Abstract

Lithium coating of the plasma facing components in NSTX has led to modifications of plasma profiles and the underlying energy transport. With lithium-coated walls, the electron temperature profiles are broader than without lithium, and this is reflected by a sharp reduction in the electron thermal diffusivity. This reduction in electron transport is further manifest as an increase in the thermal energy confinement time overall, as well as H-mode confinement enhancement. The energy confinement scaling of discharges with lithium-coated walls shows a much stronger I_p scaling and weaker B_T scaling than those without lithium coating, similar to the ITER98y,2 scaling trends. The change of confinement with lithium coatings is associated with a concomitant change in collisionality, either through changes in the plasma temperature profiles themselves or the impurity levels. Furthermore, the relative amount of pedestal to core stored energy increases with increasing lithium deposition (decreasing collisionality).

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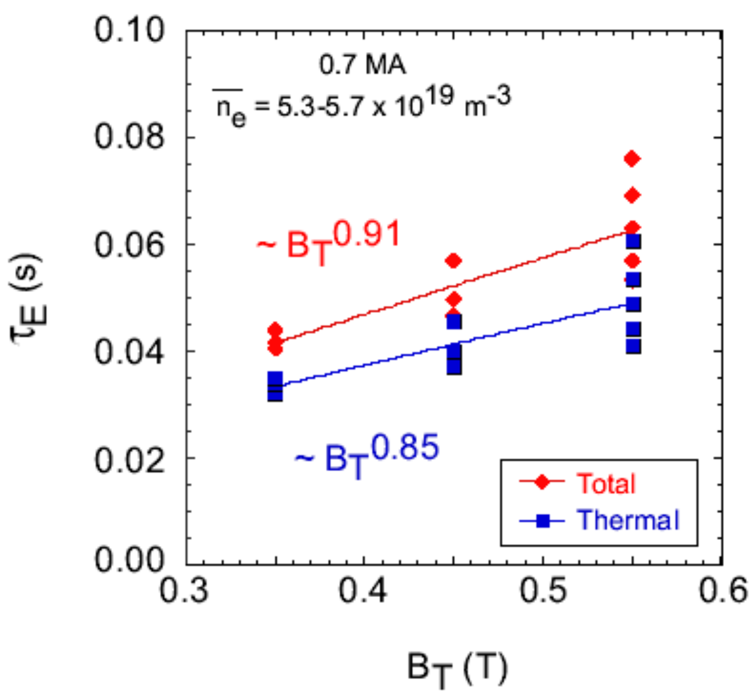
The Purpose of This Poster is to Explore Differences in H-Mode Confinement Scaling Between NSTX Discharges Without and With Lithium Wall Conditioning

- Without Li conditioning, H-mode confinement in NSTX scales differently than at higher aspect ratio
  - Strong B_T scaling, weak I_p scaling
  - Electrons control B_T scaling, neoclassical ions control I_p scaling [Kaye et al., Phys. Rev. Lett. **98** (2007) 175002, Nuc. Fusion **47** (2007) 499]
- Scalings show a strong dependence on collisionality
  - $B\tau_E \sim \nu_*^{-1}$ (at fixed q), weak dependence on β_T
- Lithium wall conditioning has been used in experiments over the past several years
  - Broadening of electron temperature profile with increasing Li deposition, higher confinement times
  - Confinement scalings closer to H98y,2 (strong I_p, weak B_T)
  - Difference between Li and non-Li conditioned discharges governed by impurity content and collisionality scaling with B_T
  - Li conditioned discharges generally at lower ν_*; scale with collisionality, consistent with non-Li conditioned discharges

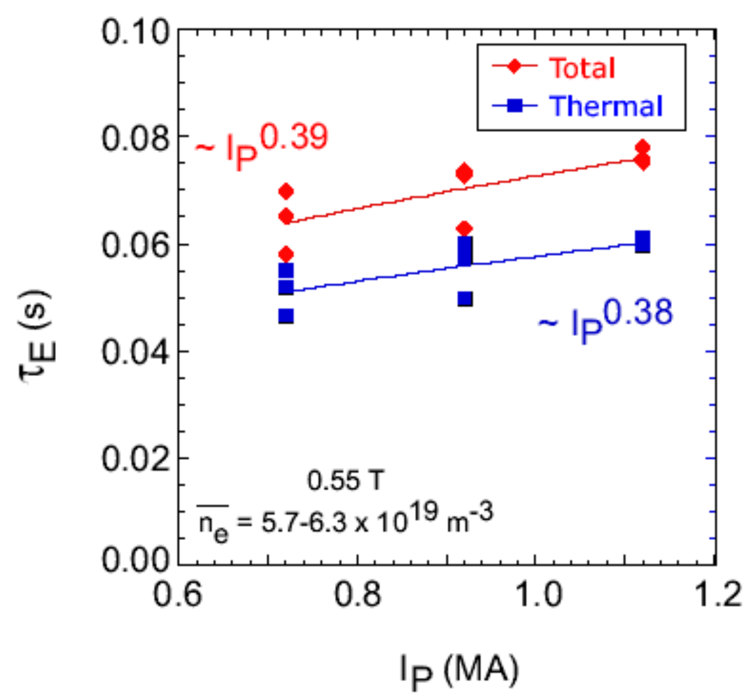
Early Transport Experiments in NSTX Revealed Confinement Scalings Different From Those at Higher Aspect Ratio

- Dedicated experiments in 2004-2006: ***Boronization, HeGDC for wall conditioning***

- ***Strong dependence of τ_E on B_T***



- ***Weaker dependence on I_p***



As compared to:

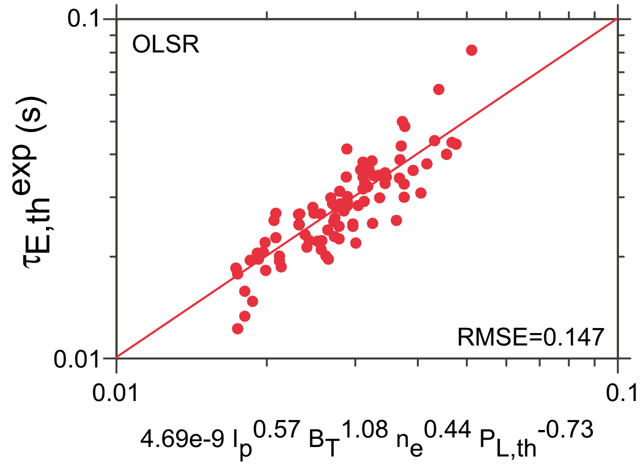
$\tau_{E,98y,2} \sim B_T^{0.15}$

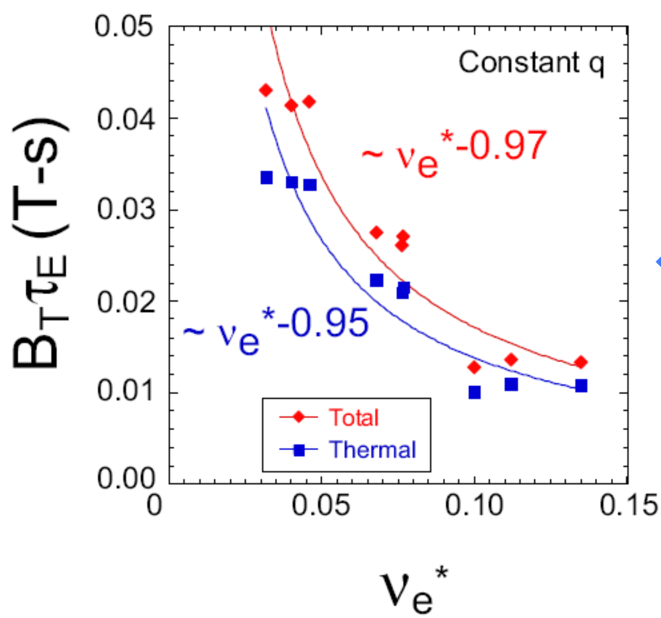
$\tau_{E,98y,2} \sim I_p^{0.93}$

Parametric Scalings Different Than Usual H98y,2

- Stronger toroidal field scaling, weaker plasma current scaling a robust feature of regression fits to the NSTX data

- Observe the "usual" density dependence and power degradation



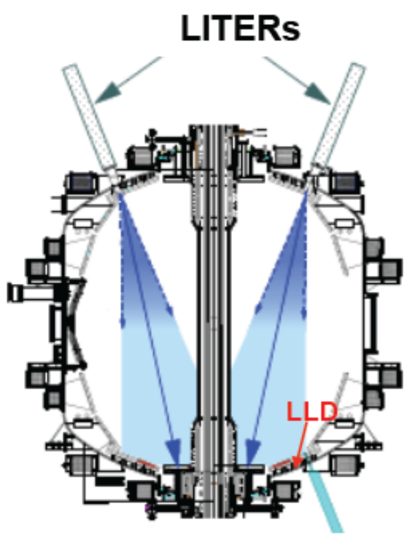


- Nearly inverse linear dependence of normalized confinement on collisionality
  - Weak dependence on β_T ($\beta_T^{-0.1}$)

- Important ramifications for future STs, FNSF which will operate at collisionalities up to 2 orders of magnitude lower

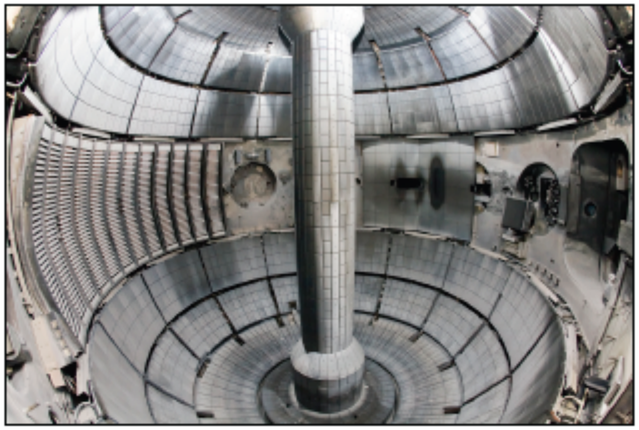
Over the Past Several Years, NSTX has Used Lithium for Wall Conditioning

- Origins of Li conditioning were in TFTR
- Also being carried out in a number of devices (FTU, T-11M, LDX, TJ-II, KTM (in progress), EAST (planned)
- Lithium Evaporators (LITERs) used in 2008-2010, Liquid Lithium Divertor implemented in 2010



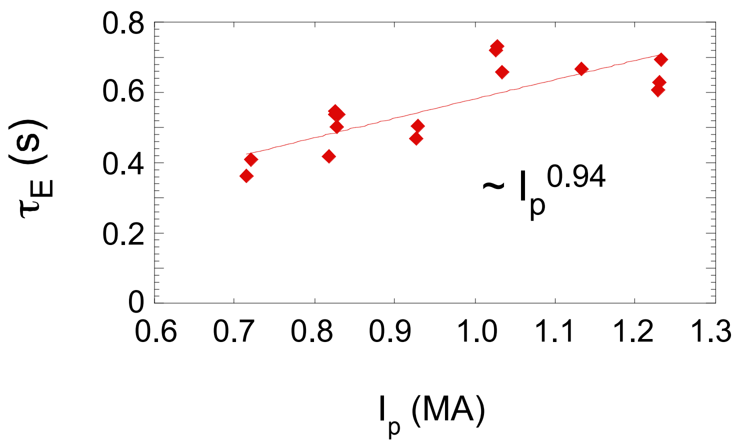
LITERs aimed toward the graphite divertor. Shown are 1/e widths of the emitted distribution.

