NSTX-U

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# XP1517: Neoclassical toroidal viscosity at reduced collisionality (independent coil control)


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Y.S. Park, (et al…)

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**NSTX-U Macrostability TSG Meeting**

**June 30th, 2015**

**PPPL**

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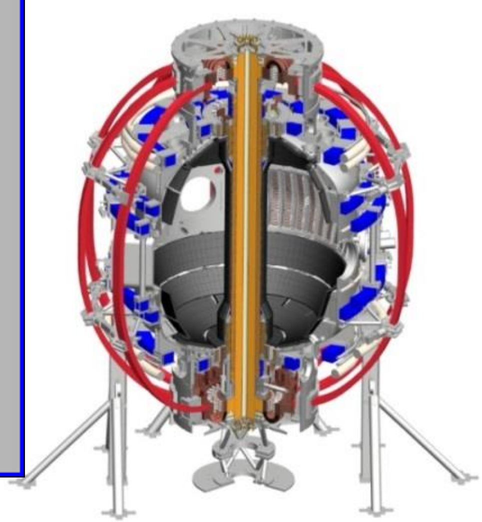

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V1.1

# Columbia U. Group 2015 Macrostability TSG XPs (Short Summary)

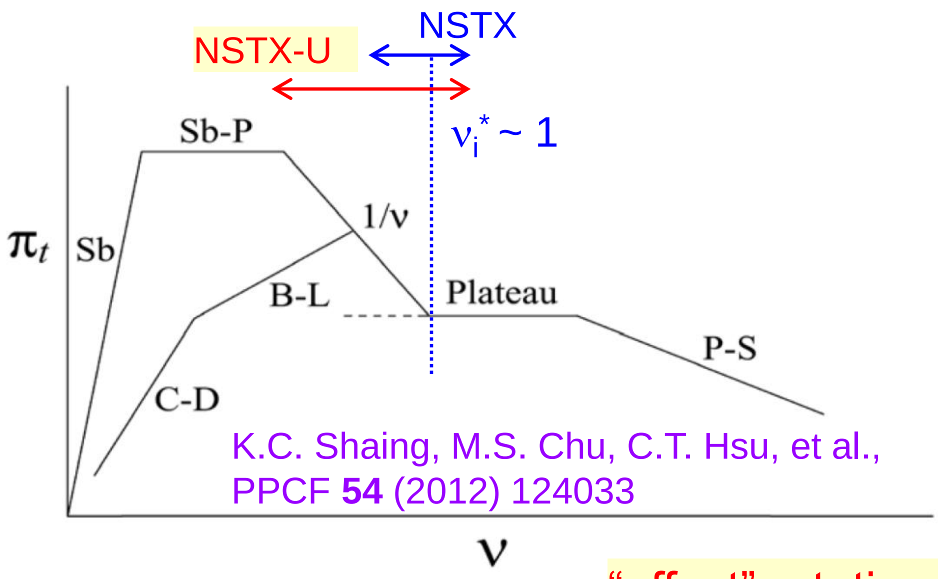
- XPs (related XPs assigned numbers for "2011 run")
  - RWM stabilization dependence on neutral beam deposition angle (~XP1149) (Berkery)
  - RWM stabilization physics at reduced collisionality (~XP1148) (Berkery)
  - RWM state space active control physics (independent coil control) (~XP1145) (Sabbagh)
  - RWM control physics with partial control coil coverage (JT-60SA) (~XP1147) (Y-S Park)
  - RWM PID control optimization based on theory and experiment (~XP1111) (Sabbagh)
  - RWM state space active control at low plasma rotation (~XP1146) (Y-S Park)
  - Neoclassical toroidal viscosity - reduced $\nu$ (independent coil control) (~XP1150) (Sabbagh)
  - NTV steady-state rotation at reduced torque (HHFW) (~XP1062) (Sabbagh)
  - Multi-mode error field correction using the RWMSC (to follow initial EFC XP)
  - NTM Entrainment in NSTX-U (Y.S. Park)
- Piggyback XPs
  - Disruption PAM characterization, measurements, and criteria (Sabbagh, for DPAM WG)

NOTE: - some shot plans already scoped out in web submissions (not repeated here)
- run day requests mostly assume leveraging "2nd NBI XP", "Ip/Bt scaling XP"

