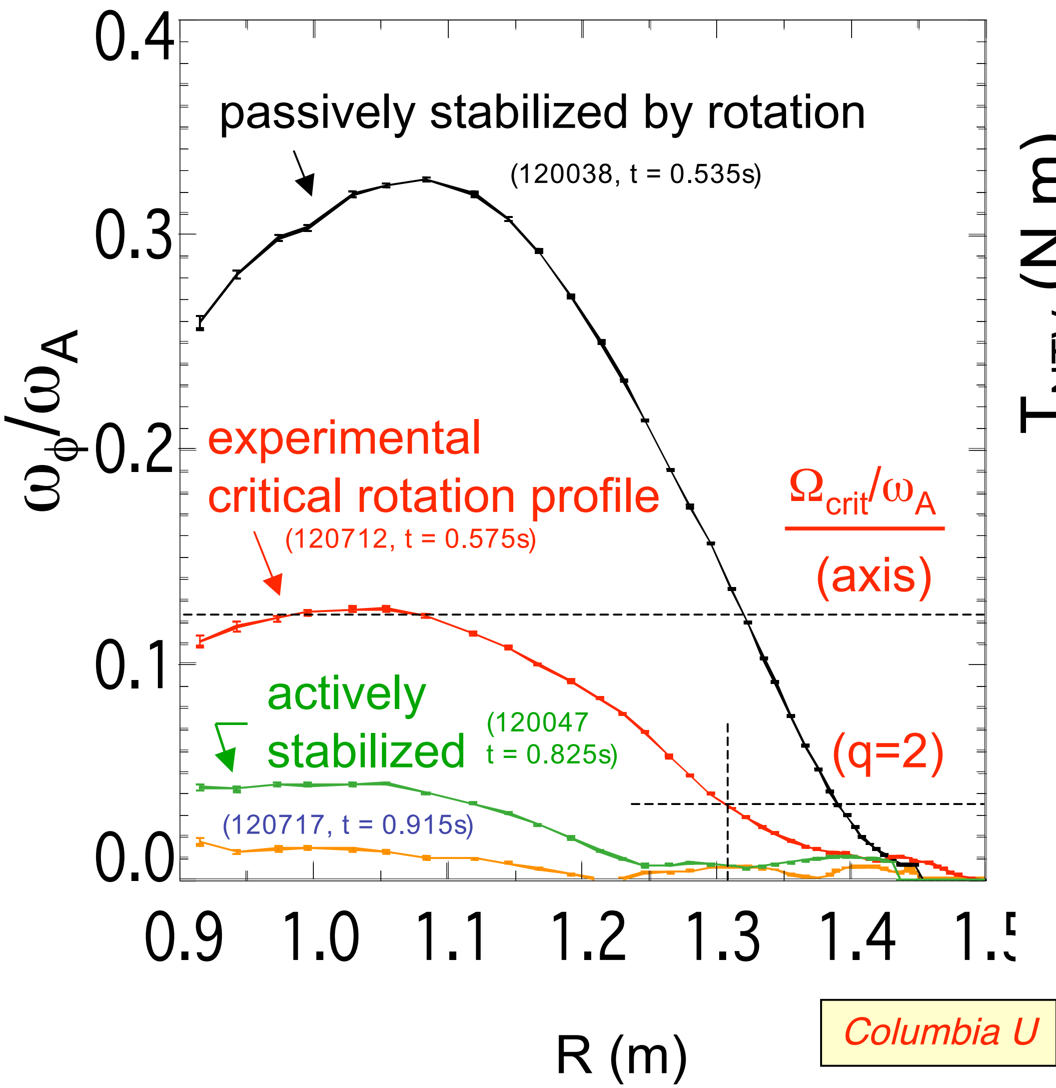
Columbia U

(Sabbagh, et al., PRL **97** (2006) 045004)

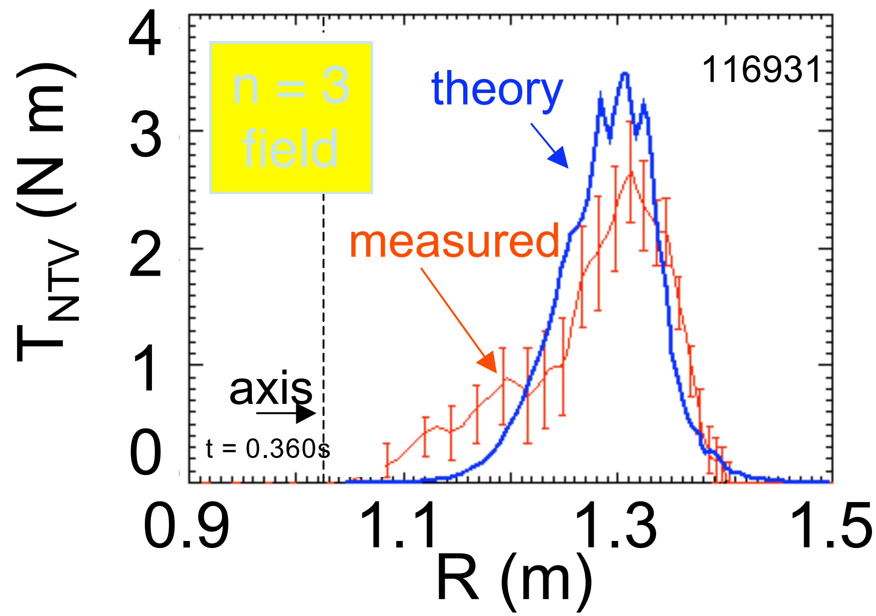
Rotation reduced far below RWM critical rotation profile

NSTX

Non-resonant n = 3 magnetic braking used to slow entire profile



First quantitative agreement with full neoclassical toroidal viscosity theory



Viable physics for simulations of plasma rotation in future devices (ITER, CTF, KSTAR)

