NSTX-U

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The dependence of H-mode energy confinement and transport on collisionality in NSTX

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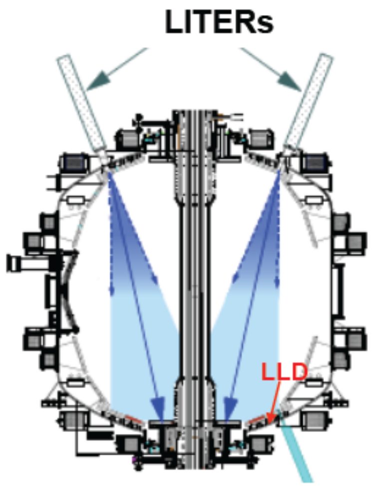
H-mode confinement scales differently in two wall conditioning scenarios used in NSTX

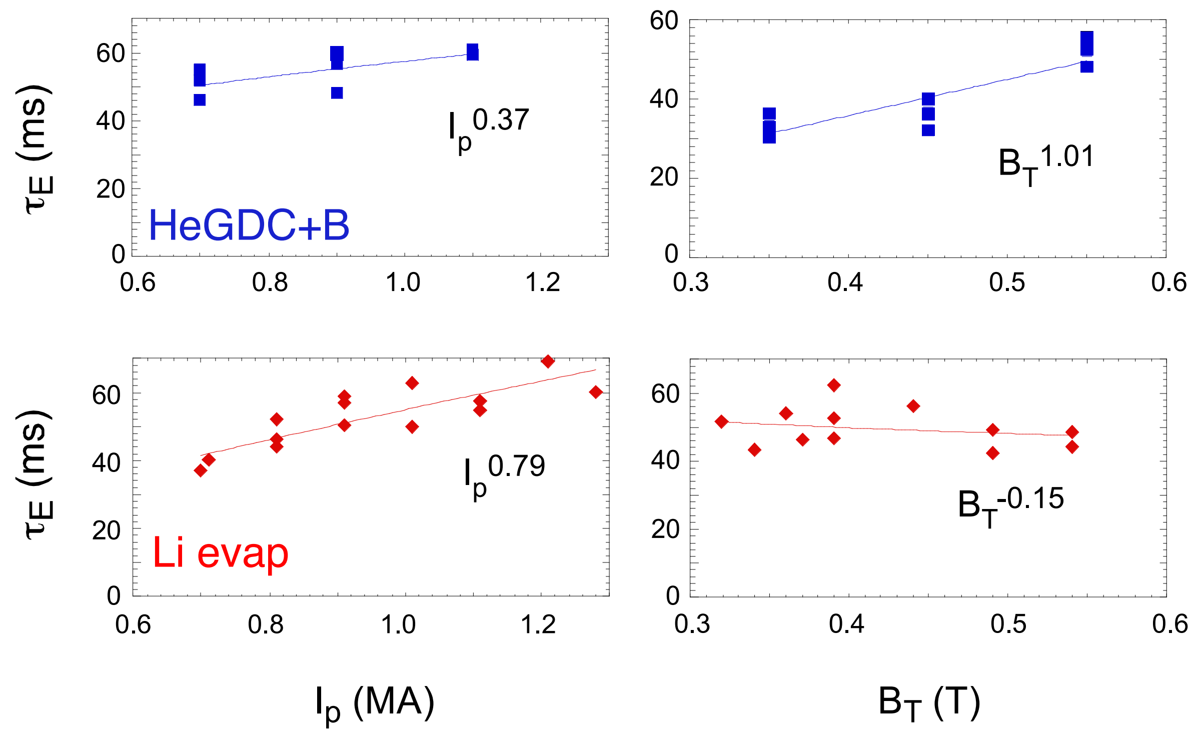


LITERs aimed toward the graphite divertor. Shown are 1/e widths of the emitted distribution.

Li remains outside the main plasma (Podesta EX/P3-02)

NSTX has used HeGDC+boronization as well as lithium evaporation for wall conditioning

- Strong B_T, weak I_p scaling with HeGDC+B
- $H_{98y,2}$ scaling trends with Li evaporation



Kaye (2007), Gerhardt (2011)

Can the difference in dimensional parameter scalings be reconciled?

We find that:

- Discharges using lithium evaporation generally have lower collisionality
- **Collisionality unifies the scalings:** *Strong increase of normalized confinement time with decreasing ν^**
  - Favorable implications for ST-based Fusion Nuclear Science Facility (FNSF)
- Collisionality decreases primarily due to broadening of the electron temperature profile
- ***The reasons for the strong scaling with collisionality will be explored in this talk***
  - *Global scaling*
  - *Profile and transport changes (in both e^- and i^+) with collisionality*
  - *Results from linear gyrokinetic calculations*

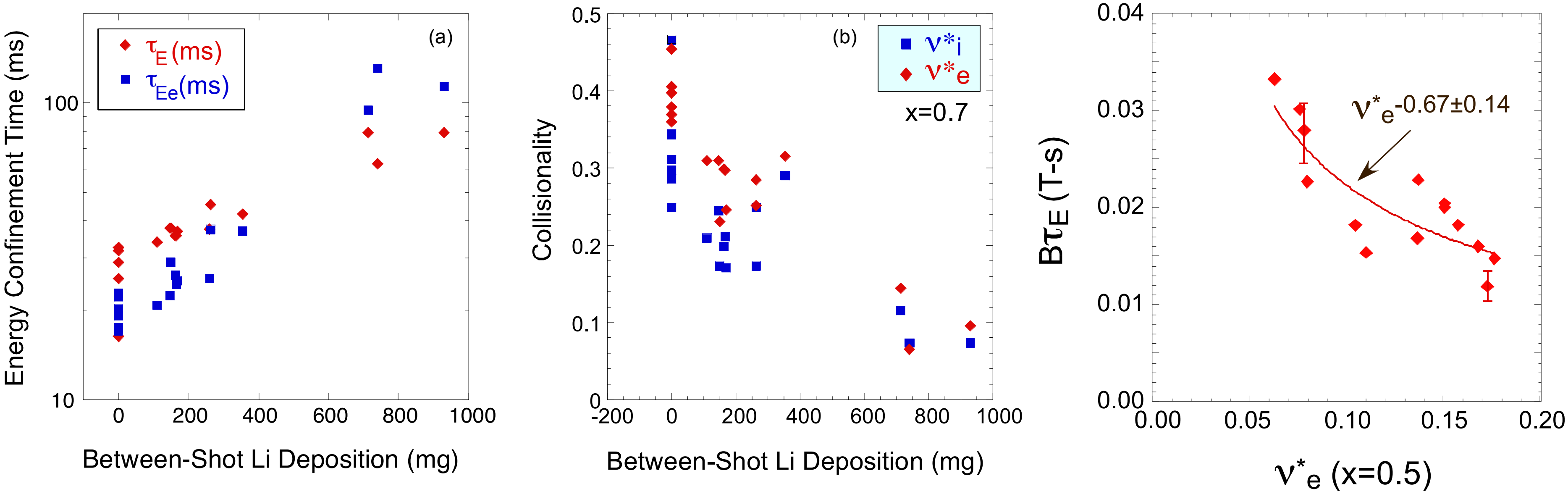
Two methods were used to change collisionality in NSTX NBI-heated H-mode discharges

Results will be reported from both:

- Vary I_p, B_T at constant I_p/B_T (no Li evap + fixed Li evap): Nu scan
  - No Li evap: Type V (small) ELMs that have minimal impact on confinement
  - Li evap: no ELMs
  - q, β vary strongly: constrain dataset to limited q and β ranges for analysis
- Vary amount of between-shots Li evaporation (fixed I_p & B_T): Li scan
  - Little Li evap: Type I ELMS: choose analysis times to be inter-ELM
  - Large Li evap: no ELMs
  - I_p, B_T, q, $\langle\beta\rangle$, κ, …. constant for all discharges
- For both scans, choose analysis times
  - When $P_{rad}/P_{heat} < 20\%$
  - During steady periods