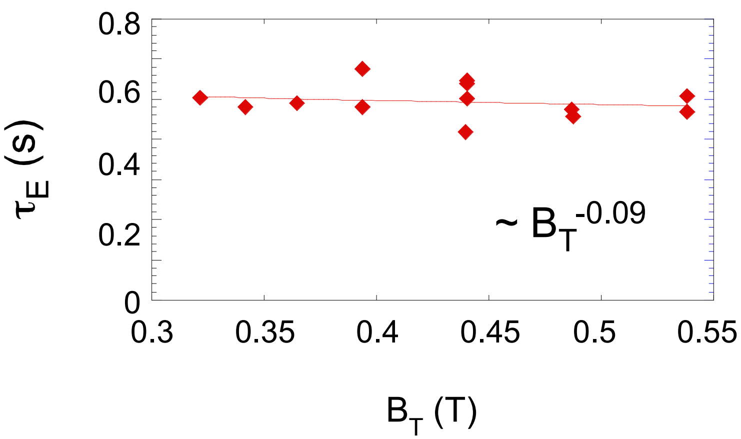
LLD

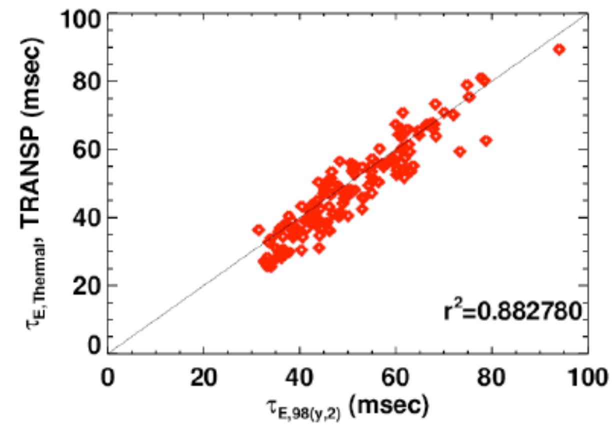


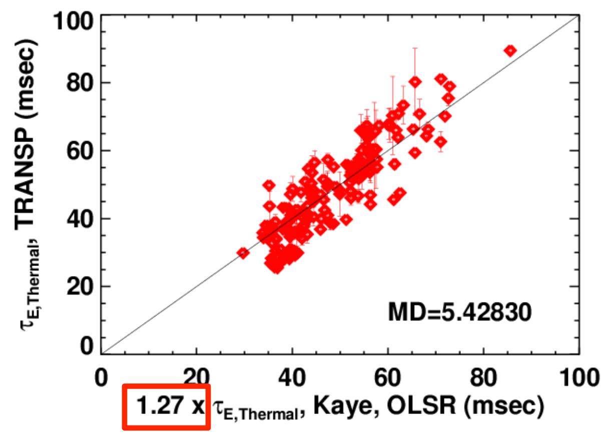
Experiments With Lithium Conditioned Walls Revealed Energy Confinement Scalings Closer to H98y,2

- 90 – 300 mg lithium deposited between shots
- Also, higher kappa (>~2.5)
  - Strong, I_p dependence, no B_T dependence









Gerhardt et al., APS-DPP YI2:00002

Why is There a Difference in Scalings?

- Lithium modifies the plasma edge
  - Extends gradients farther inside the plasma
  - Max gradient region moves farther in from the separatrix

- Can a two-term scaling yield any information?
  - Separate plasma into pedestal vs core region
  - Do the two scale differently in different situations?
  - Use tanh fitting routine to determine position of pedestal top
    - Typically around 0.05-0.1Ψ_N farther inside for discharges with lithium

- What is the common thread between the confinement time scalings with and without Lithium conditioning?
  - Collisionality appears to be the controlling factor

Examine Results from Two Different Experimental Datasets

1. Fixed between-shot lithium deposition: I_p, B_T scaling (S. Gerhardt, R. Maingi)
   - 90 – 270 mg between shots
   - I_p = 0.7 – 1.3 MA
   - B_T=0.34 – 0.54 T
   - κ ~ 2.2
   - P_{heat} ~ 3 MW
2. Between-shot lithium deposition scan (R. Maingi)
   - 0 – 1000 mg between shots
   - I_p = 0.8 MA
   - B_T = 0.44 T
   - κ ~ 1.8
   - P_{heat} = 2 – 3.2 MW

Maingi et al., PRL 107 145004 (September 2011)

1. I_p, B_T Scaling

- First look at fixed B_T
  - No lithium evap: B_T = 0.53 T
  - w/ lithium evap: B_T = 0.44 T

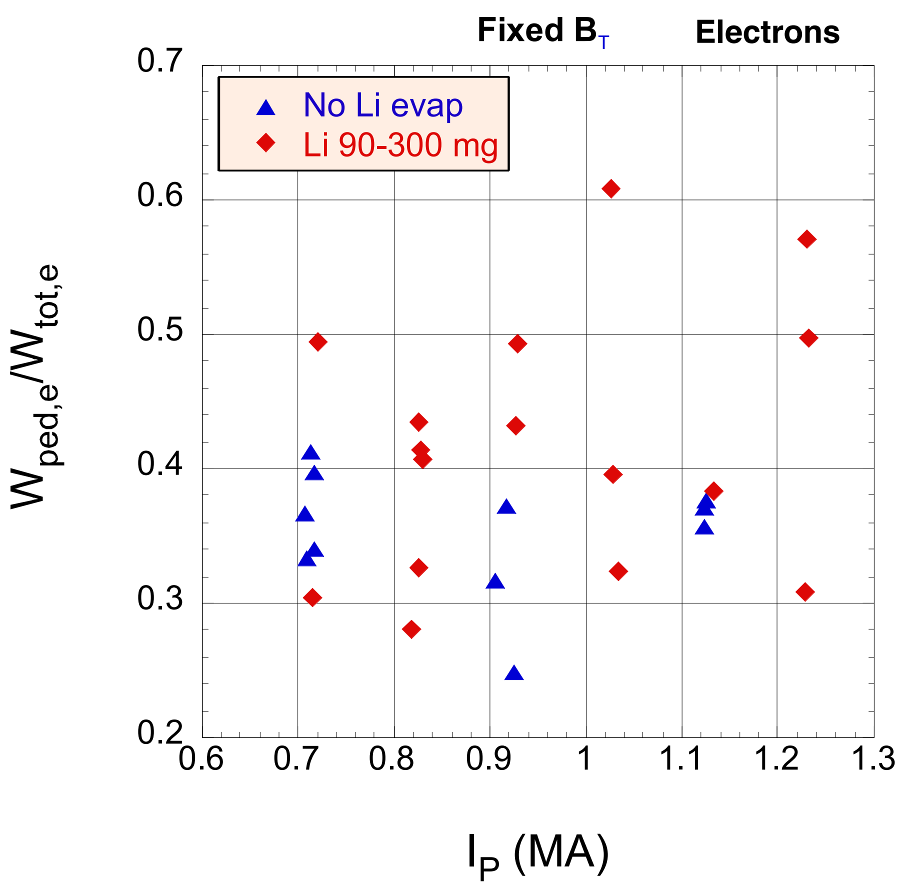
- Then look at fixed I_p
  - No lithium evap: I_P = 0.7 MA
  - w/ lithium evap: I_P = 0.8 MA

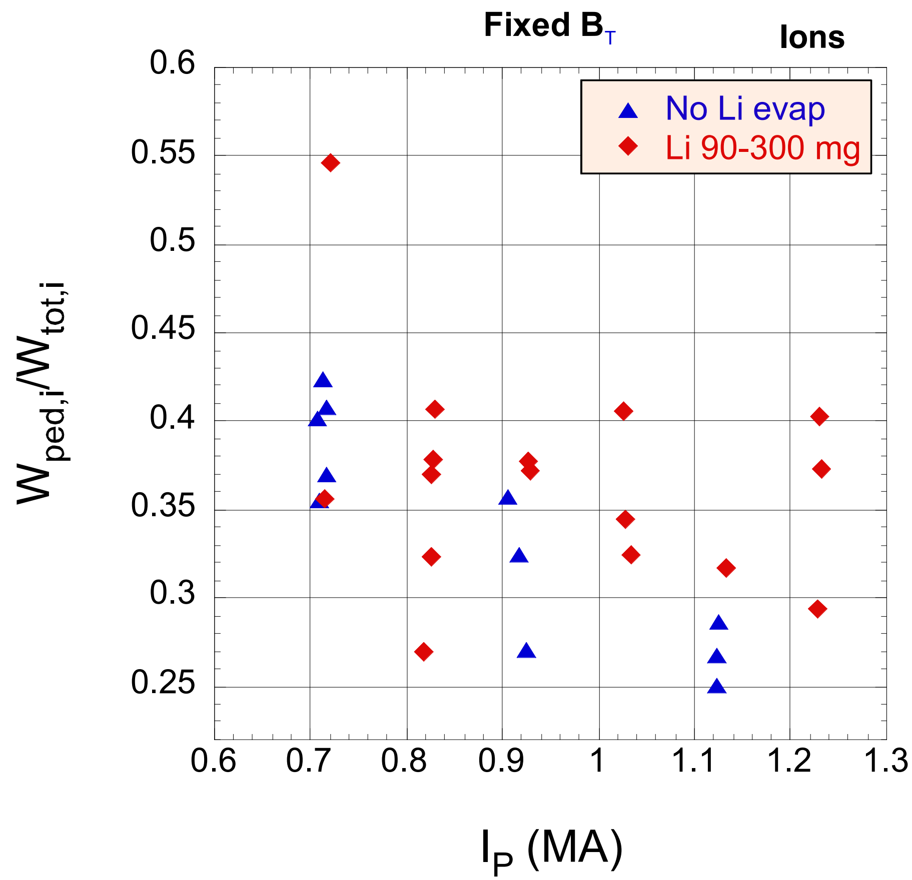
In following vugraphs:

BLUE symbols are for discharges WITH NO lithium conditioning

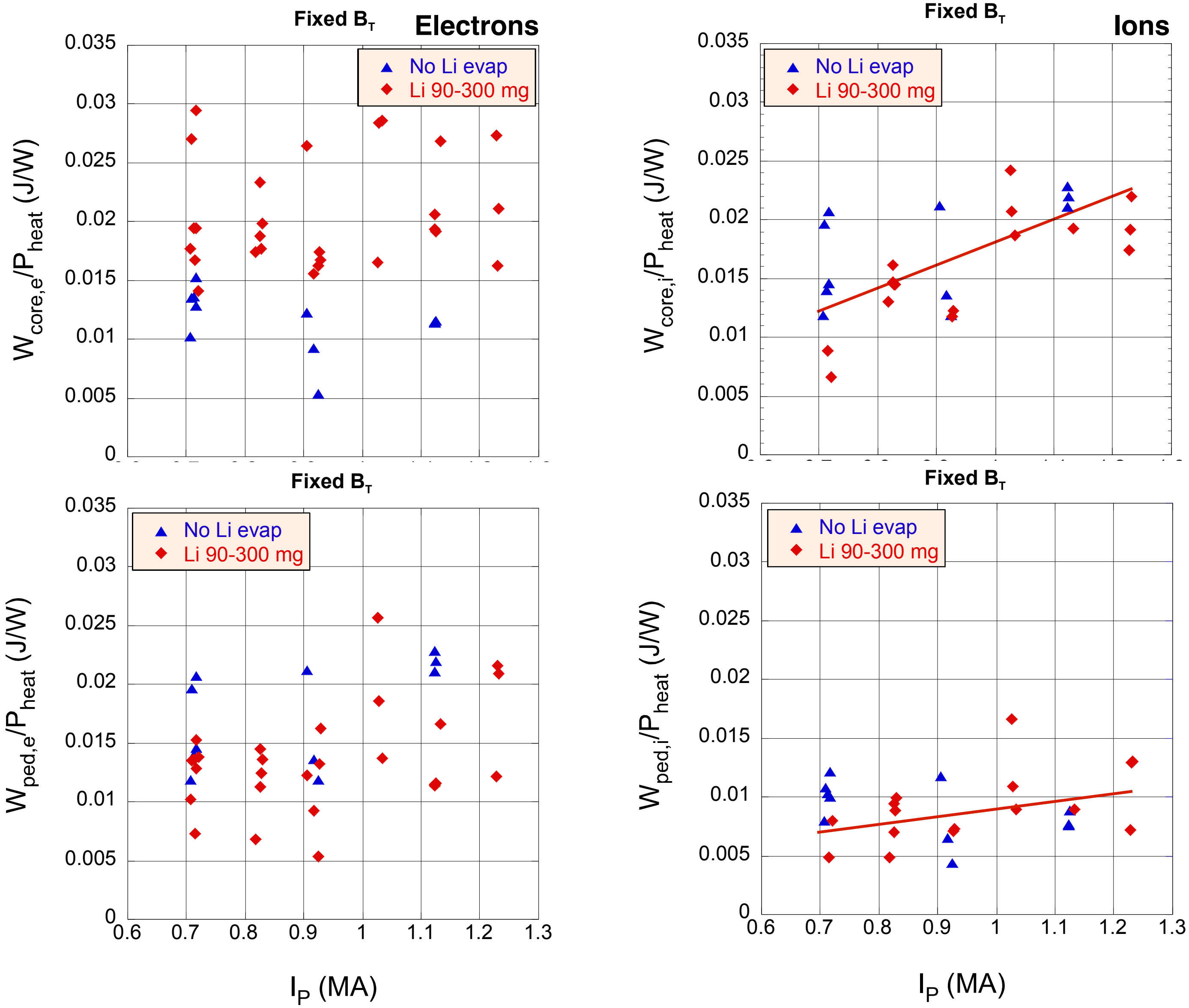
RED symbols are for discharges WITH lithium conditioning

Fraction of Ion Pedestal Energy Slightly Decreases with I_p
- Little Change in Fraction of Electron Pedestal Energy -





Little Change in Electron Pedestal 'Confinement' for Both Cases
Strong Increase in Ion Core 'Confinement' in Both Cases



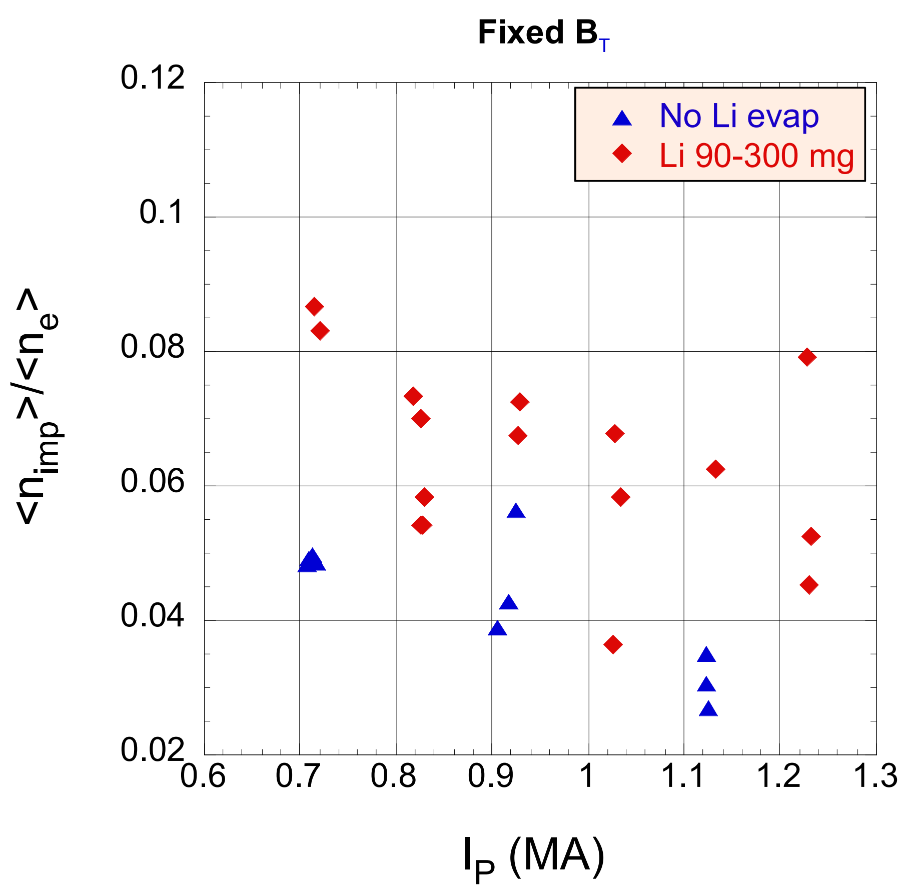
Increase in ion core confinement for both Li and no-Li cases

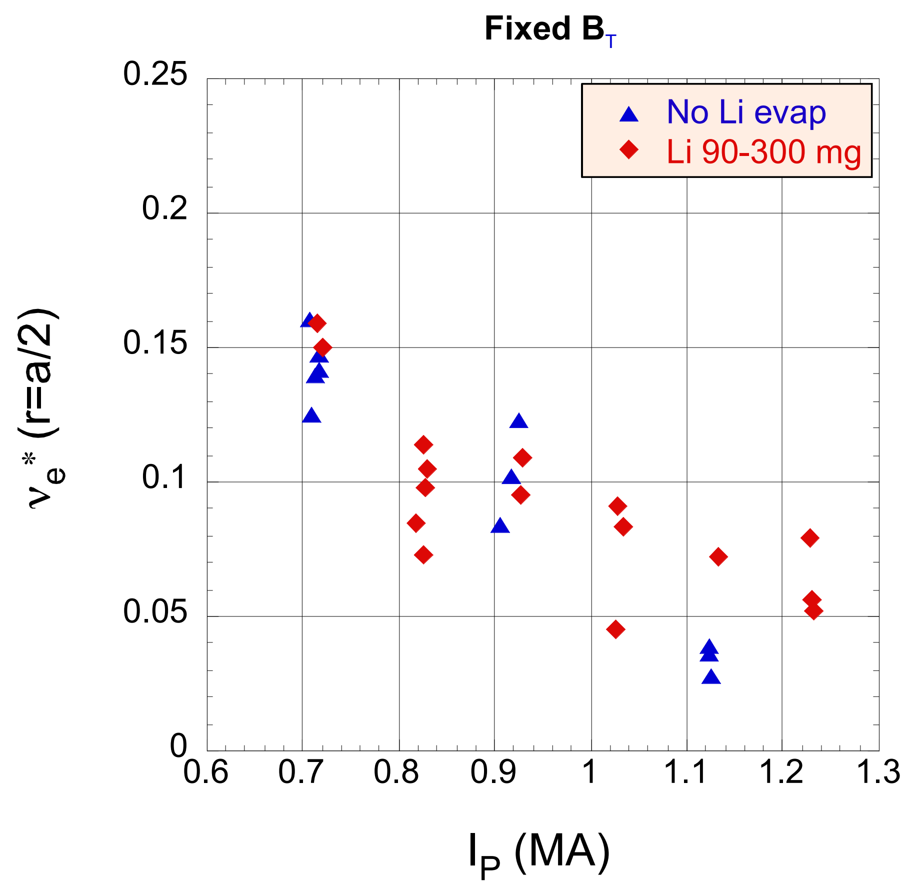
+

Little change in pedestal Ion confinement

Decrease in ion pedestal energy fraction (see previous vugraph)

Decrease of Fractional Impurity Density and Collisionality With Increasing I_p for Both Sets of Discharges