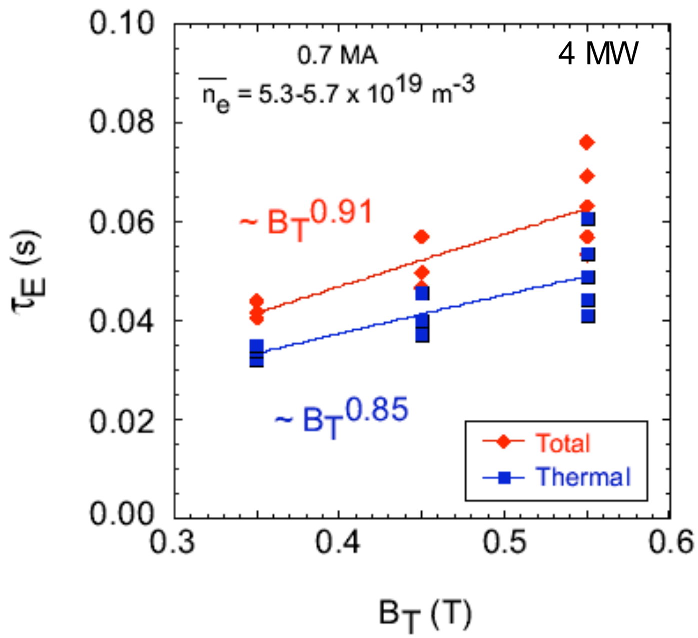
(Zhu, et al., PRL **96** (2006) 225002.)
Columbia U. thesis dissertation

Dedicated H-mode Confinement Scaling Experiments Have Revealed Some Surprises

NSTX

Strong dependence on B_T

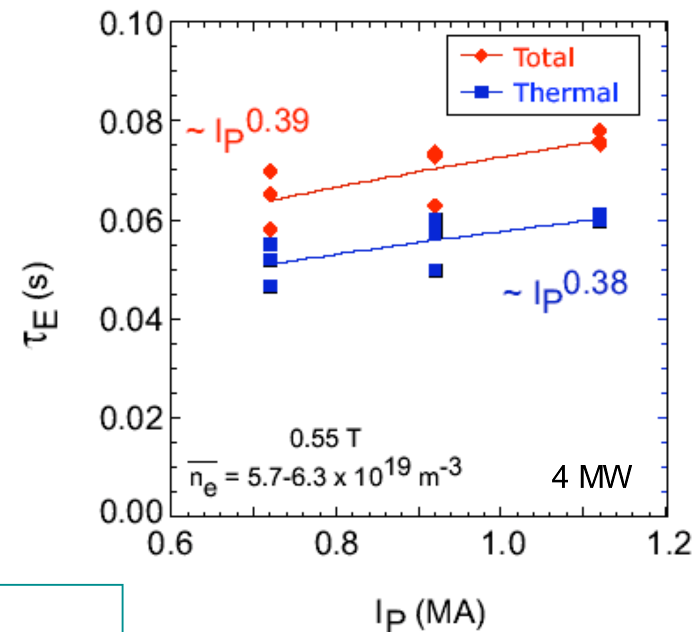
$H_{98y,2}$ ~ 0.9 → 1.1 → 1.4



$\tau_{E,98y,2}$ ~ $B_T^{0.15}$

Weaker dependence on I_p

$H_{98y,2}$ ~ 1.4 → 1.3 → 1.1



(Kaye et al,
NF **46** [2006] 848)

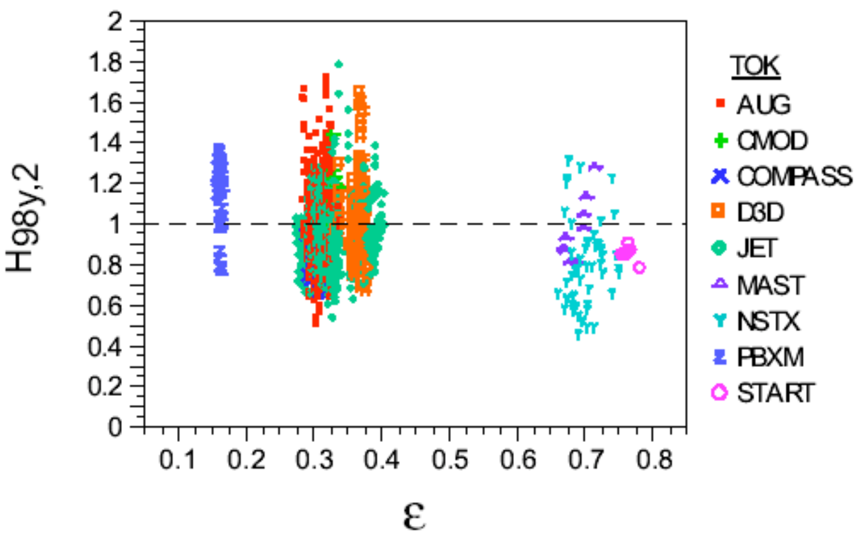
$\tau_{E,98y,2}$ ~ $I_p^{0.93}$

$\tau_E \sim I_p^{1.3\text{-}1.5}$ at fixed q

$\tau_{E,98y,2} \sim I_p^{1.1}$ at fixed q

NSTX Data Key to Addressing High-Priority ITPA Tasks

ITER98PB(y,2) scaling does not represent low R/a data well



NSTX data used in conjunction with higher R/a data to establish ε (=a/R) scaling with more confidence