A strong dependence of global confinement on between-shot Li deposition and collisionality is prominent in the Li Scan

- Strong increase in total thermal and electron confinement
- Factor of five decrease in collisionality
- Strong and favorable dependence of τ_E with decreasing collisionality
  - Implications for ST-FNSF (over one order of magnitude lower ν_ε^*)



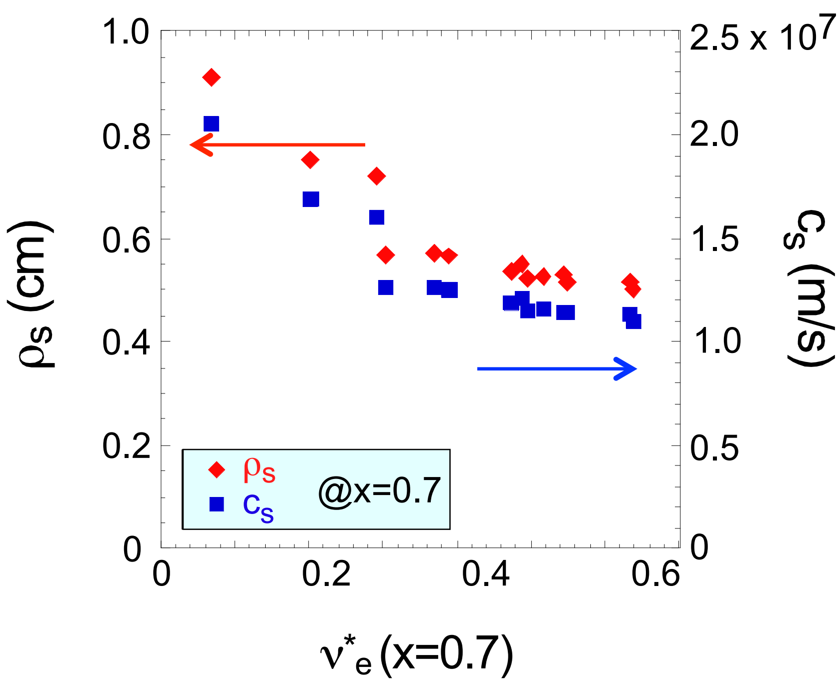
Maingi et al. PRL (2011), EX/11-2

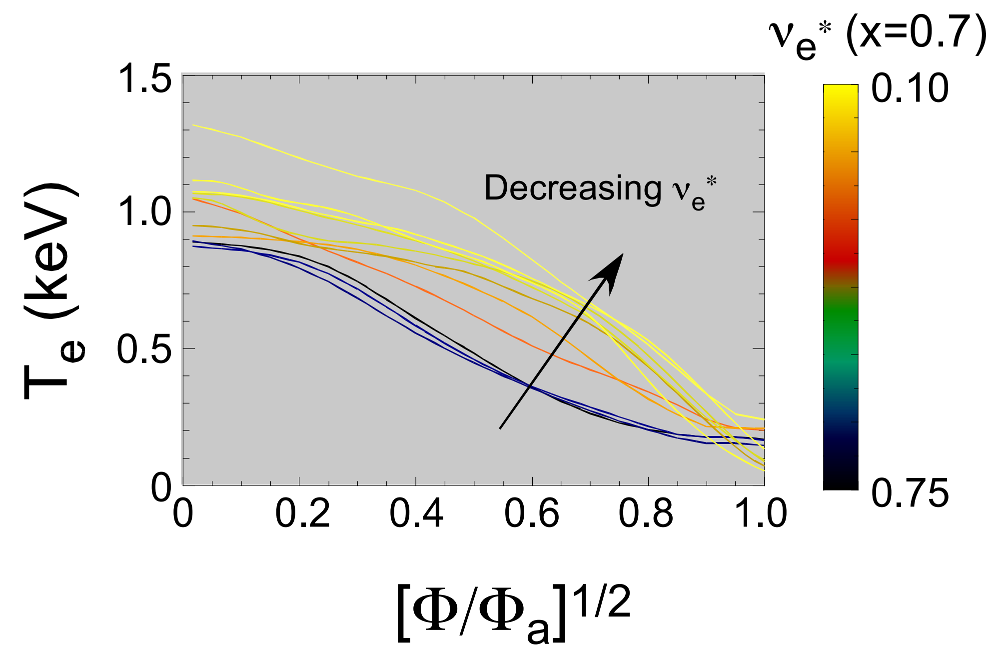
$$x=[\Phi/\Phi_a]^{1/2}$$

*Not all dimensionless variables are fixed across the range of ν**

$\rho*$ (=ρ_s/a, a constant) changes across range of collisionality

Primarily due to T_e profile broadening



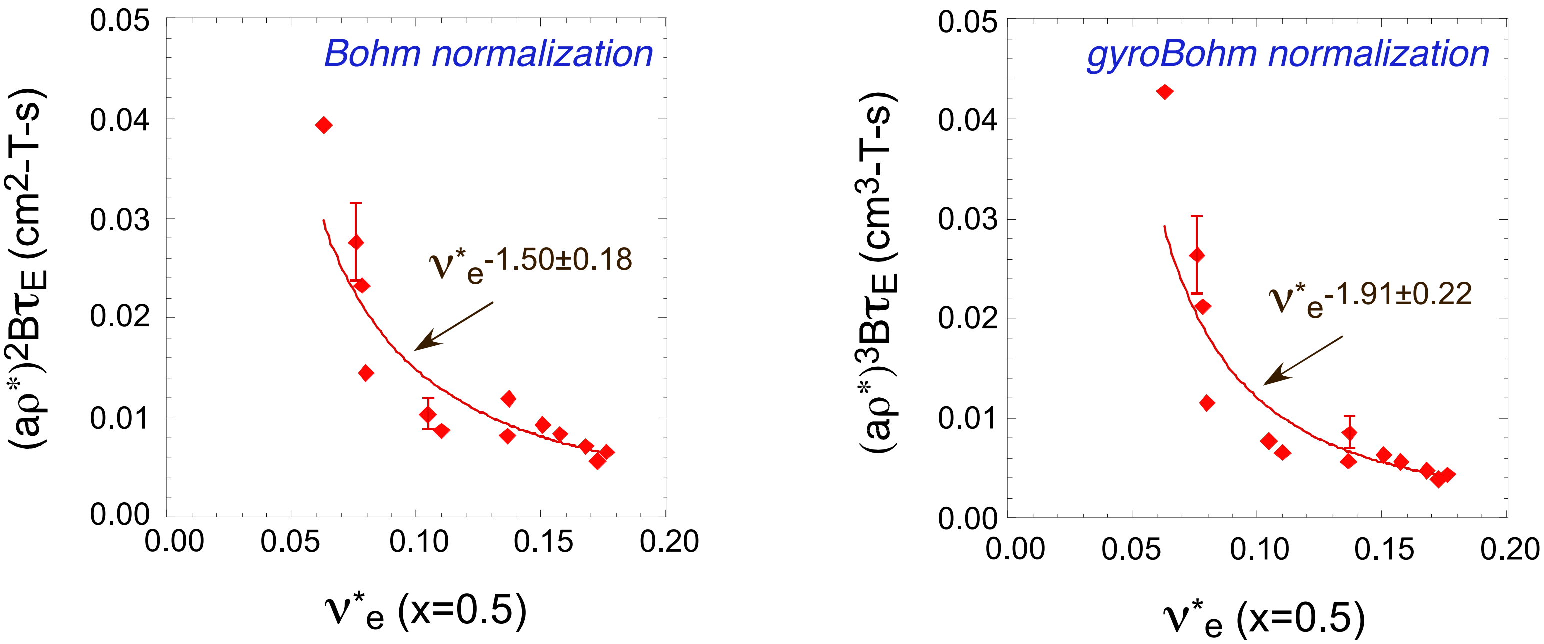


Need to normalize confinement trends by ρ^* variation