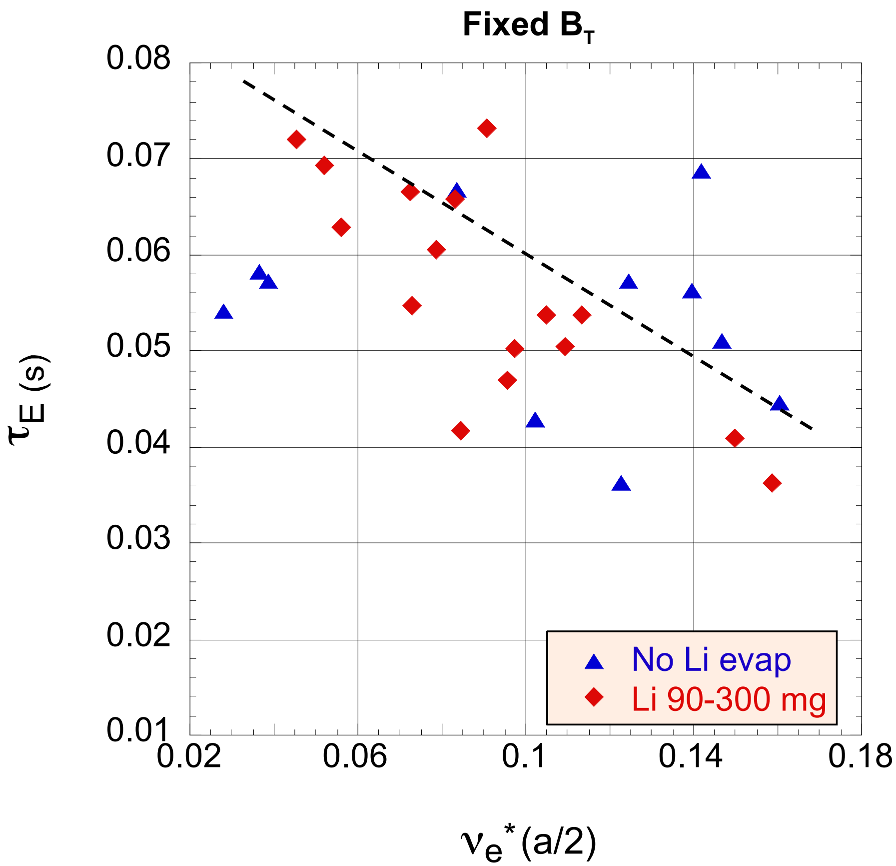


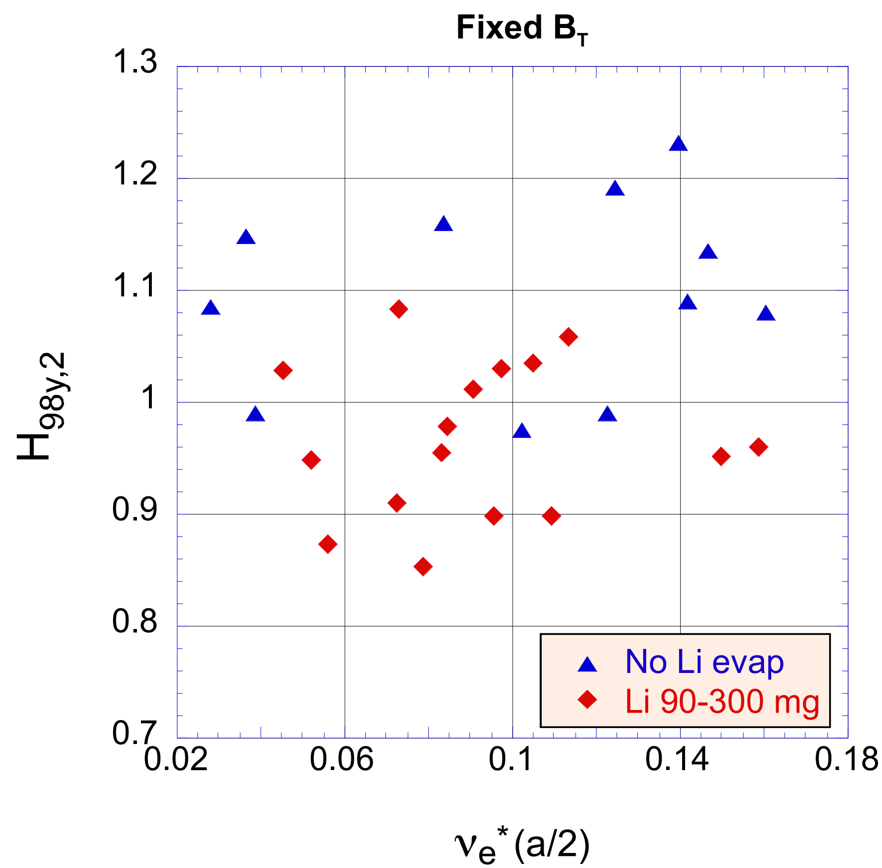


Collisionality dependence governed by Z_{eff}, q dependences with I_p
- Also n_{imp} dependence for no Li case

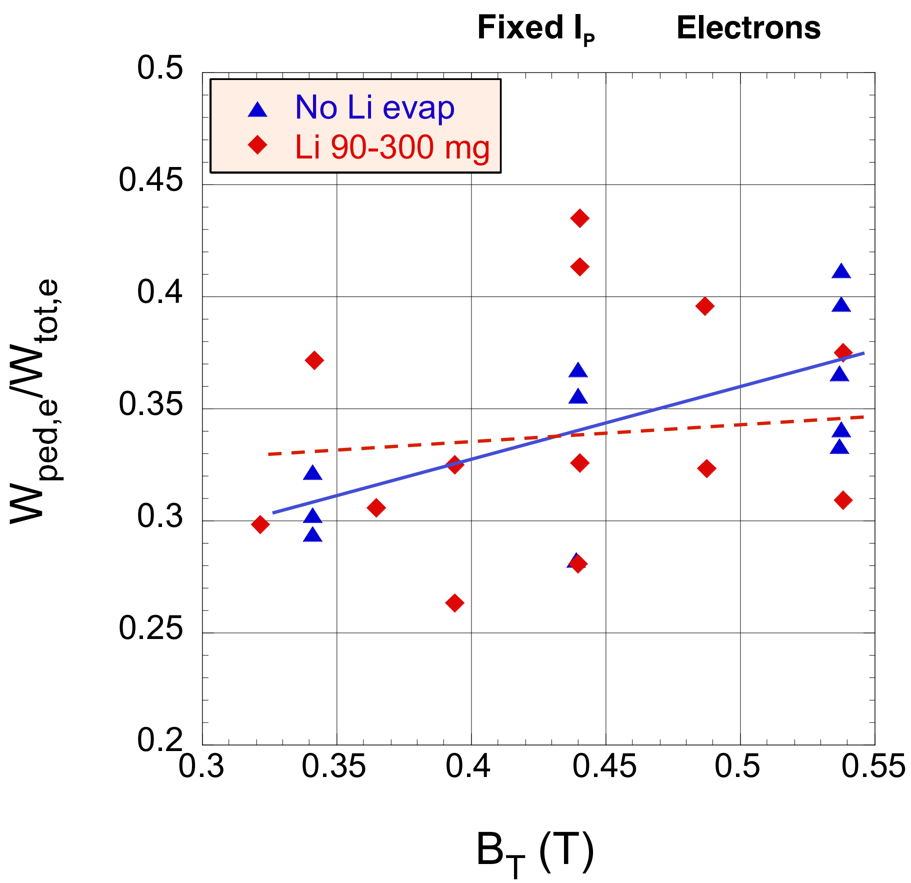
Lower Collisionality Discharges Have Higher Energy Confinement