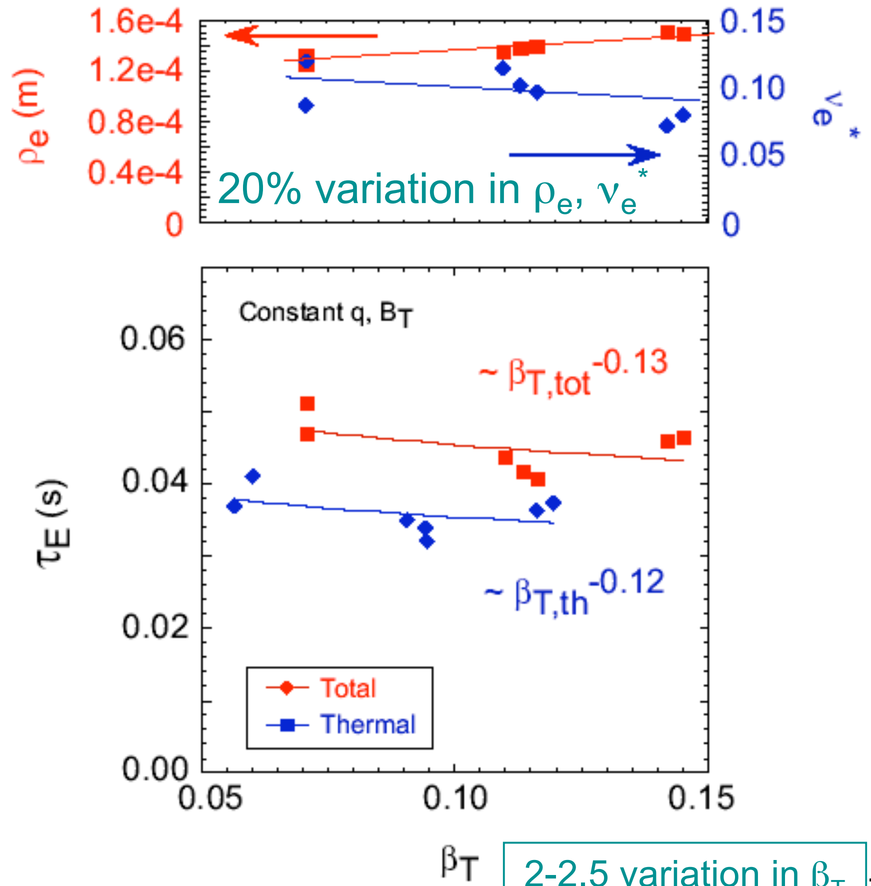
$\tau_{98y2} \sim \varepsilon^{0.58}$

$\tau_{new} \sim \varepsilon^{1.03}$

(Kaye et al., PPCF **48** [2006] A429)

β-scan at fixed ρ_e, ν_e^*

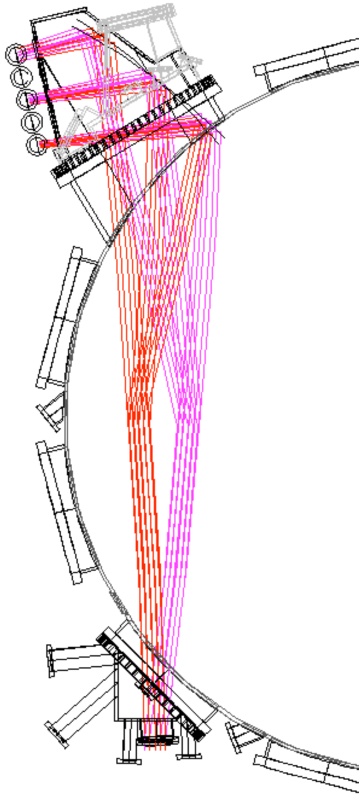
- β-dependence important to ITER advanced scenarios ($B\tau_{98y2} \sim \beta^{-0.9}$)
- Degradation of τ_E with β weak on NSTX



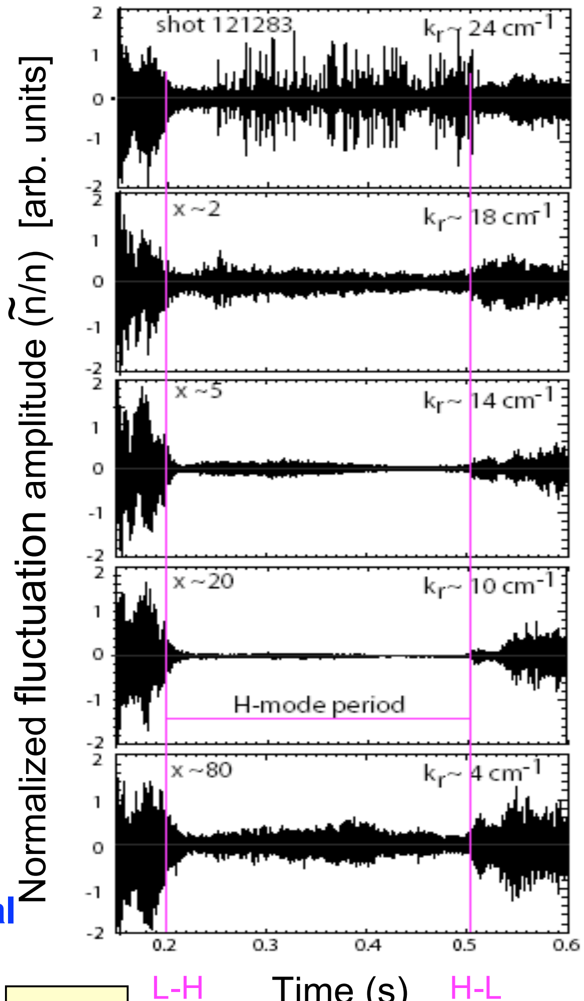
2-2.5 variation in β_T

Detailed Transport and Turbulence Measurements during L-H Transition Reveals Important and Tantalizing Electron Transport Physics