Dependence on ν^* even stronger when ρ^* variations are taken into account

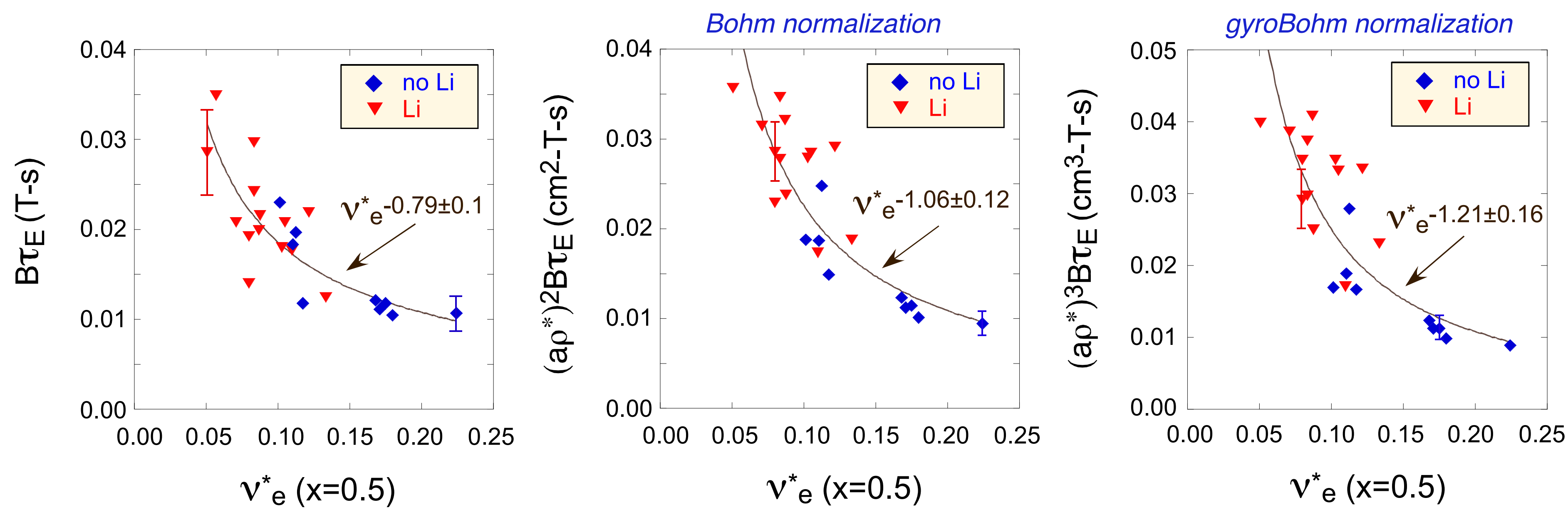
- ***Express confinement scaling in terms of dimensionless parameters** $\Omega\tau_E = B\tau_E = \rho^{*\alpha} f(\nu, \beta, T_e/T_i, \kappa, q, \ldots\ldots.)$ where $\alpha = -2$ for Bohm and $\alpha = -3$ for gyroBohm scaling*
  - ***NSTX HeGDC+B discharges found to be consistent with gyroBohm (Kaye, 2006)***
- ***For the Li scan, B, q, <β>, κ, a … constant for all discharges***

Normalize τ_E further by $\rho^{*\alpha}$: test both Bohm and gyroBohm



Strong dependence of normalized confinement on ν* also in "Nu scan"

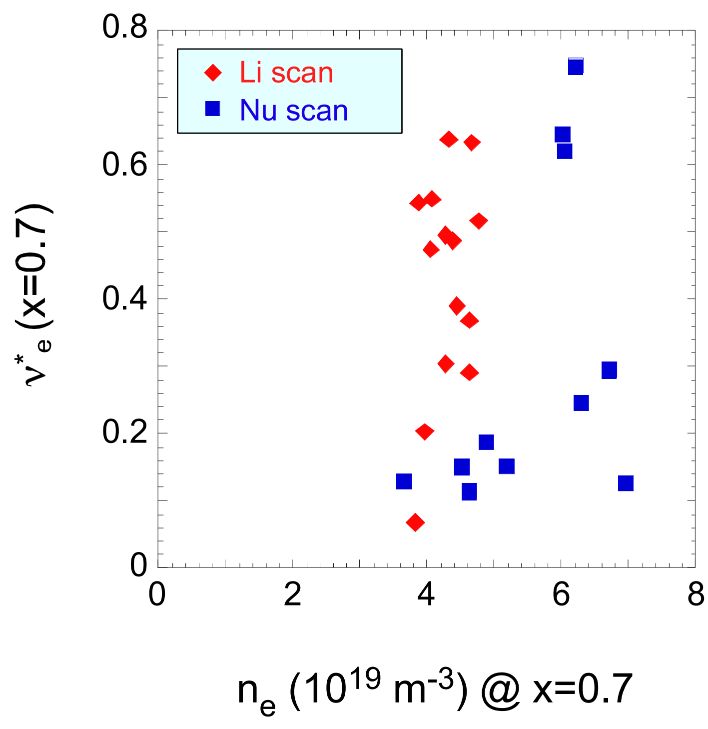
- Constrain data to $q_{a/2}$ = 2-2.5 and $\langle\beta_T\rangle$ = 8.5-12.5%