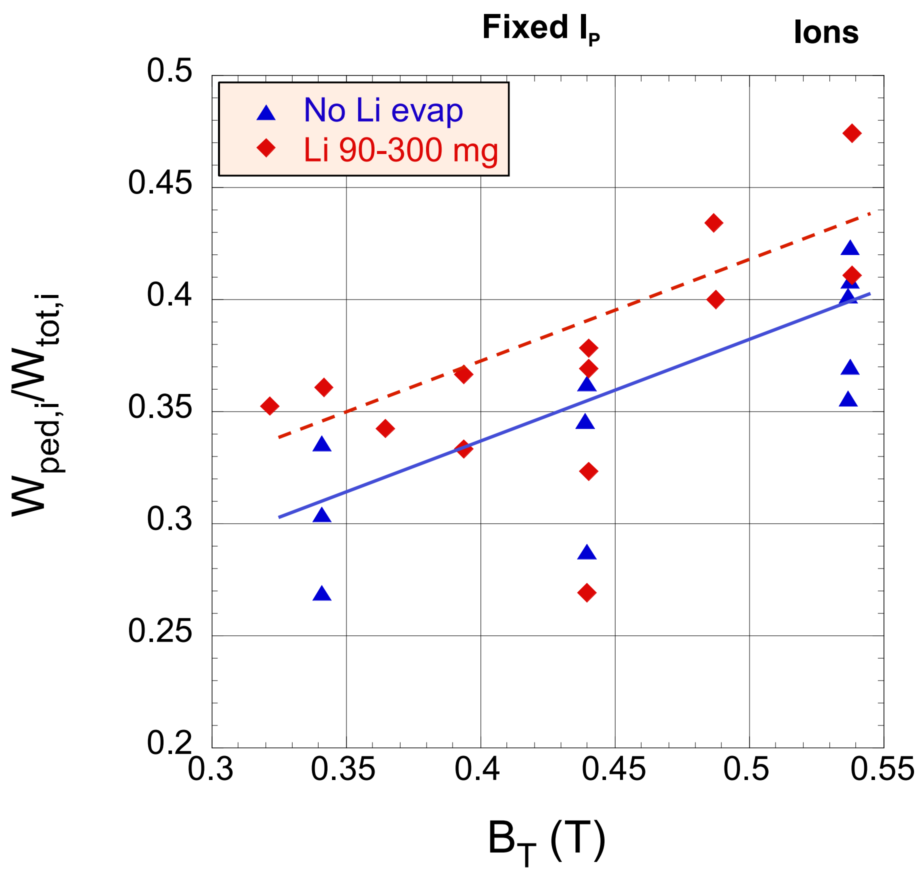
H-factor shows little dependence



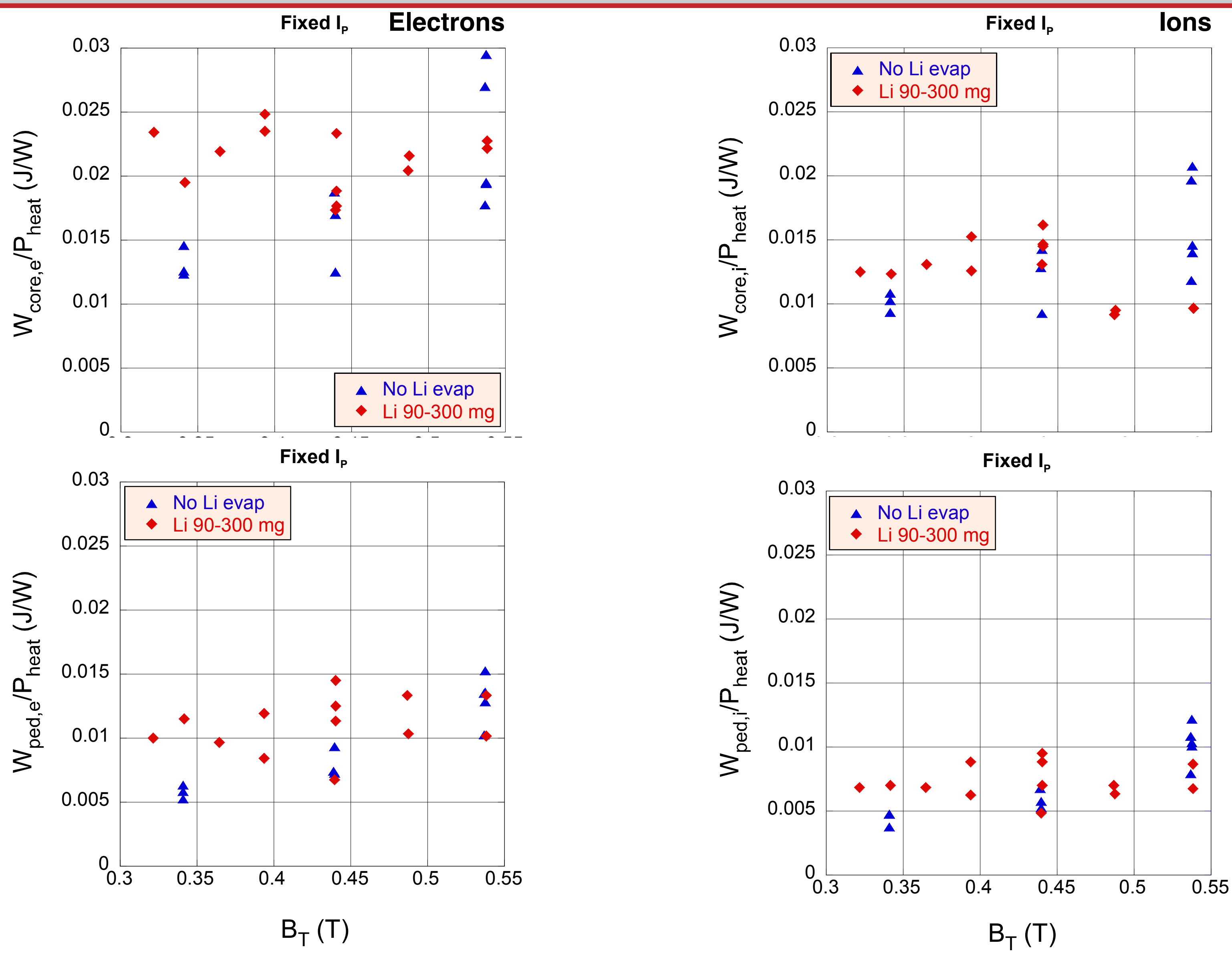


Fractional Electron Pedestal Energy Increases with B_T for No Li
Fractional Ion Pedestal Energy Increases with B_T w/ & w/o Li

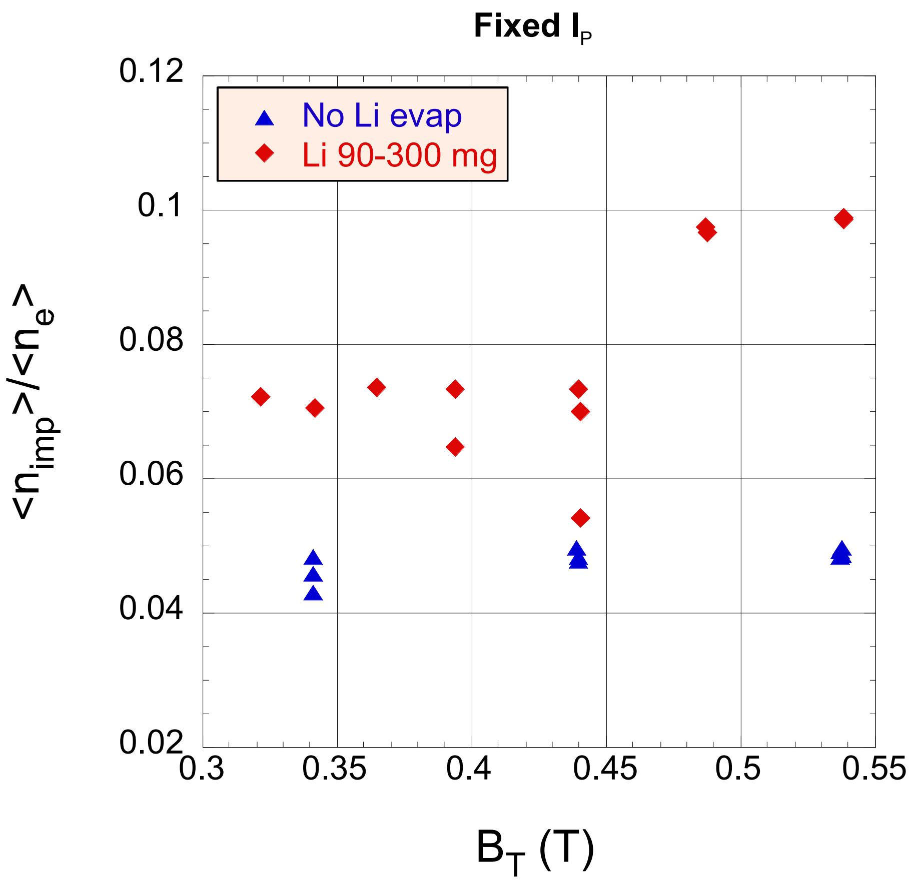


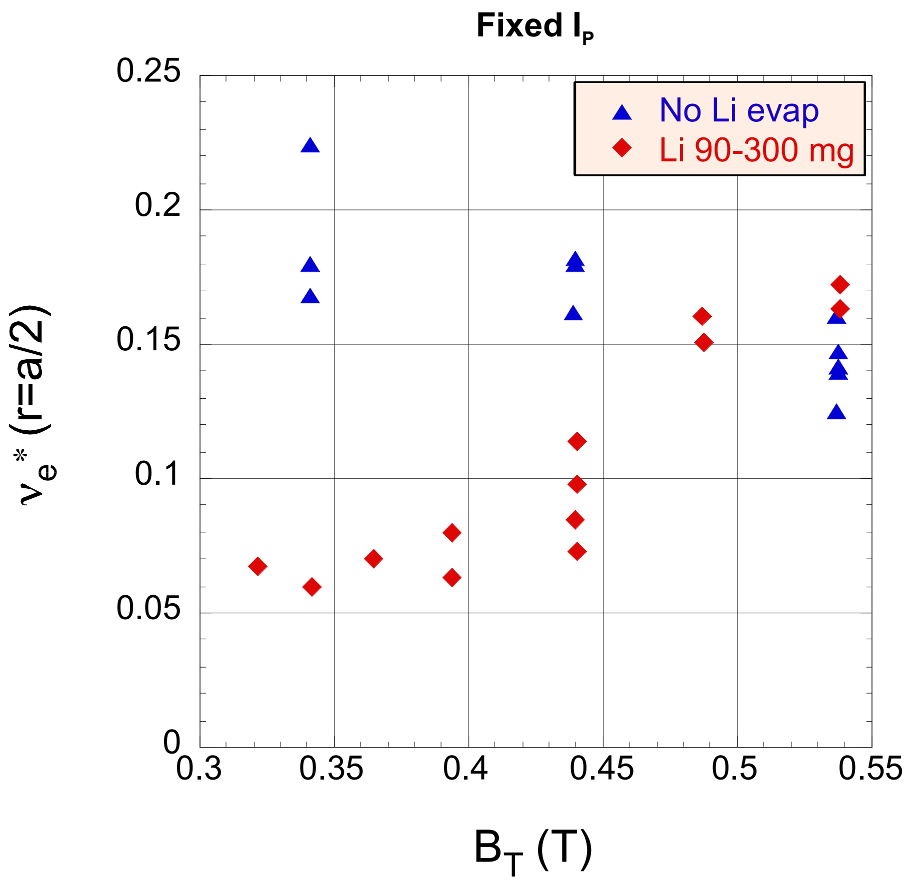


Strong Increase in Core/Pedestal e^- Confinement with no Li
Reduced Core i^+ Confinement w/ Li, Increased Pedestal i^+ Confinement w/o Li
-- Consistent with Results on Previous Slide --



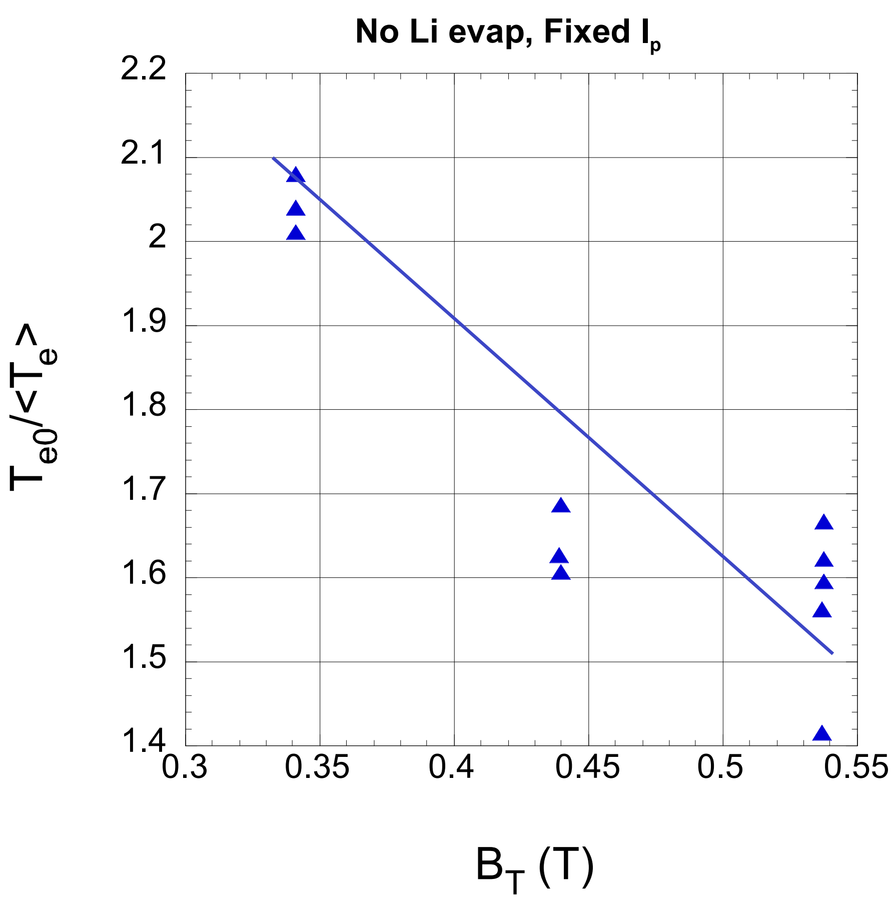
Collisionality Decreases with B_T for No Li Increases with B_T with Li Evap (due to increase in n_{imp}/n_e)