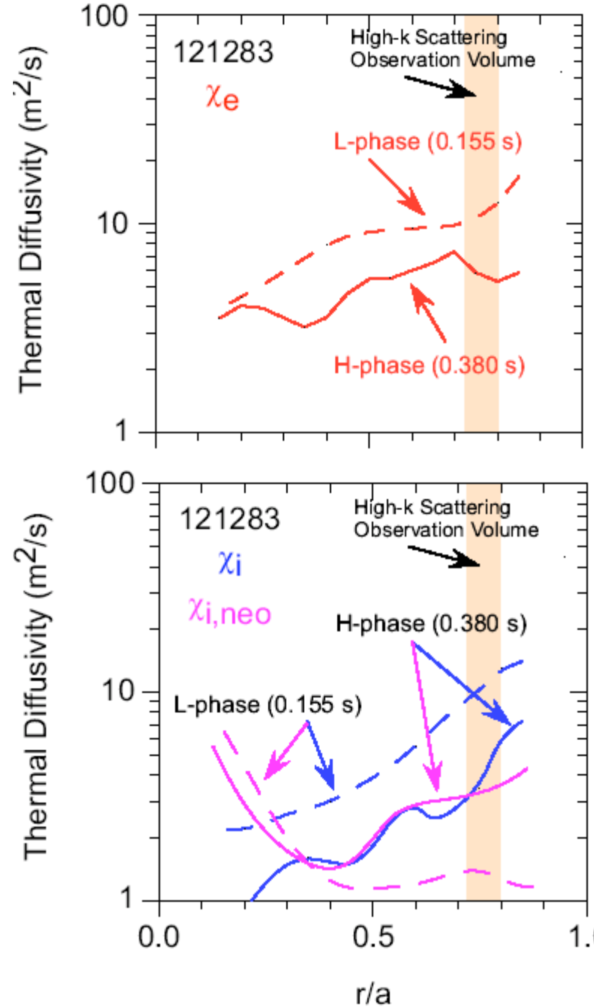
Tangential scattering system measures reduced fluctuations ($\tilde{n}/n$) in both ITG/TEM and ETG ranges during H-mode



Unprecedented spatial resolution at high k



UCD



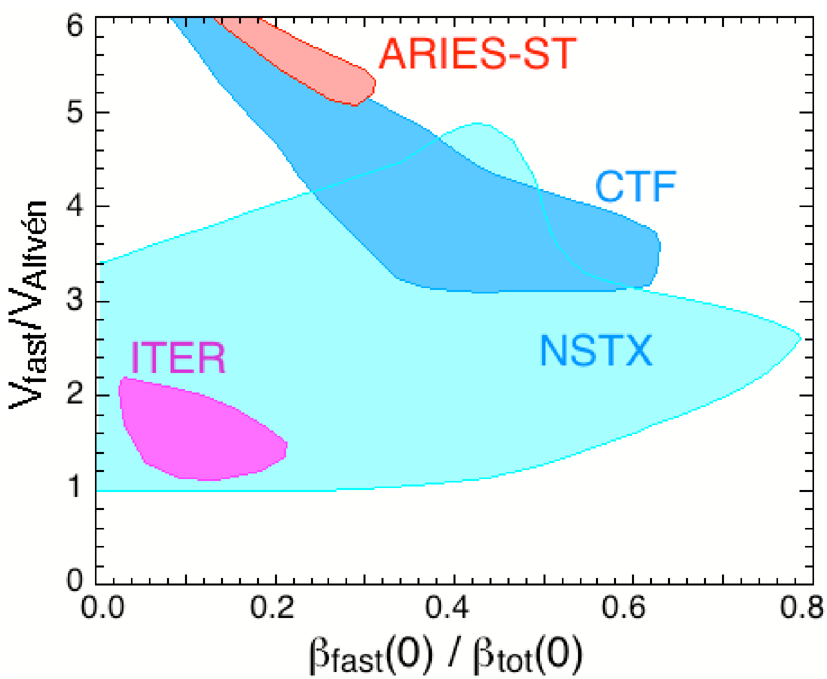
Electron transport reduced, but remains anomalous

Ion transport during H-phase at neoclassical level

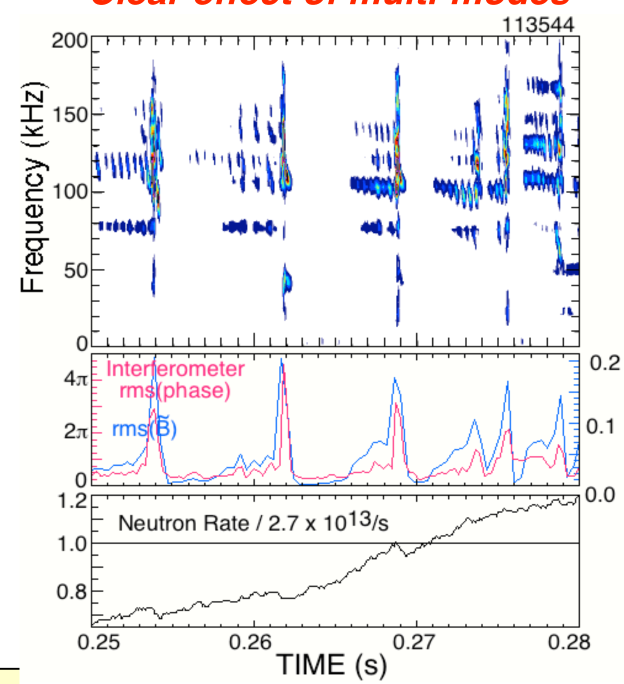
Clear effect of multi-modes observed for super-Alfvénic, fast ion population

NSTX

- ITER in new regime for fast ion transport
  - Interaction of many modes
- NSTX also routinely operates with super-Alfvénic fast ions;
  - Due to high power NBI, multi-mode transport can be investigated
  - Only machine capable of measuring q profile at large v_{fast} / v_{Alfven}