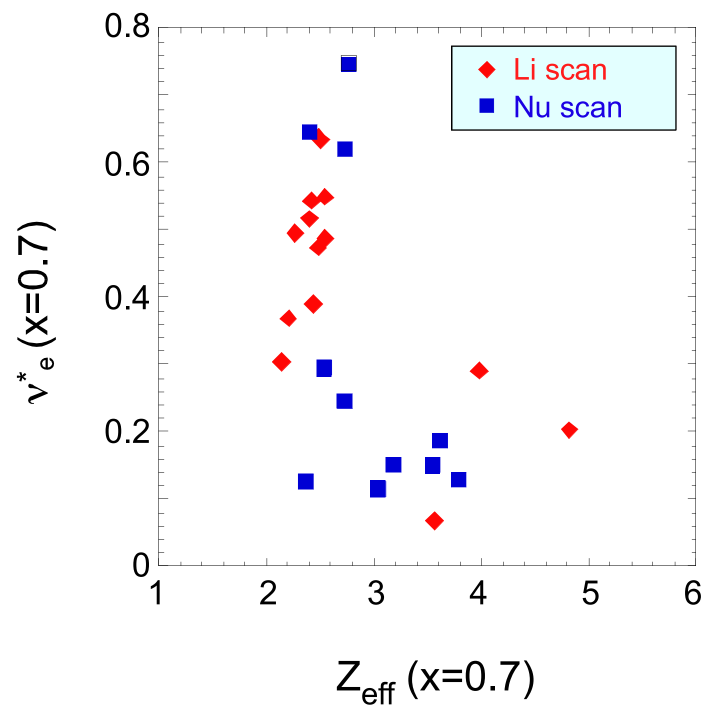


ITER98y,2 ν* scaling weak

n_e and Z_{eff} variations do not control the variation of ν^*

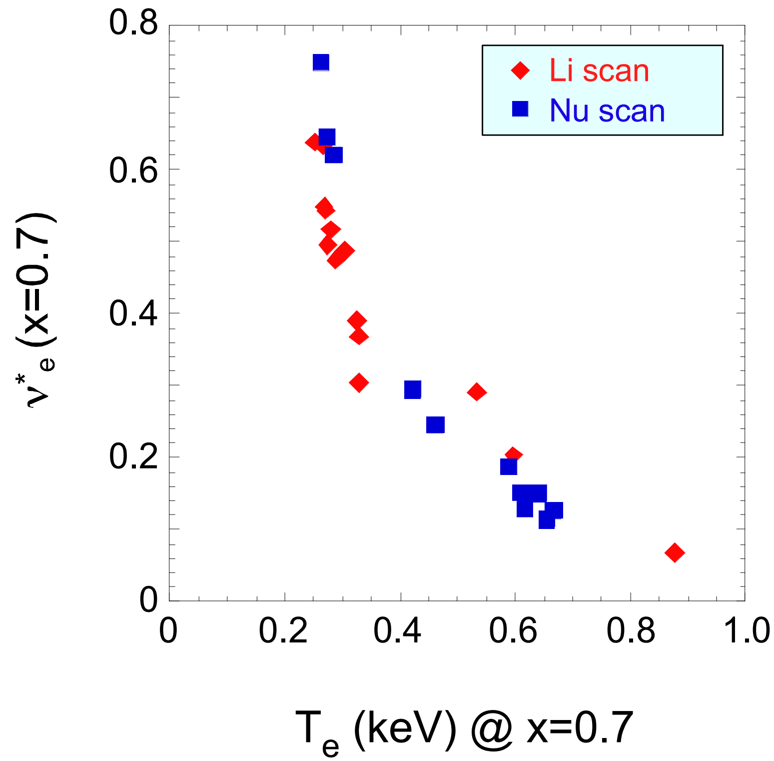
- Would expect a linear dependence between parameter pairs if they were controlling factors ($\nu^* \sim n_e Z_{eff}$)

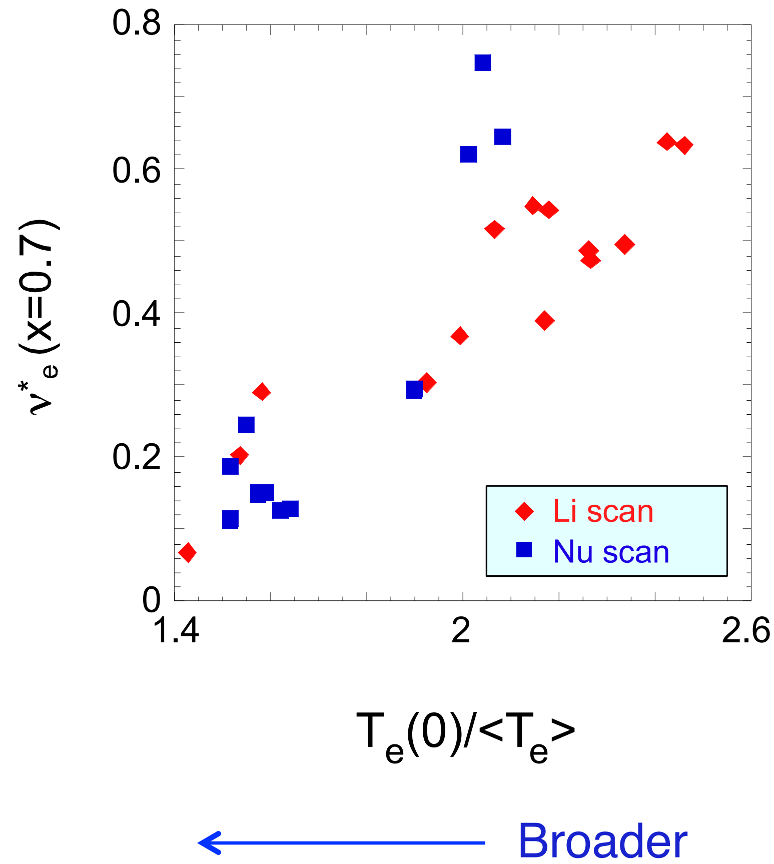




The variation in T_e and T_e profile broadness is the fundamental reason ν (and ρ*) varies*

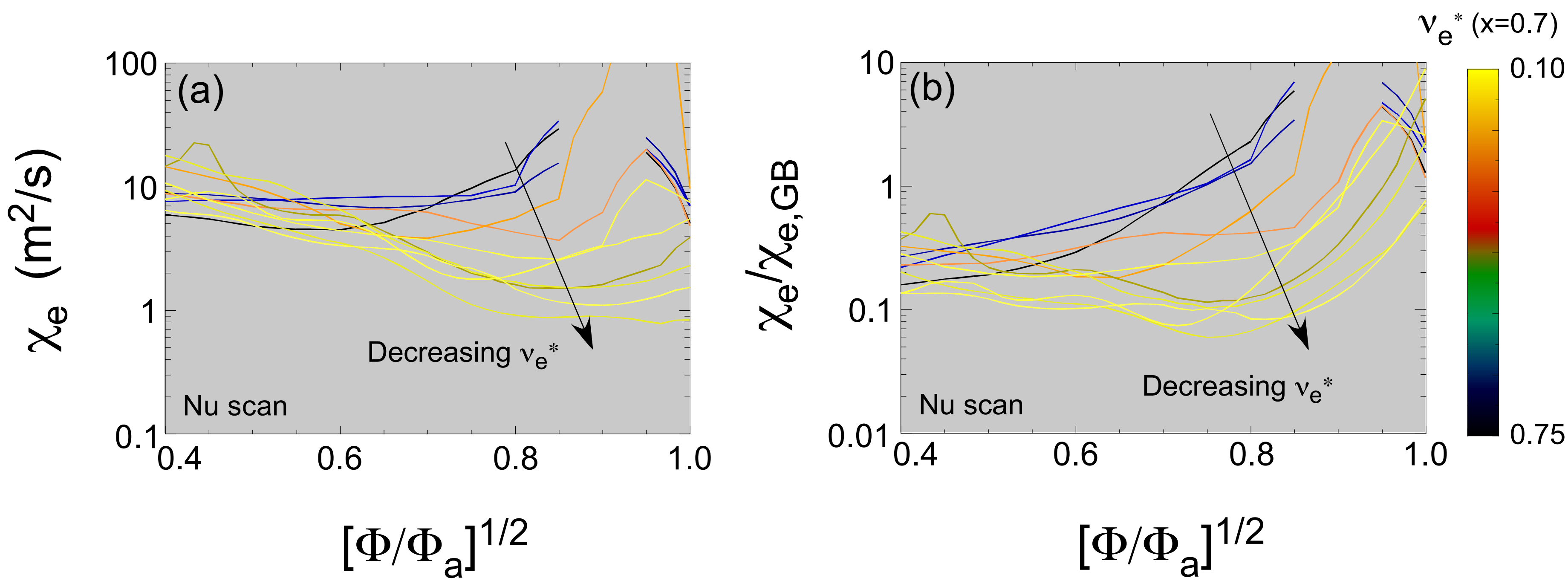
$$\nu^* \sim 1/T_e^2$$





T_e broadening reflects a strong reduction in electron transport with decreasing collisionality in the outer region of the plasma