# XP1517: Neoclassical toroidal viscosity at reduced collisionality (independent coil control)

- Motivation
  - Experimentally, the dependence of neoclassical toroidal viscosity (NTV) at low collisionality needs further study
  - Understanding important for NSTX-U $V_\phi$ control, other tokamaks, future devices
- Goals / Approach
  - Examine the dependence of NTV on ion collisionality
    - expected to increase with decreasing $\nu_i$ from present experiments, and theory
  - Determine if superbanana plateau increase of NTV depends on $\nu_i$
  - Operate with pre-programmed n = 2, 3 applied fields for $V_\phi$ feedback control testing at reduced $\nu_i$
- Addresses
  - NSTX Milestones R(15-3), closed-loop rotation control with 3D fields
  - ITPA joint experiment MDC-21

## NTV strength varies with plasma collisionality $\nu$, $\delta B^2$, rotation




K.C. Shaing, M.S. Chu, C.T. Hsu, et al., PPCF **54** (2012) 124033

## NTV force in "1/ν" collisionality regime

$$\left\langle \hat{e}_t \bullet \vec{\nabla} \bullet \overleftrightarrow{\Pi} \right\rangle_{(1/\nu)} = B_t R \left\langle \frac{1}{B_t} \right\rangle \left\langle \frac{1}{R^2} \right\rangle \frac{\lambda_{1i} p_i}{\pi^{3/2} \nu_i} \varepsilon^{3/2} (\omega_\phi - \omega_{NC}) I_\lambda$$

"offset" rotation

$T_i^{5/2}$

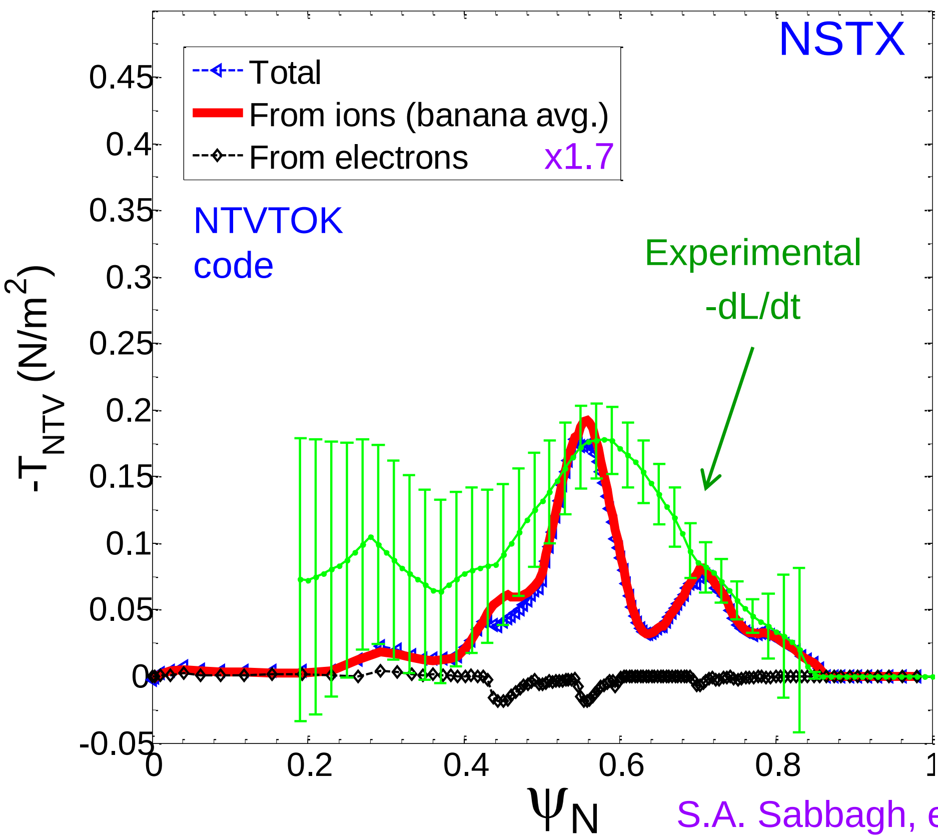
plasma rotation

1/aspect ratio (compare to KSTAR)