Clear effect of multi-modes

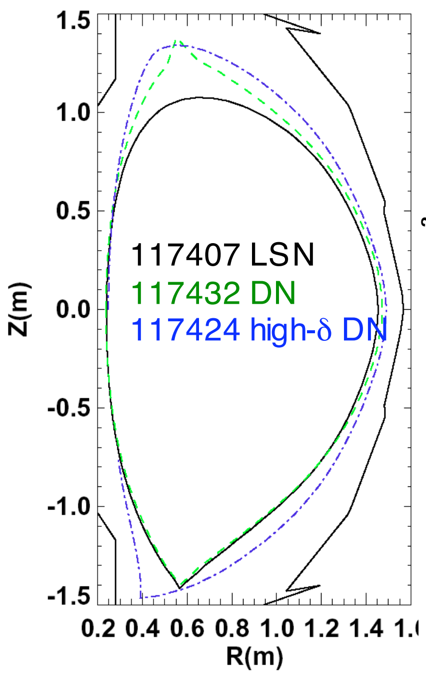


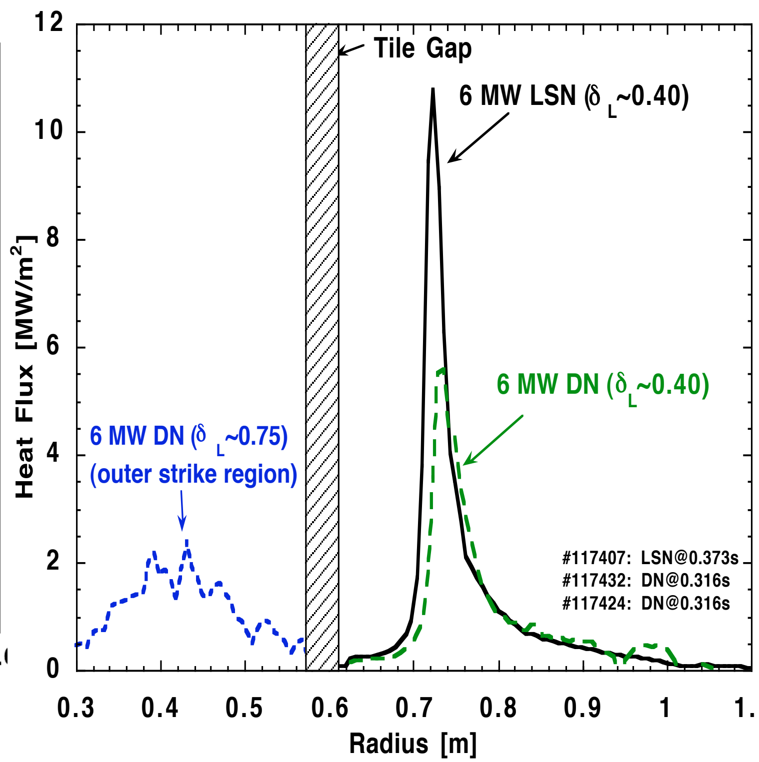
L, UC Irvine, UCLA

Increased Triangularity Reduces Peak Heat Flux to Divertor Target

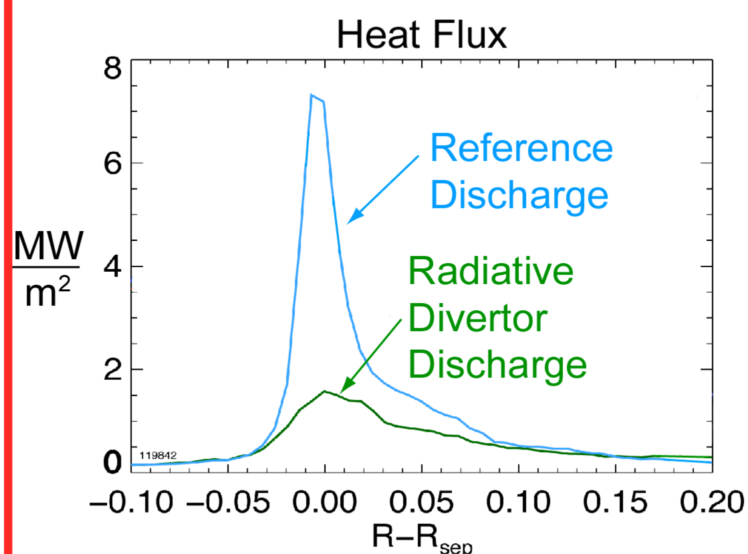
Compare **single-null** & double-null configurations with triangularity $\delta \approx 0.4$ at X-point and **high triangularity δ = 0.8 double-null** plasmas

Peak heat flux decreases as **1 : 0.5 : 0.2**





Developed Radiative Divertor regime: Obtained by steady-state D_2 injection into private flux region or ISP