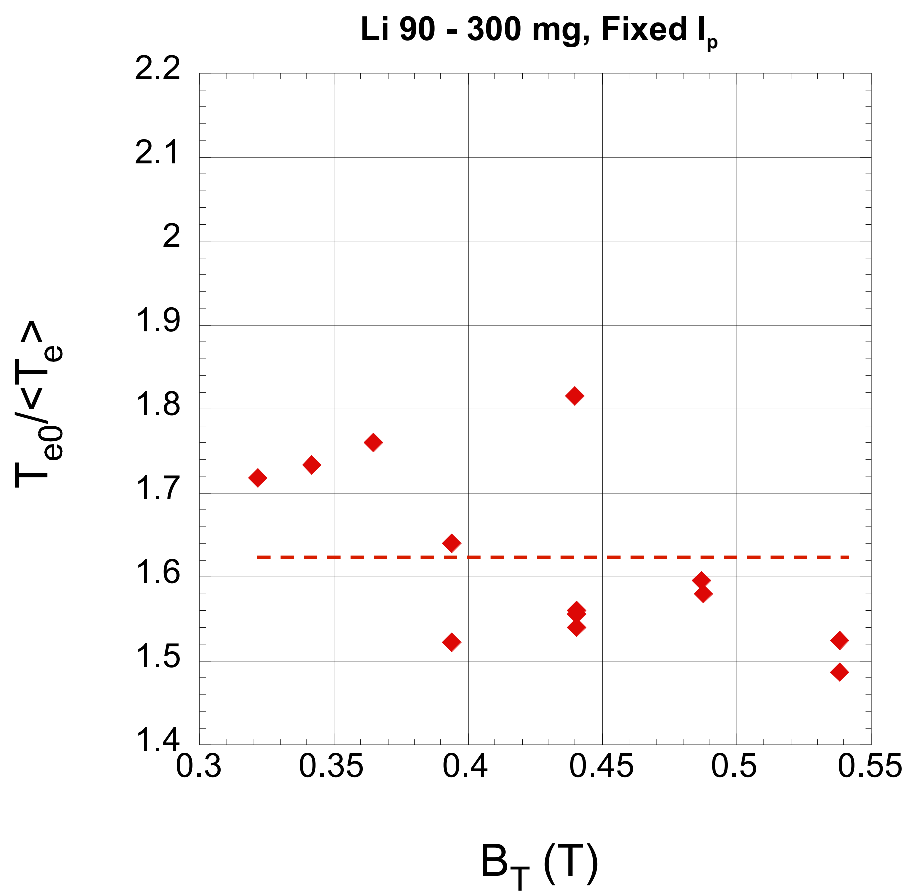


Broadening of T_e w/o Li Reason for Decreasing ν^* Dominates Increase in q, etc.

Strong T_e broadening w/ B_T

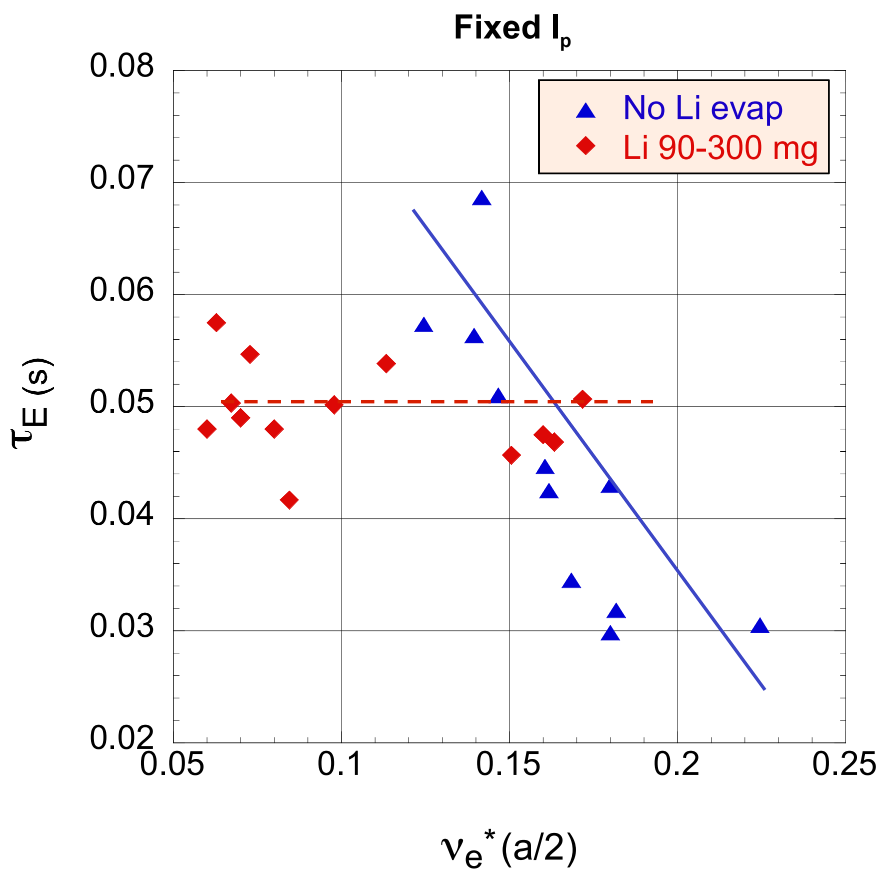


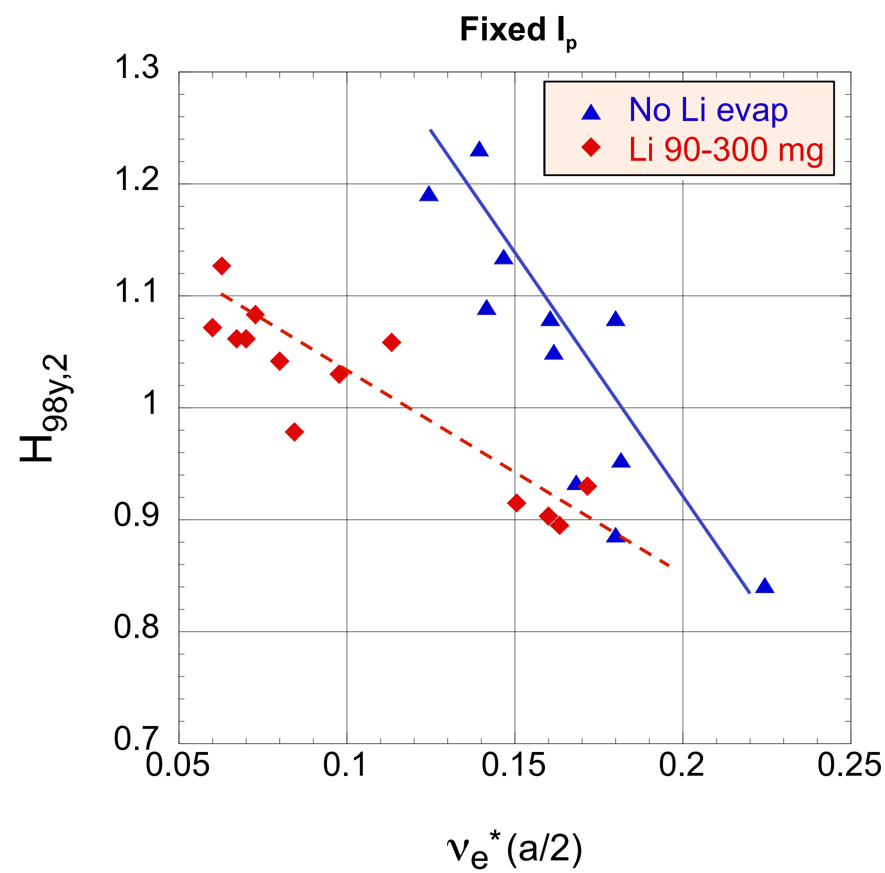
No T_e broadening w/ B_T



Strong Reduction in τ_E With ν^* for No Lithium Not Much Change Seen with Li (but q Changing)

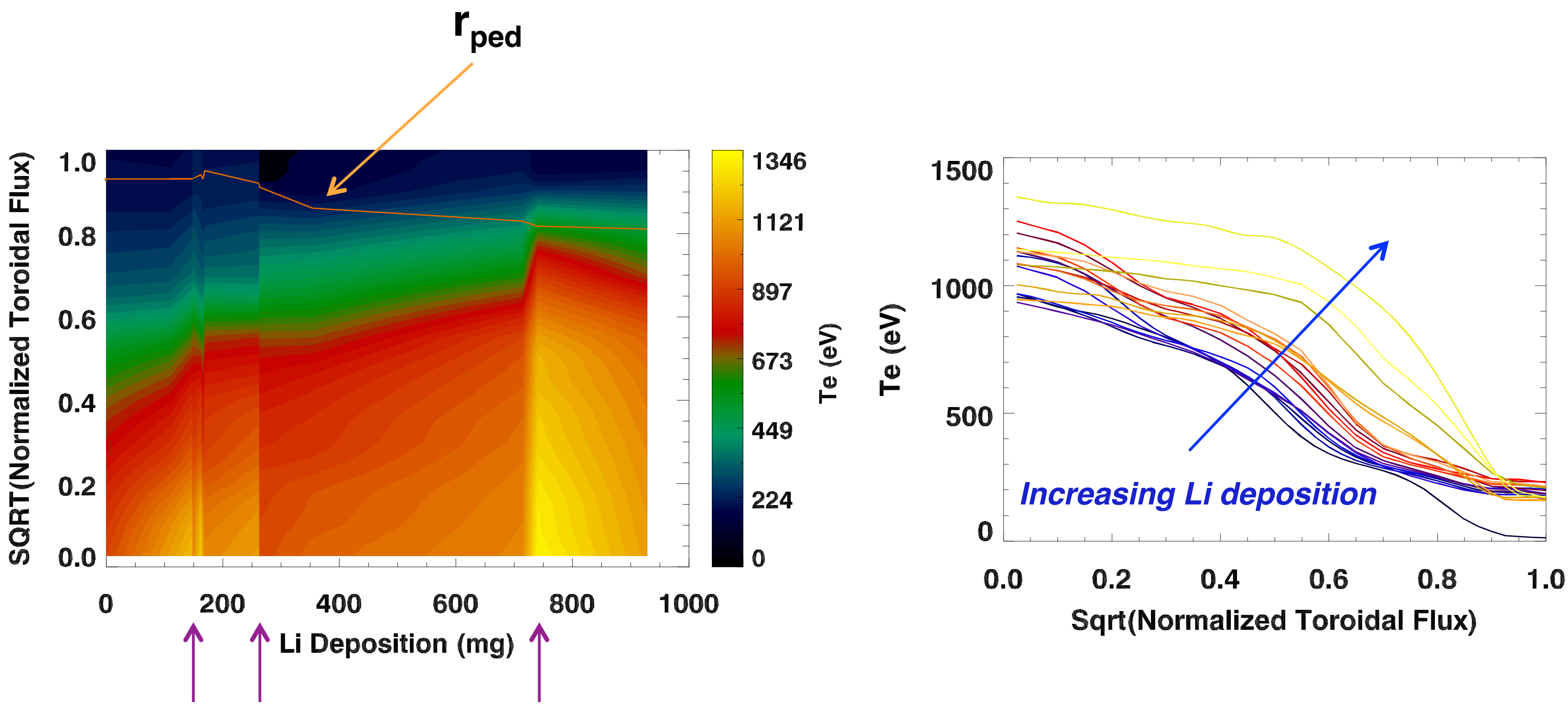
H decreases with ν^* in both cases – n^* scaling in data stronger than in 98y,2 scaling ($\nu^{*\,-0.1}$)