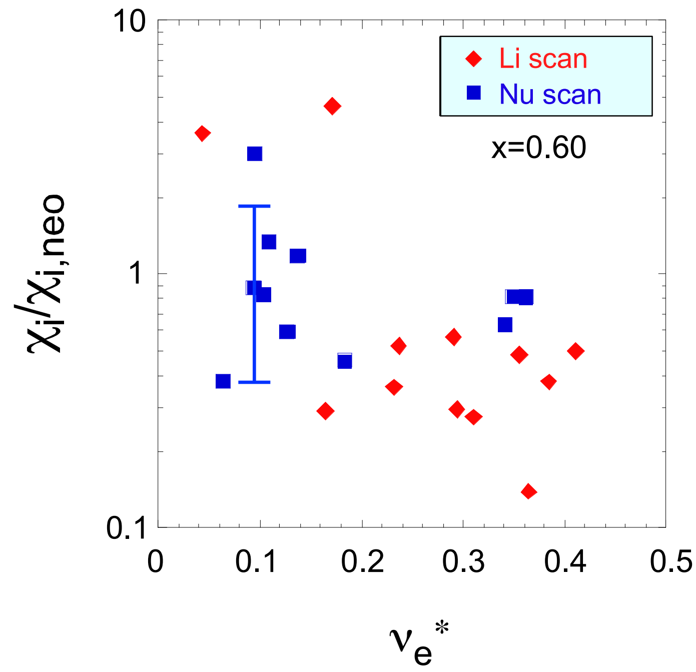
- This can be seen in both χ_e and χ_e/χ_{GB}, where $\chi_{GB} \sim \rho_s^2 c_s/a$

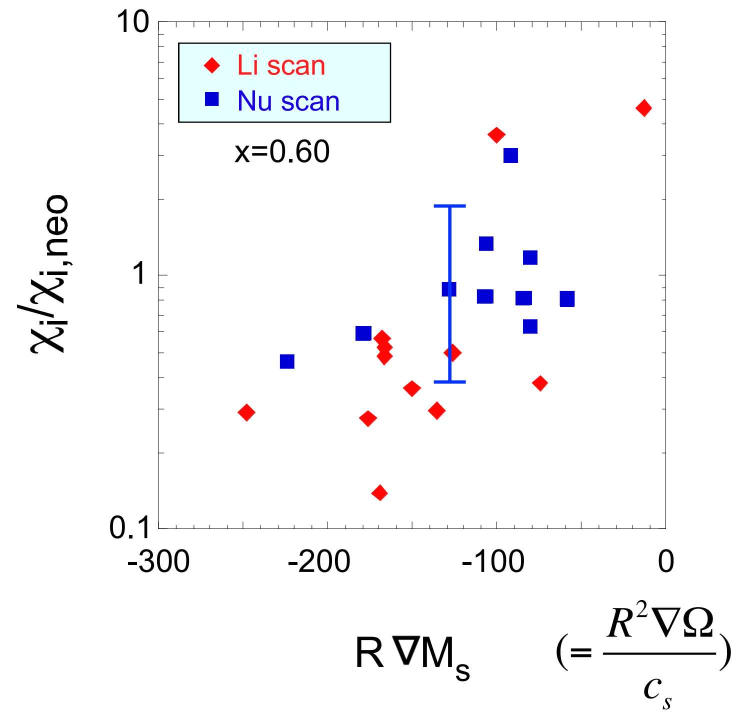


Curves color coded relative to value over full range of collisionality

There is a general <u>increase</u> of <u>anomalous</u> ion transport in outer regions with decreasing collisionality

- The dependences are more complicated
  - Overall increase in $\chi_i/\chi_{i,neo}$ with decreasing collisionality, but there is large scatter even at similar ν_e^*
    - ~Neoclassical (NCLASS) ion transport at lowest collisionality (factor of ~2 uncertainty in $\chi_i/\chi_{i,neo}$)
  - Ion transport also correlated with rotation shear

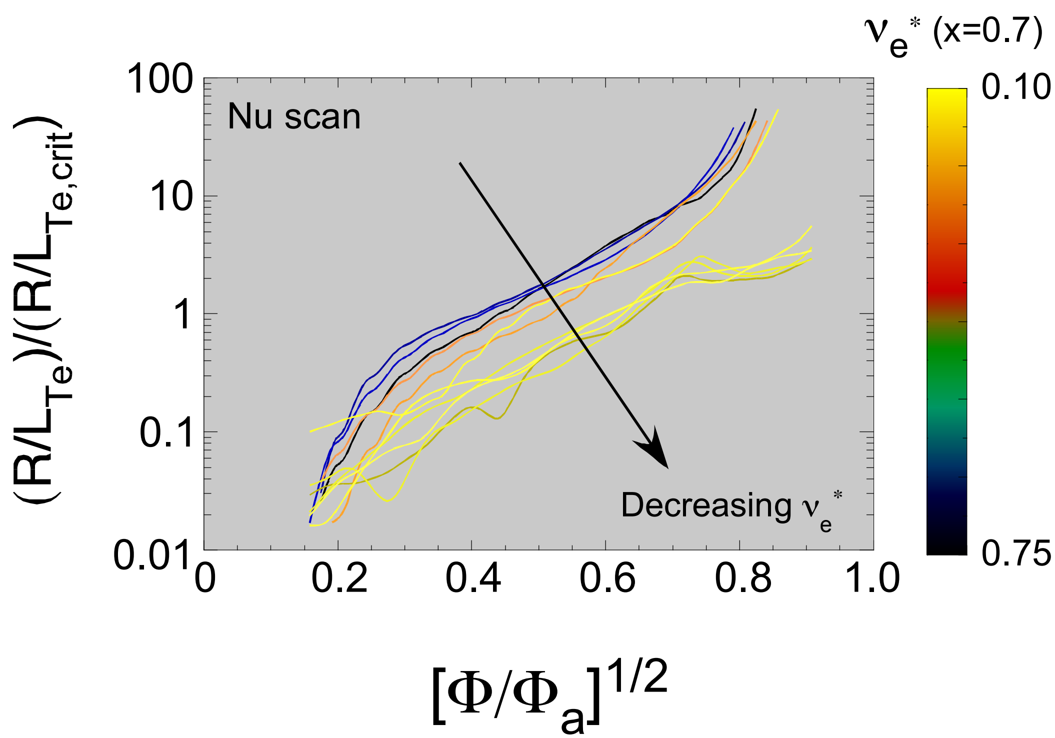




Now look at microstability properties of plasmas at high- and low-k

High-k ETG becomes more stable for lower collisionality discharges

- Comparison of experimental R/L_{Te} to analytic ETG critical gradient (Jenko et al., 2001) indicates reduction of ETG drive as collisionality decreases
  – Consistent with reduction in electron transport

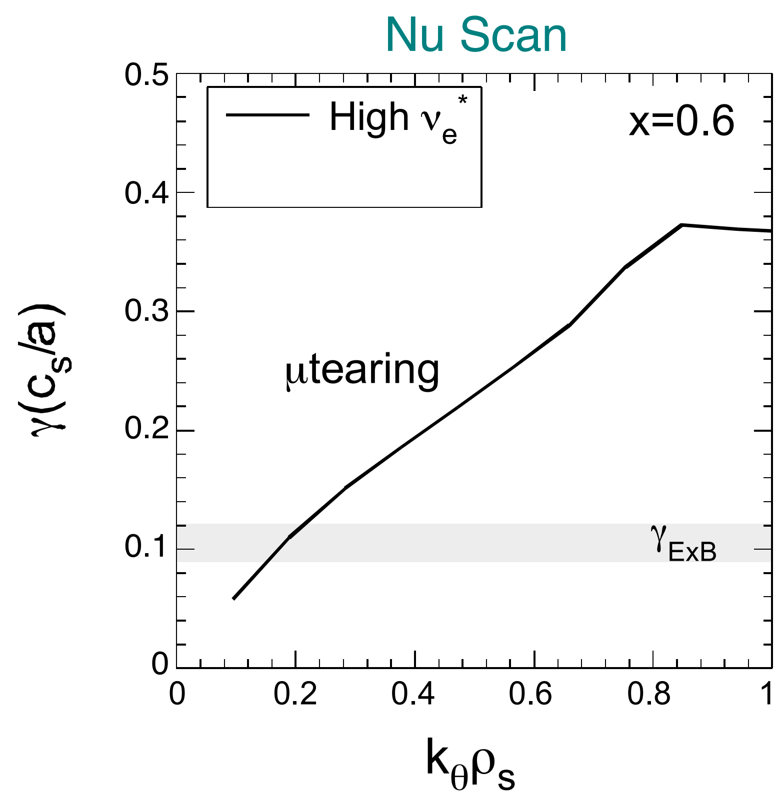


- Linear gyrokinetic indicated ETG completely stabilized for low collisionality discharges
  - Stability due to reduced T_e gradient
    (Guttenfelder TH/6-1)