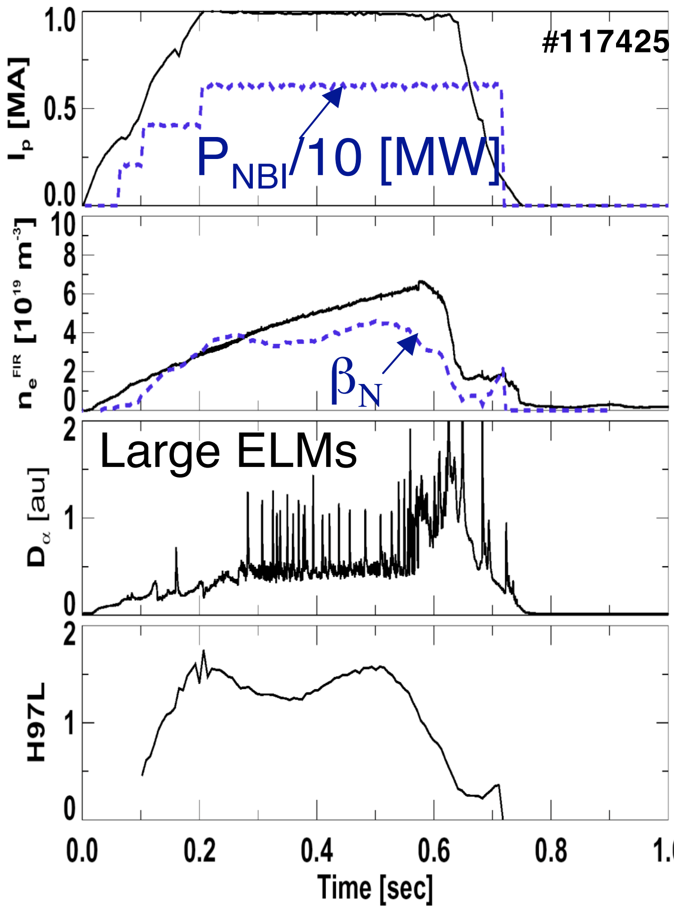
– Outer SP (OSP) heat flux reduced by 4-5
– No change in H-mode τ_E

ORNL, LLNL

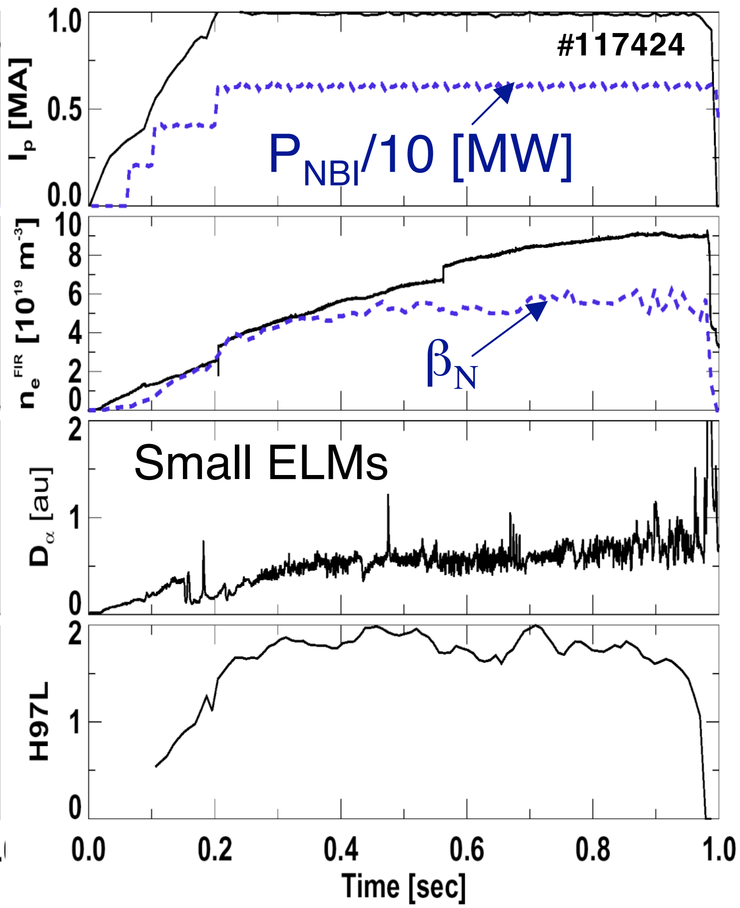
NSTX studying access conditions and structure of different ELM types