2. Lithium Deposition Scan at Fixed I_p, B_T

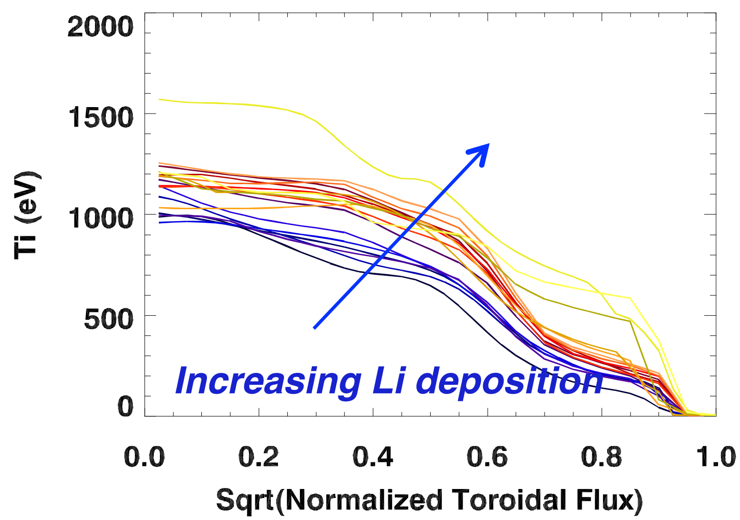
T_e Profile Exhibits Broadening with Increasing Between-Shot Lithium Deposition

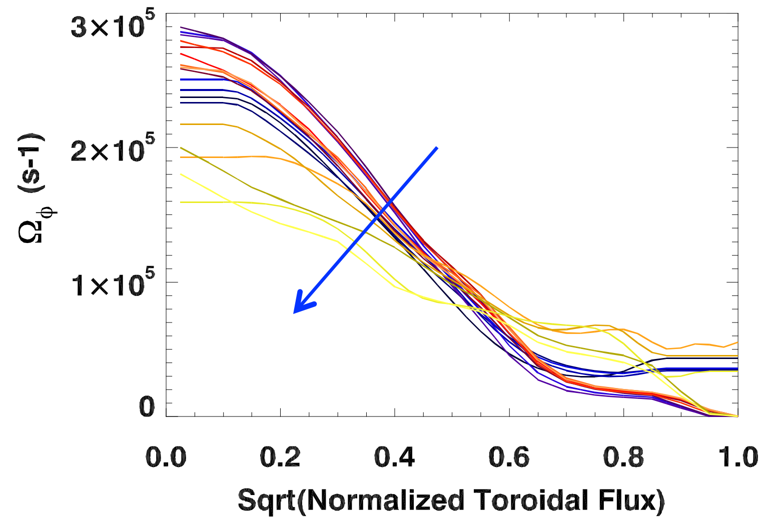


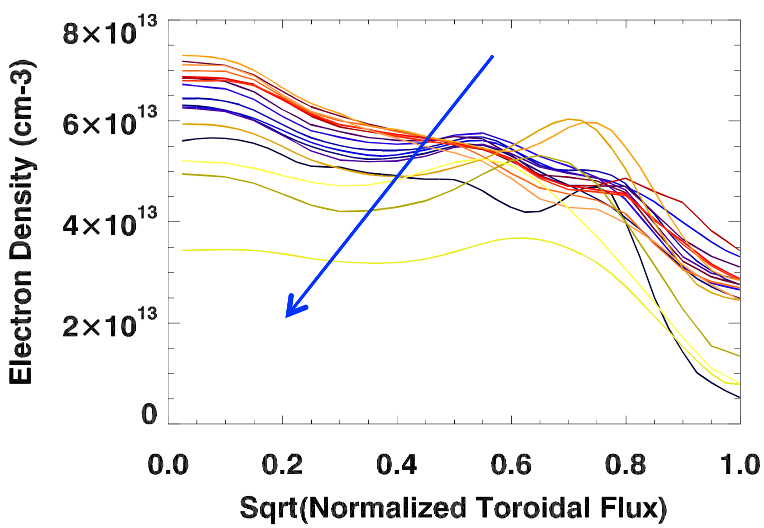
Disruptions can cause reduced broadening of subsequent discharge even with high Li deposition

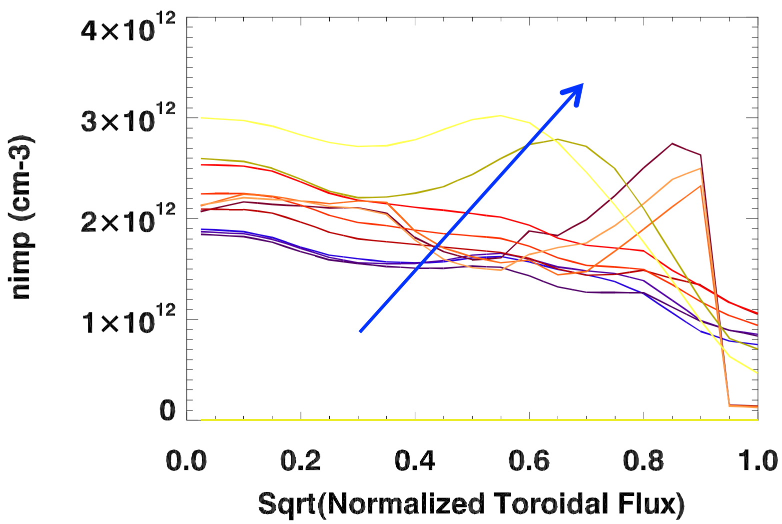
Profiles taken between ELMs (at low Li deposition rates)

Slight Broadening of T_i, Ω_ϕ; Reduced n_e, Increased n_{imp}



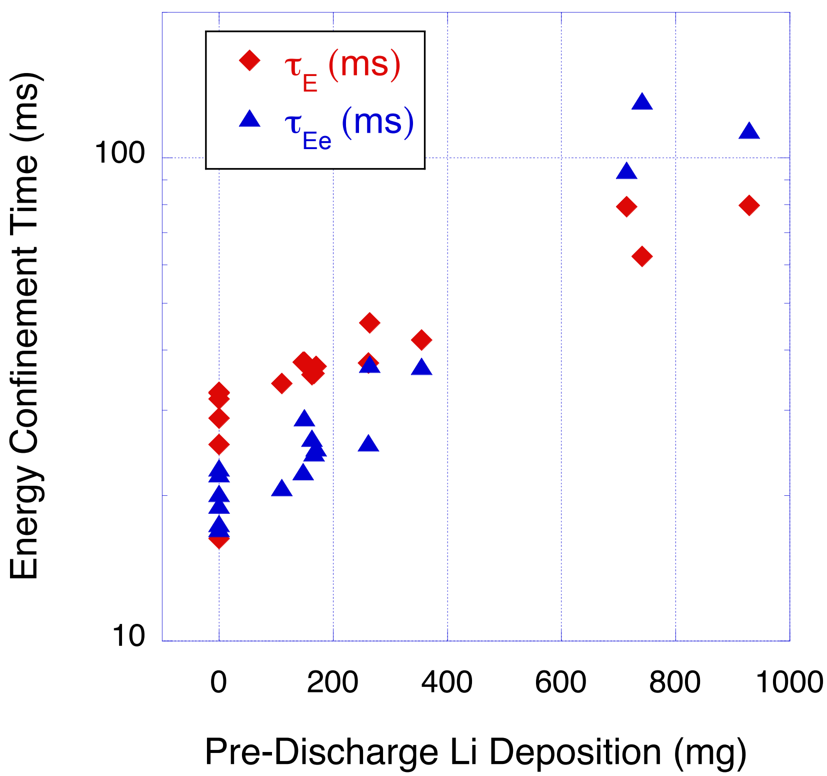


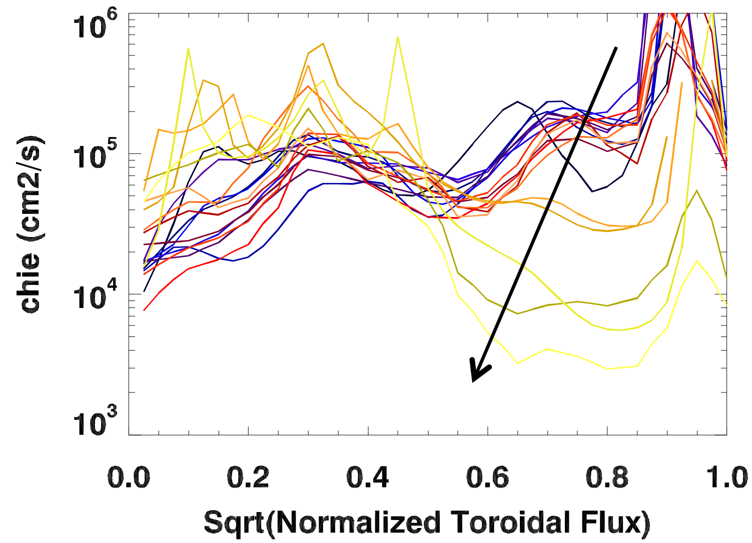


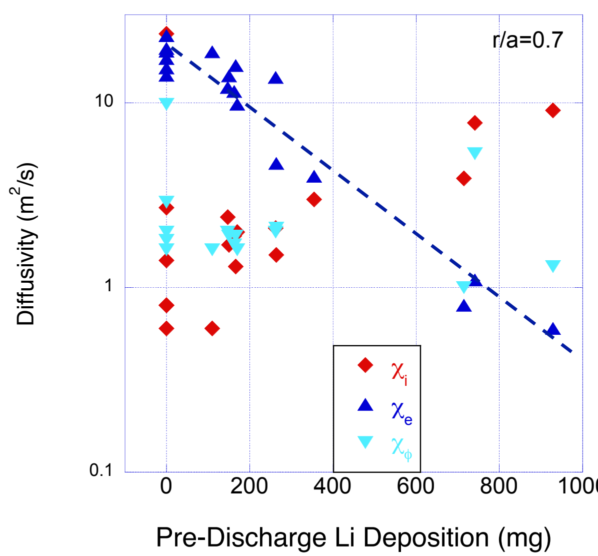


Strong Increase in Energy Confinement, Reduction in χ_e With Increased Li Deposition