- Reduction of high-k turbulence ($k_r\rho_\theta \sim 5 – 30$) at lower collisionality in pedestal region
  (Canik 2011, EX/P7-16)

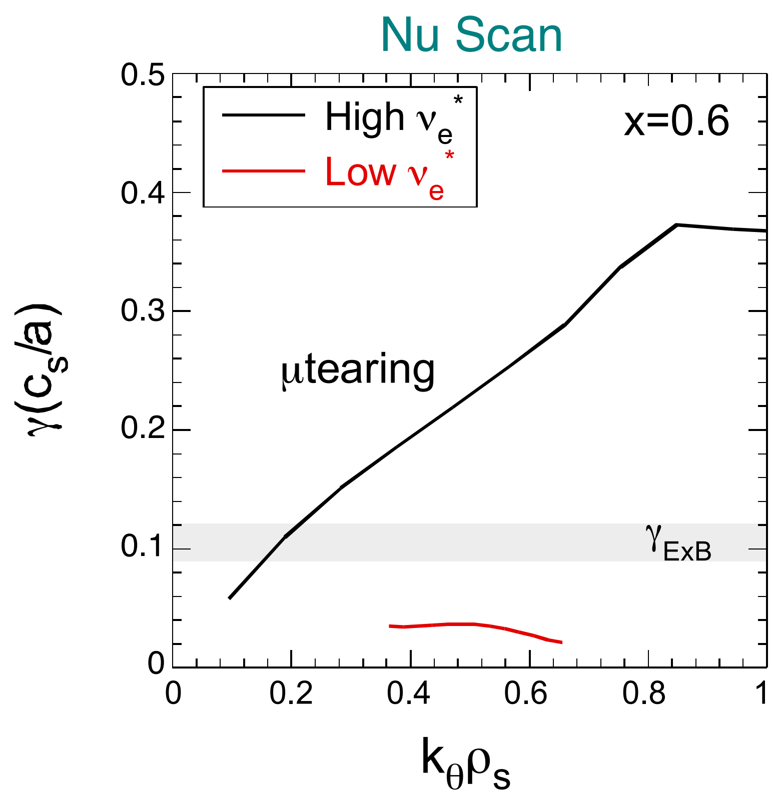
Low-k modes show more complicated dependence

- Linear GYRO calcs indicate microtearing growth dominates low-k spectrum at high collisionality



Low-k modes show more complicated dependence

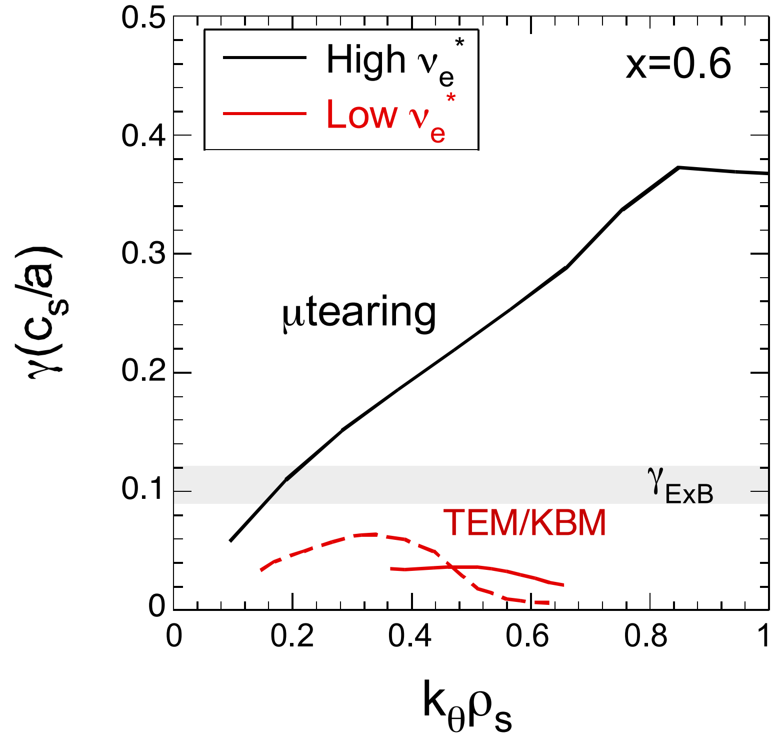
- Linear GYRO calcs indicate microtearing growth dominates low-k spectrum at high collisionality
- At low collisionality, microtearing becomes weaker
  - Consistent with reduction in electron transport going from high to low collisionality



Low-k modes show more complicated dependence

- Linear GYRO calcs indicate microtearing growth dominates low-k spectrum at high collisionality
- At low collisionality, microtearing becomes weaker
  - Consistent with reduction in electron transport going from high to low collisionality
- Low-k hybrid mode (TEM/KBM) predicted to exist at low collisionality
  - Consistent with increase in ion transport
  - Can provide some electron transport
- Mode growth rates near γ_{EXB} at low collisionality
  - Non-linear calculations underway to assess effect on predicted transport levels
- Li scan shows similar result

Nu Scan



Guttenfelder TH/6-1
(next talk)

Summary and Conclusions

- Collisionality is the unifying parameter in understanding confinement trends in NSTX plasmas
- Normalized confinement shows a strong and favorable dependence with decreasing collisionality
  - Trend is even stronger when Bohm or gyroBohm variation of ρ^* is taken into account
- Improved confinement is governed primarily by reduction in electron transport in outer region
  - Broader T_e profiles with decreasing ν_e^*
  - ETG, microtearing more stable going from high to low ν_e^*
- Ions, however, become more anomalous going from high to low collisionality
  - Hybrid TEM/KBM mode unstable at low ν_e^*
  - Need to assess respective roles of ν_e^* and rotation shear

- **Will be able to explore these trends at even lower collisionality (5x) with more control of the rotation profile on NSTX-U**