- **Small shape change leads to reduction of ELM size**

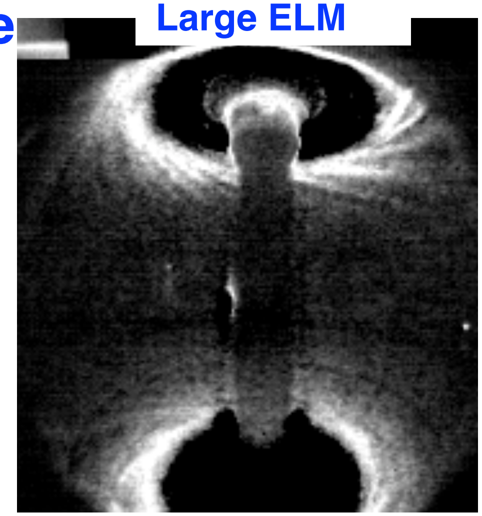
Balanced DN or biased slightly up



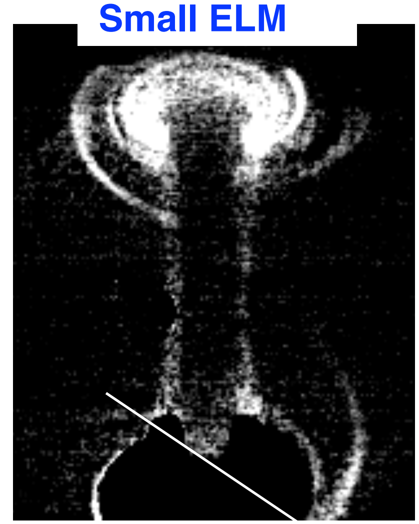
Biased slightly down



Large ELM



Small ELM



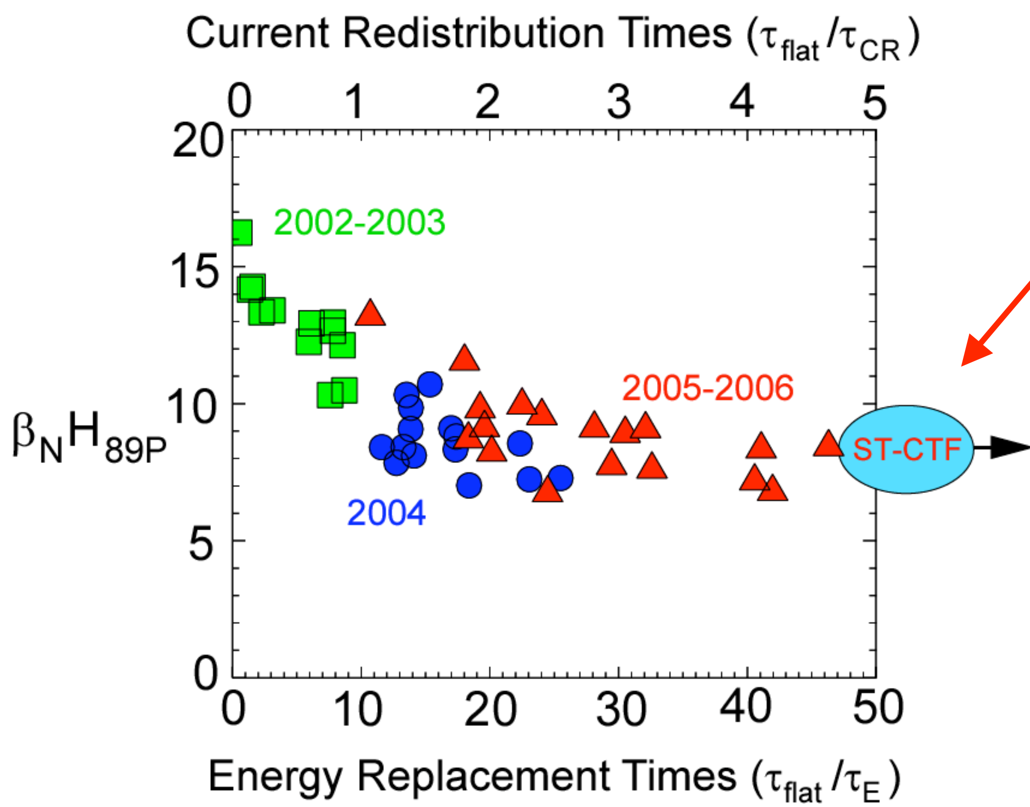
ORNL, Nova Photonics, Hiroshima Univ

Maingi, POP 2006

High performance can be sustained for several current redistribution times at high non-inductive current fraction

- **∇p and NBI current drive provide up to 65% of plasma current →**

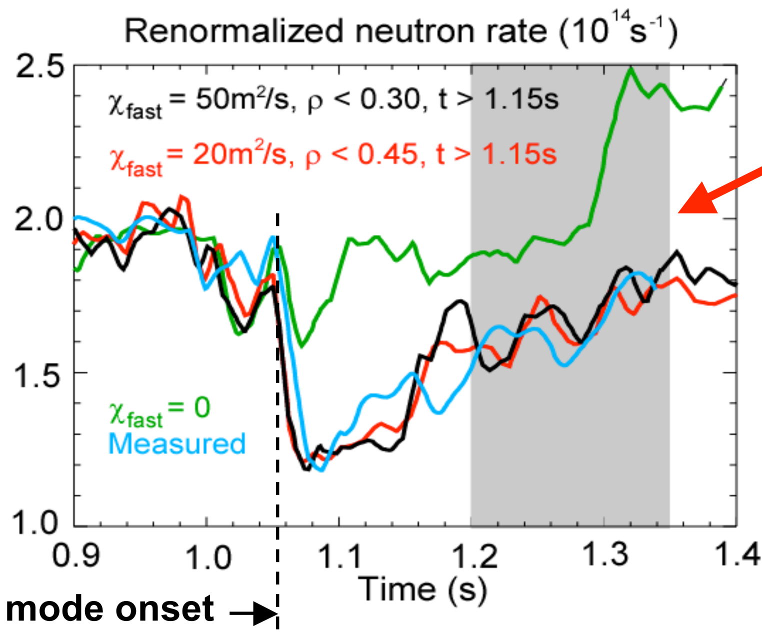
High $\beta_N \times H_{89P}$ ~ 9 **now sustained for ~ 50 τ_E**



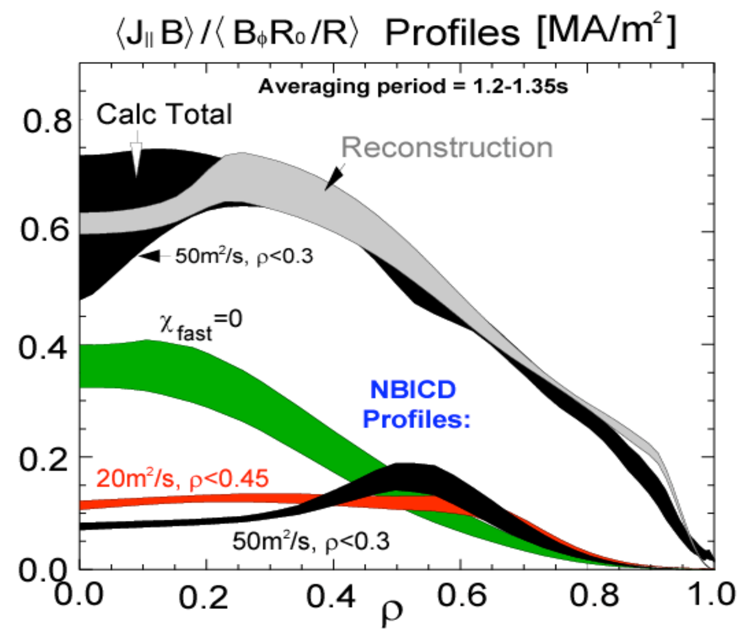
D. Gates, Phys. Plasmas **13**, 056122 (2006)