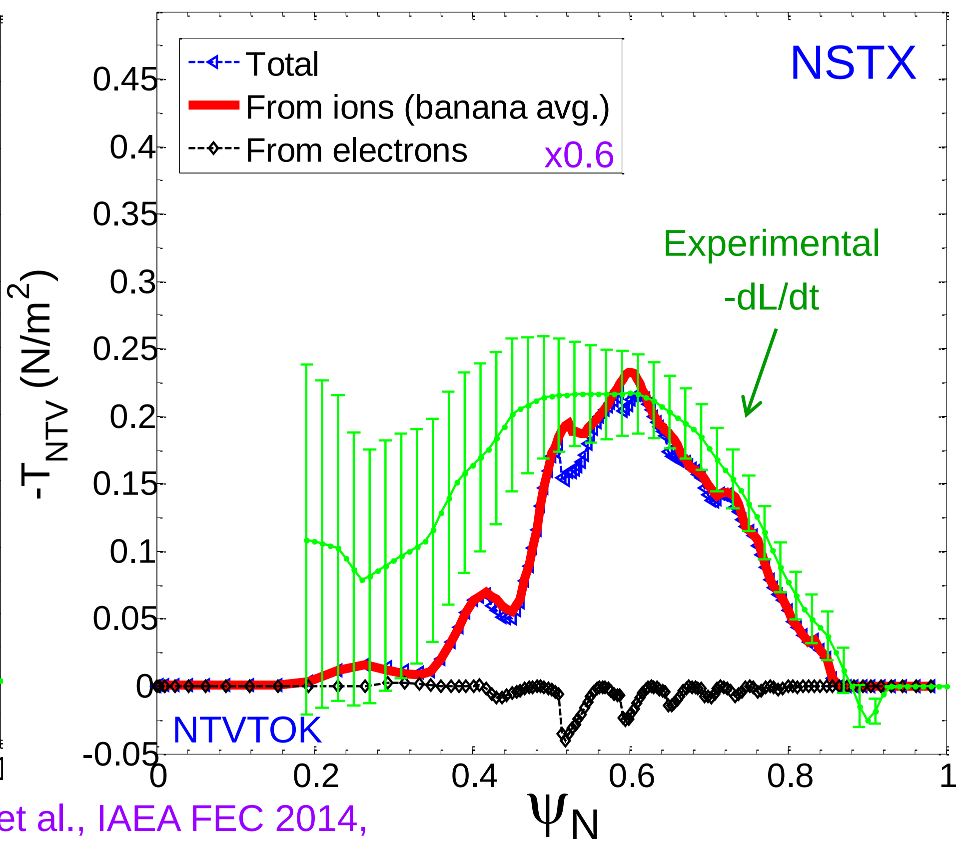
K.C. Shaing, et al., PPCF **51** (2009) 035004

# Measured NTV torque density profiles quantitatively compare well to computed $T_{NTV}$ – NTVTOK code interfaced to NSTX-U

n = 2 coil configuration




n = 3 coil configuration

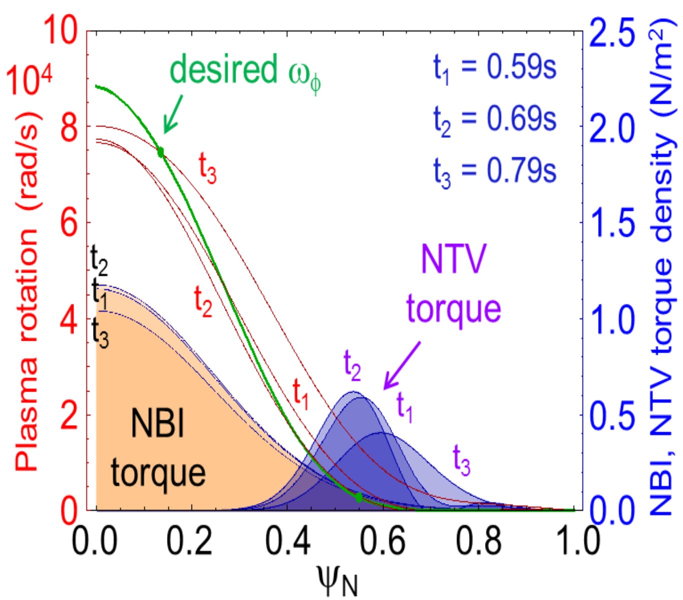



S.A. Sabbagh, et al., IAEA FEC 2014, paper EX/1-4

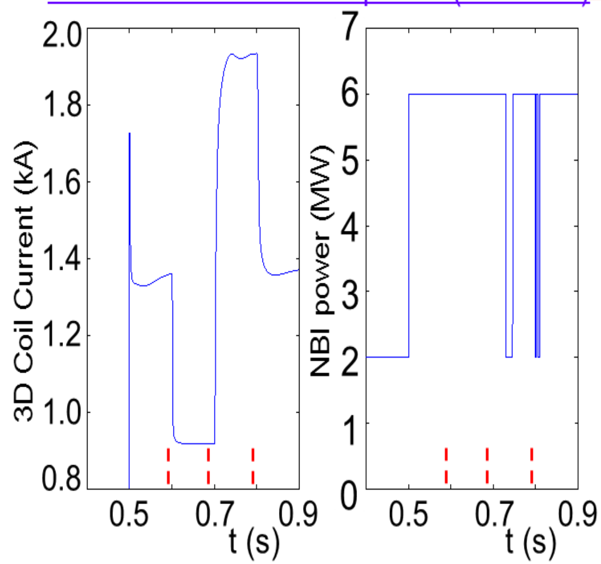
- Scale factor ($(dL/dt)/T_{NTV}$) = 1.7 and 0.6 (for cases shown above) – O(1) agreement
- Comparison to full Shaing, et al. theory with NTVTOK code (applicable for all collisionality (as shown above) is possible to compute between shots for NSTX-U
- Comparisons will also be made to other NTV codes (e.g. by J-K. Park, et al.)