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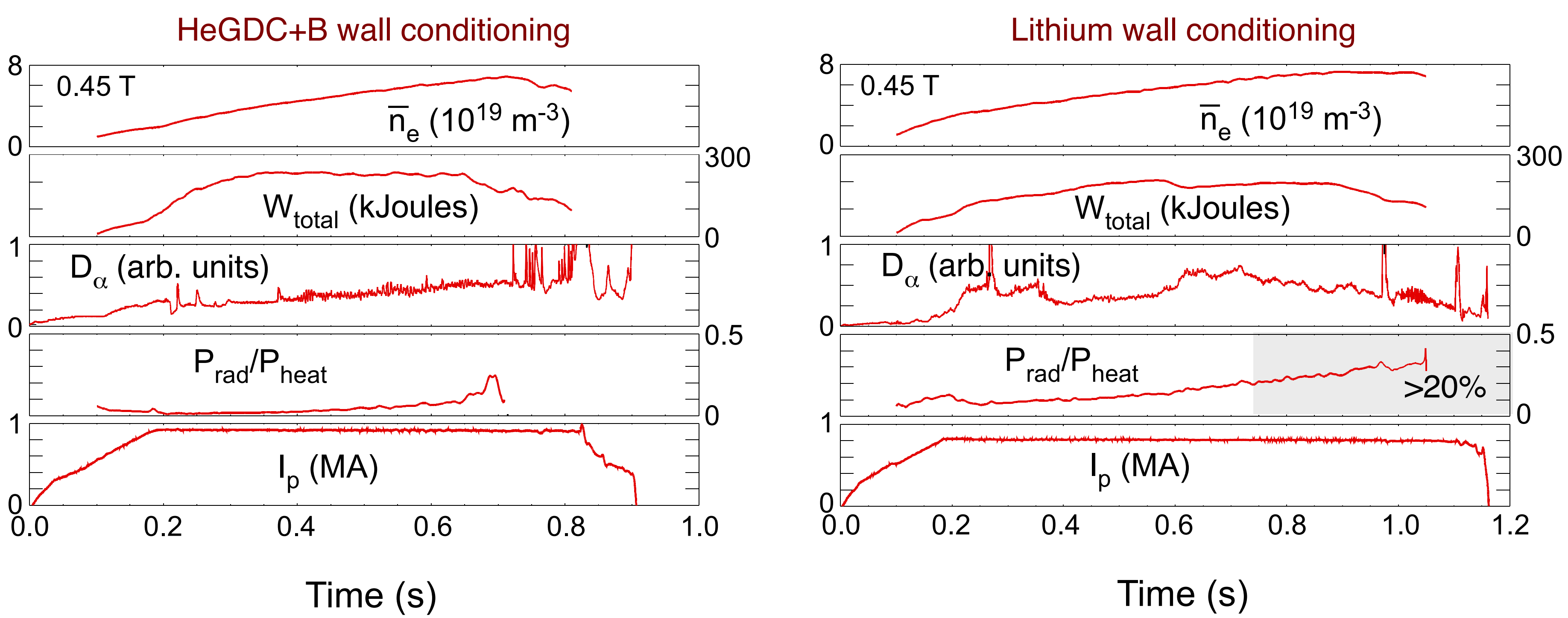
Two methods were used to change collisionality in NSTX H-mode discharges

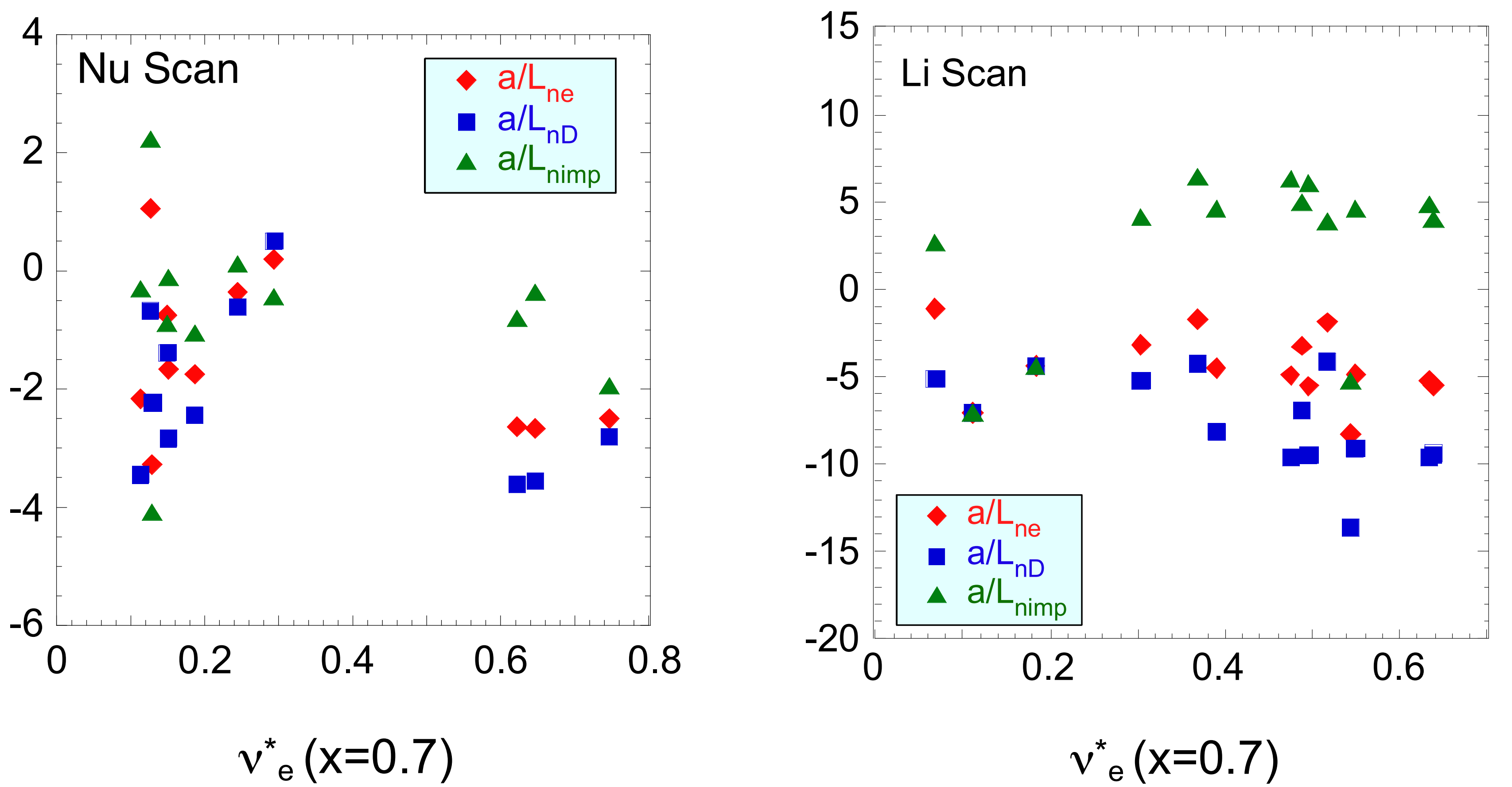
Results will be reported from both:

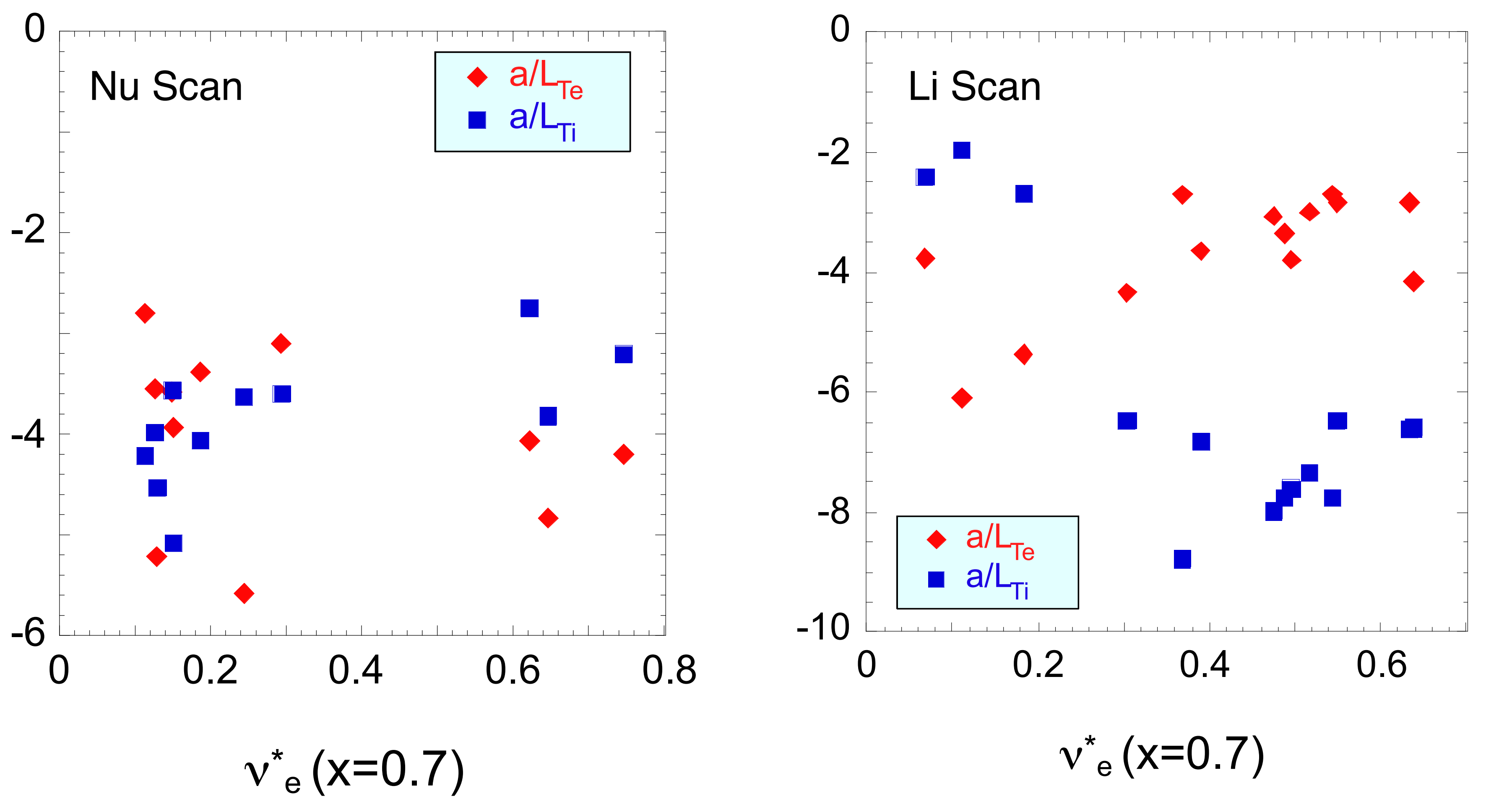
- Vary I_p, B_T at constant I_p/B_T (fixed Li + no Li): Nu scan
- Vary amount of between-shots Li evaporation (fixed I_p & B_T): Li scan



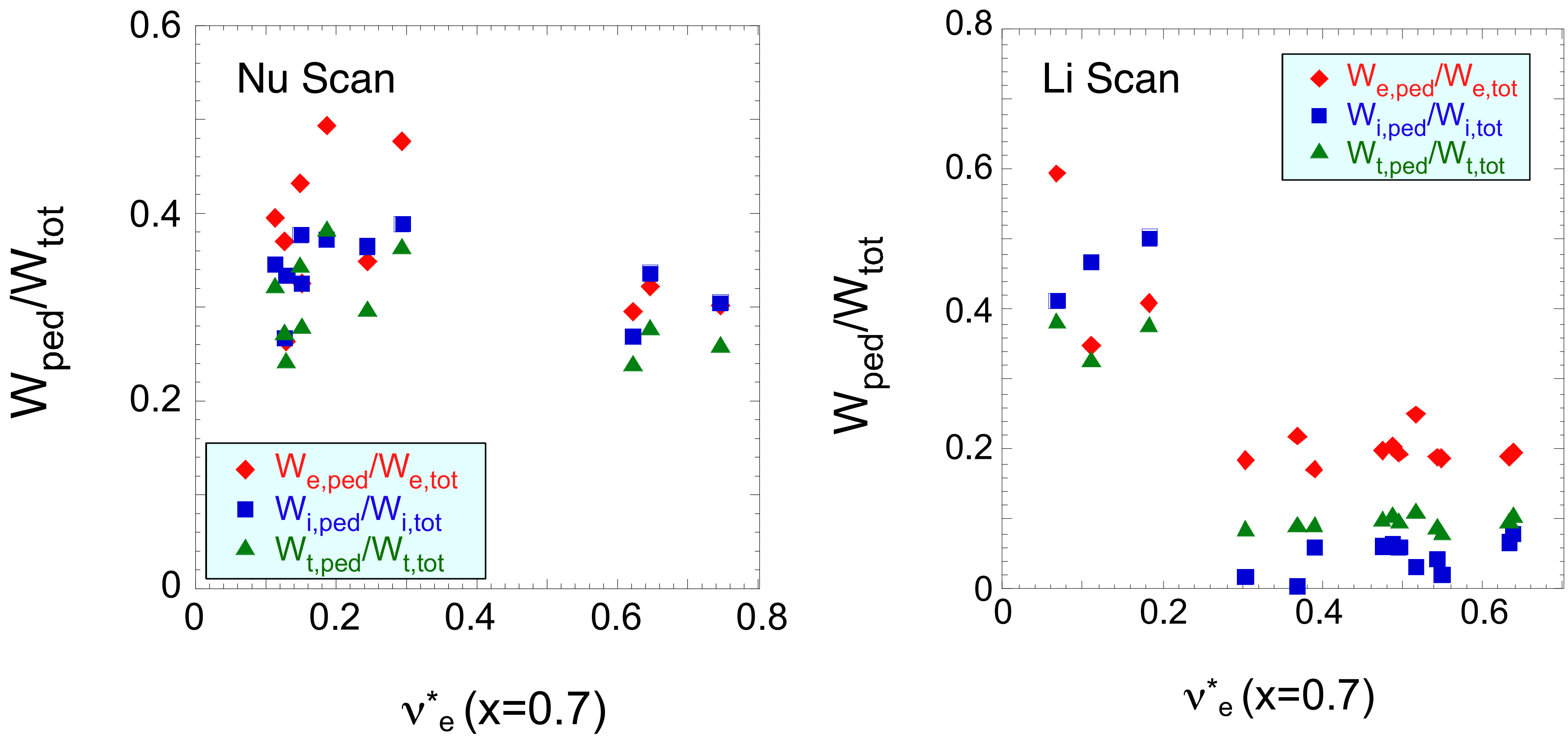
Type V (small) ELMs)

Type I ⟶ No ELMs (Maingi EX/11-2)
Choose toi when $P_{rad}/P_{heat} < 0.20$


Nu Scan
a/Lne
a/LnD
a/Lnimp
4
2
0
-2
-4
-6
0
0.2
0.4
0.6
0.8
ν*e (x=0.7)
Li Scan
15
10
5
0
-5
-10
-15
-20
0
0.2
0.4
0.6
a/Lne
a/LnD
a/Lnimp
ν*e (x=0.7)



Nu Scan
a/L_Te
a/L_Ti
0
-2
-4
-6
0
0.2
0.4
0.6
0.8
ν*e (x=0.7)
Li Scan
0
-2
-4
-6
-8
-10
0.2
0.4
0.6
ν*e (x=0.7)



Nu Scan
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
W_{ped}/W_{tot}
$W_{e,ped}/W_{e,tot}$
$W_{i,ped}/W_{i,tot}$
$W_{t,ped}/W_{t,tot}$
ν^*_e (x=0.7)
Li Scan
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
W_{ped}/W_{tot}
$W_{e,ped}/W_{e,tot}$
$W_{i,ped}/W_{i,tot}$
$W_{t,ped}/W_{t,tot}$
ν^*_e (x=0.7)