Mode-induced fast ion diffusion needed to explain neutron rate and $J_{||}(\rho)$ evolution during late n=1 interchange activity

- High core-localized anomalous fast ion diffusion can account for neutron rate deficit
- Core δB from mode estimated to be 100's of Gauss → large χ_{fast}



- Diffusion of fast ions can convert centrally peaked J_{NBI} to flat or hollow profile
- Redistribution of NBICD makes predictions consistent with MSE



MHD-induced NBICD diffusion may contribute to "hybrid" scenarios proposed for ITER

Nova Photonics

J. Menard, Phys. Rev. Lett. **97**, 095002 (2006)

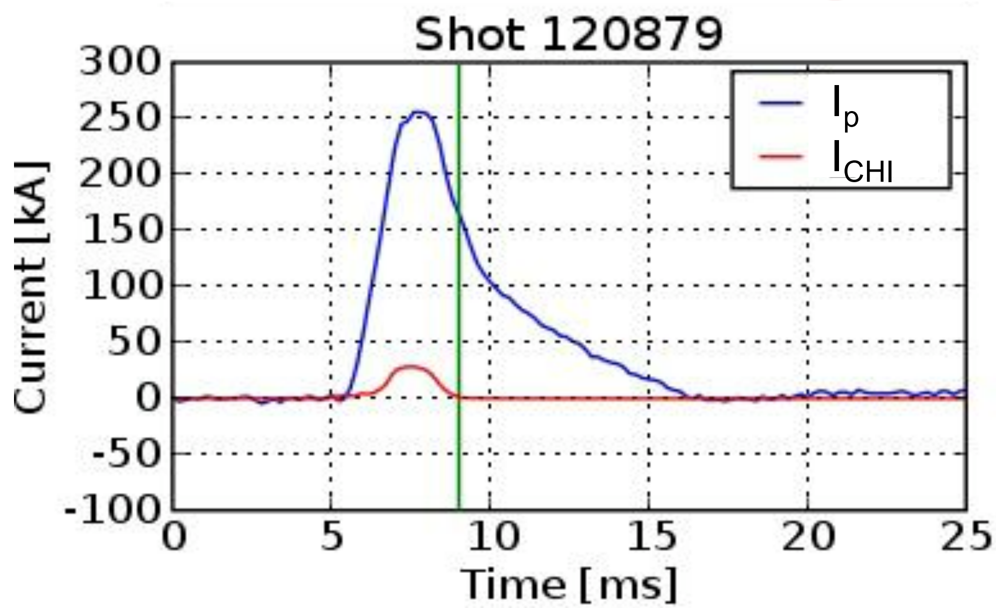
Coaxial Helicity Injection has convincingly demonstrated the formation of closed poloidal flux at high plasma current

NSTX

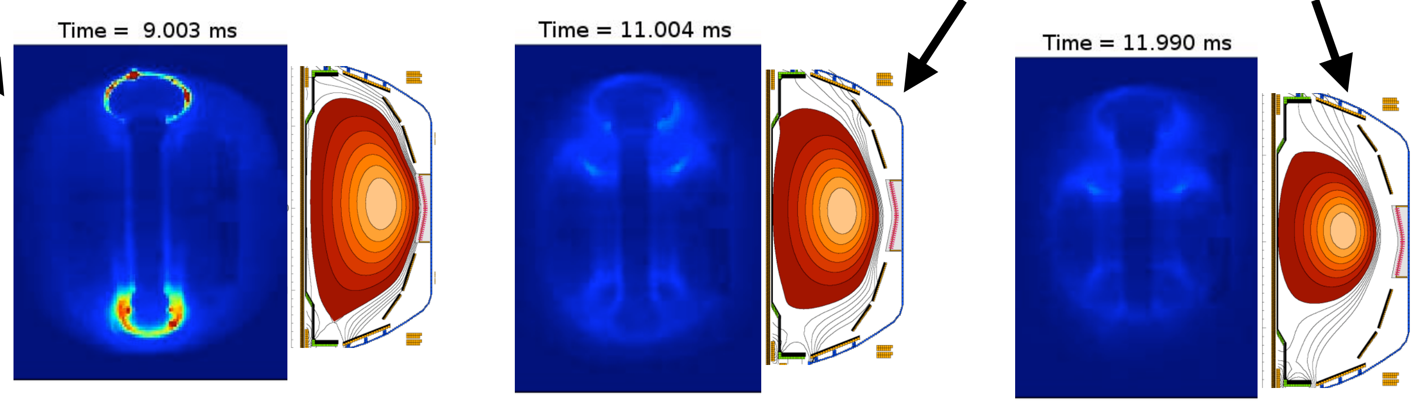
Evidence for high-I_P flux closure:

1. I_P=160kA remains after CHI injector current $I_{CHI} \rightarrow 0$ at t=9ms

2. After t=9ms, plasma current decays away inductively



3. Once $I_{INJ} \rightarrow 0$, reconstructions track dynamics of detachment & decay



NSTX contributes strongly to fundamental toroidal confinement science in support of ITER and future ST's

- Unique ST facility with powerful heating systems, advanced plasma control systems and state-of-the-art plasma diagnostics
- Wide range of accessible tokamak plasma parameters in MHD, T&T, Boundary, and Energetic Particle research supported by full diagnostic set
- Active EF/RWM feedback stabilization system demonstrated for a wide range of rotation speed including ITER relevant low rotation
- Unique opportunity for understanding electron transport and micro-turbulence with high-k (electron scale) scattering system
- Uniquely able to mimic ITER fast-ion instability drive with full diagnostics
- Broad ITER and CTF-relevant boundary physics research program
- Rapid progress toward fully non-inductive high performance scenarios
- Soleonid-free 160kA closed-flux plasma formation in NSTX using CHI