# NTV experiment at reduced ν is a key step for closed-loop $V_\phi$ feedback using 3D fields in NSTX-U

Rotation evolution and NBI and NTV torque profiles

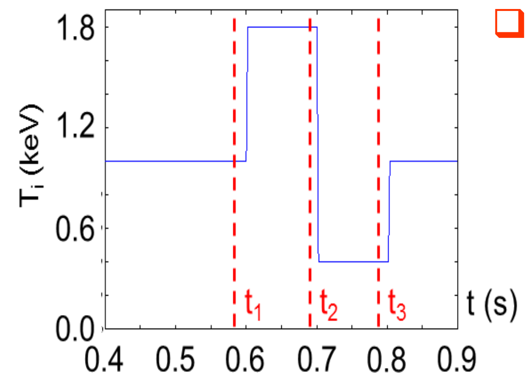



3D coil current and NBI power (actuators)




$$T_{NTV} \propto K \times f\left(n_{e,i}^{K1} T_i^{K2}\right) g\left(\delta B(\rho)\right)\left[I_{coil}^{2}\omega\right]$$

K1 = 0, K2 = 2.5




- NTV torque profile model for feedback dependent on ion temperature

- Expect stronger NTV torque at higher $T_i$ ($-d\omega_\phi/dt \sim T_i^{5/2}\,\omega_\phi$)
  - Initially shown in NSTX
    S.A. Sabbagh, et al, NF **50** (2010) 025020
  - Shown in our recent KSTAR XPs
    Y.S. Park, et al, IAEA FEC 2014, paper EX/P8-05
- Present XP
  - Operate with larger change in $\nu_i$
  - Attempt to reach quasi-steady-state $\omega_\phi$ for each $\nu_i$
  - Use braking fields envisioned for $V_\phi$ FB

I. Goumiri (PU), S.A. Sabbagh (Columbia U.), D.A. Gates (PPPL)

S.A. Sabbagh, et al., IAEA FEC 2014, paper EX/1-4

# XP1517:NTV at reduced collisionality (independent coil control) – basic shot scans / run time allocation

- Primary scans (usual 3D applied field "steps" ~ 150 ms duration)
  - Vary collisionality using usual $B_T$, $I_p$ variation at constant q (4 shots)
  - Vary collisionality at fixed, different q (2 more values) (8 shots)
- Additional scan components
  - Vary applied field spectrum (n = 2, n = 3, n = 2+3 configurations) (data points will come during shots above)
  - Vary collisionality in superbanana plateau regime (operate at low $\omega_E$) (data points will come from end of shots above)
- Additional details / options
  - Add intervals with n = 1 field correction to determine effect on NTV
  - May vary NBI mix in some shots (source 1 NBI vs source 2 NBI) (add 2 shots)
    - Primary NBI expected to be from source 1, but will use source 2 NBI (depends on success of CHERS data availability with NBI source 2)
  - For example: 1 shot can generate data for (i) n = 2, (ii) n = 3, (iii) n = 3 (n=1 EFC), (iv) superbanana plateau operation at low rotation
- Run time
  - 0.5 priority 1 run days allocated for XP1517 (~14 shots?)
  - Will have at least one primary collisionality scan, and the n = 2 and 3 configurations from NTV set-up shots in "uber" $I_p$, $B_T$ scaling XP (~ 6 shots)
  - Will have NBI 1,2; n=2,3 fields from NTV shots in "uber" NBI XP (~ 8 shots)

# XP1517:NTV at reduced collisionality (independent coil control) – Diagnostics, etc.

- Required diagnostics / capabilities
  - RWM coils generating n = 3 and n = 2 configurations
  - CHERS toroidal rotation measurement
  - Thomson scattering
  - MSE
  - Toroidal Mirnov array / between-shots spectrogram with toroidal mode number analysis
- Desired diagnostics / capabilities
  - RWM sensors
  - n = 1 field correction (slow n = 1 feedback)
  - Real-time rotation measurement
  - USXR / ME-SXR
  - Fast camera