Confinement times calculated between ELMs (when present)



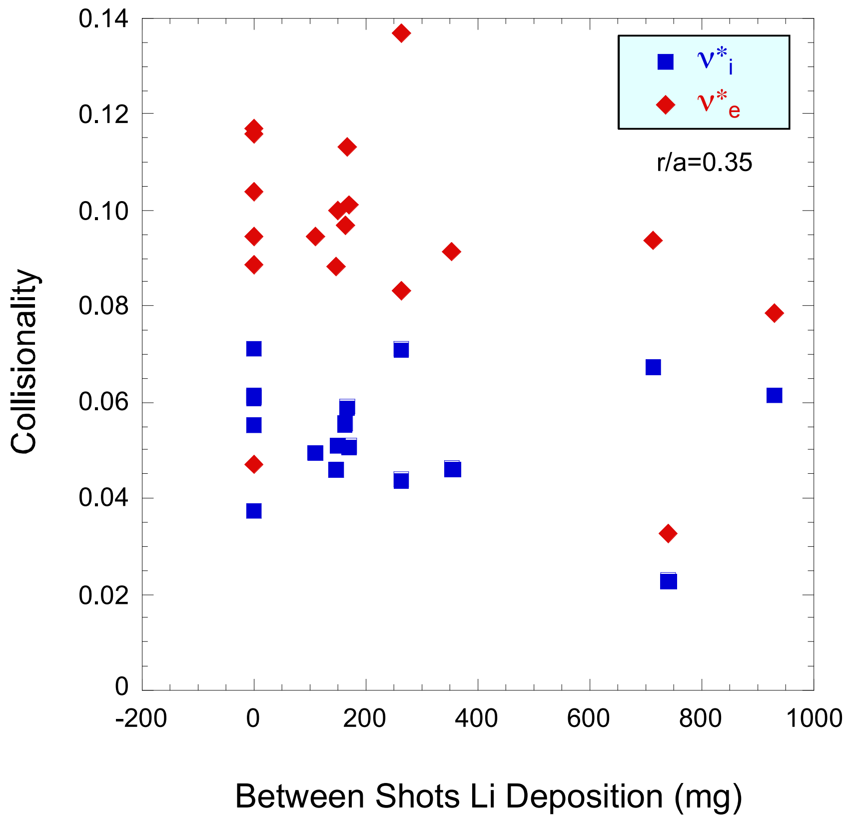


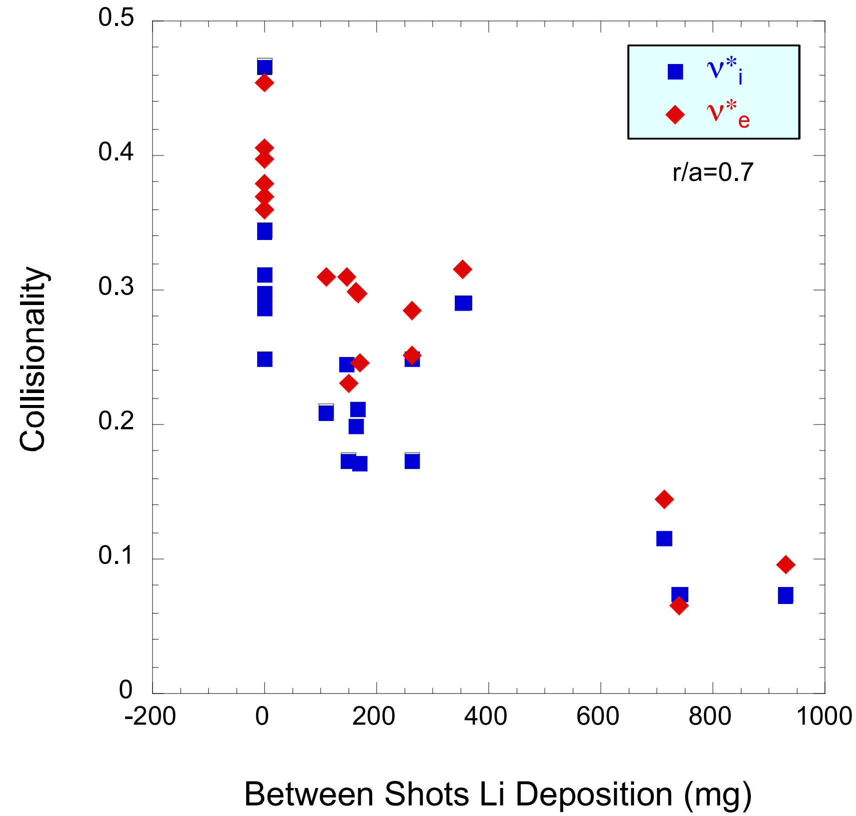


- ***What is the fundamental independent variable?***

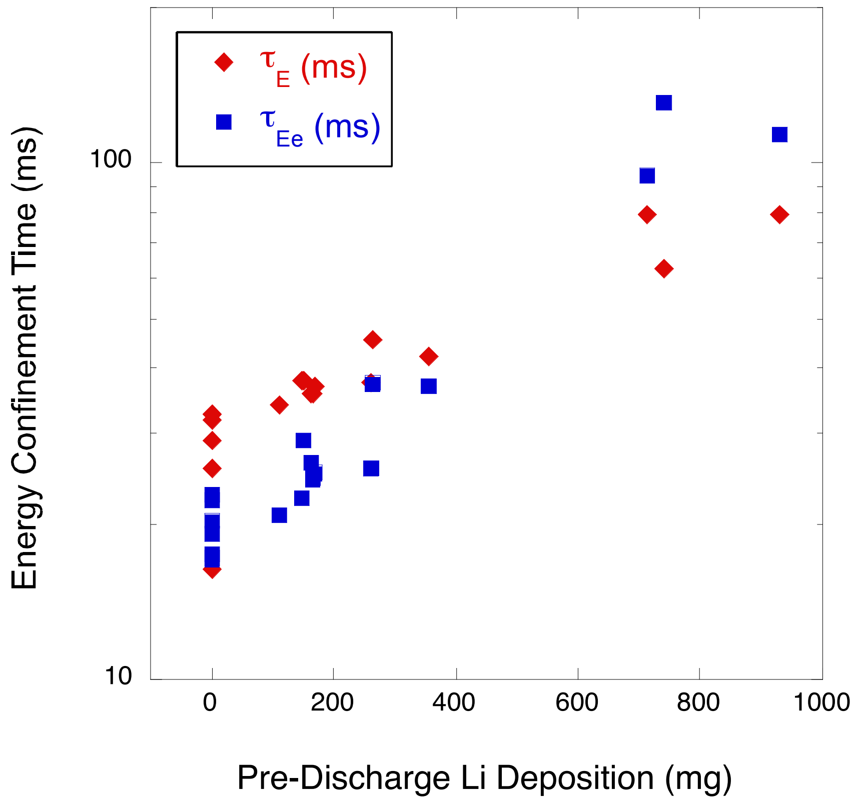
Collisionality (Especially Near Edge) is Coupled Strongly to Amount of Li Deposition

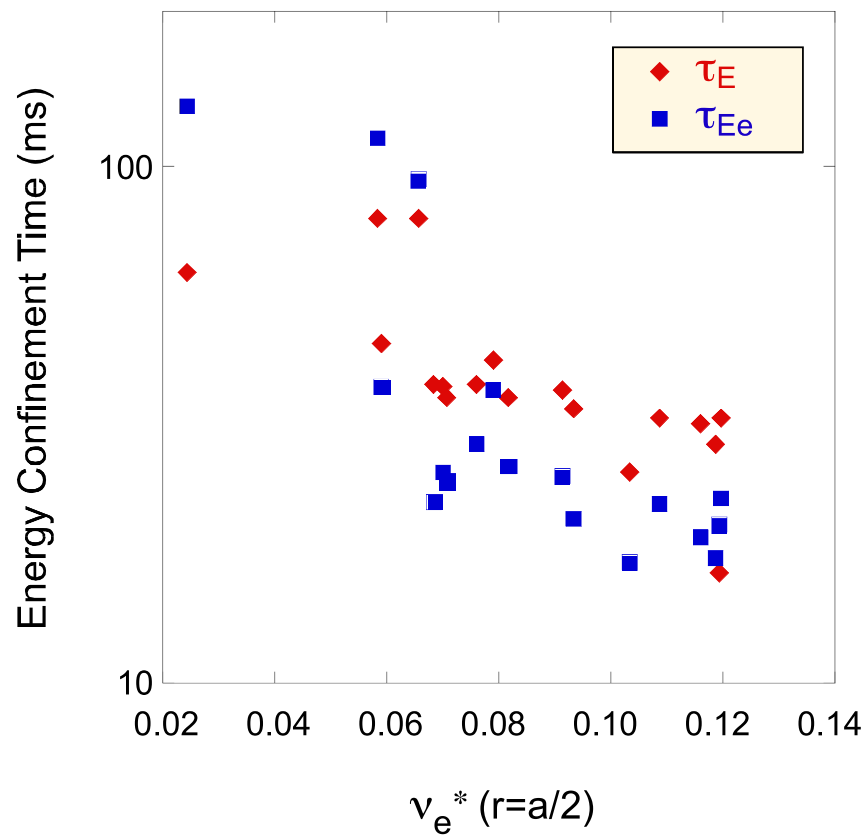
- T_e broadening, reduced n_e with Li controlling factors
- Seen in both ion and electron collisionality





Energy Confinement Exhibits Strong Dependence on Collisionality

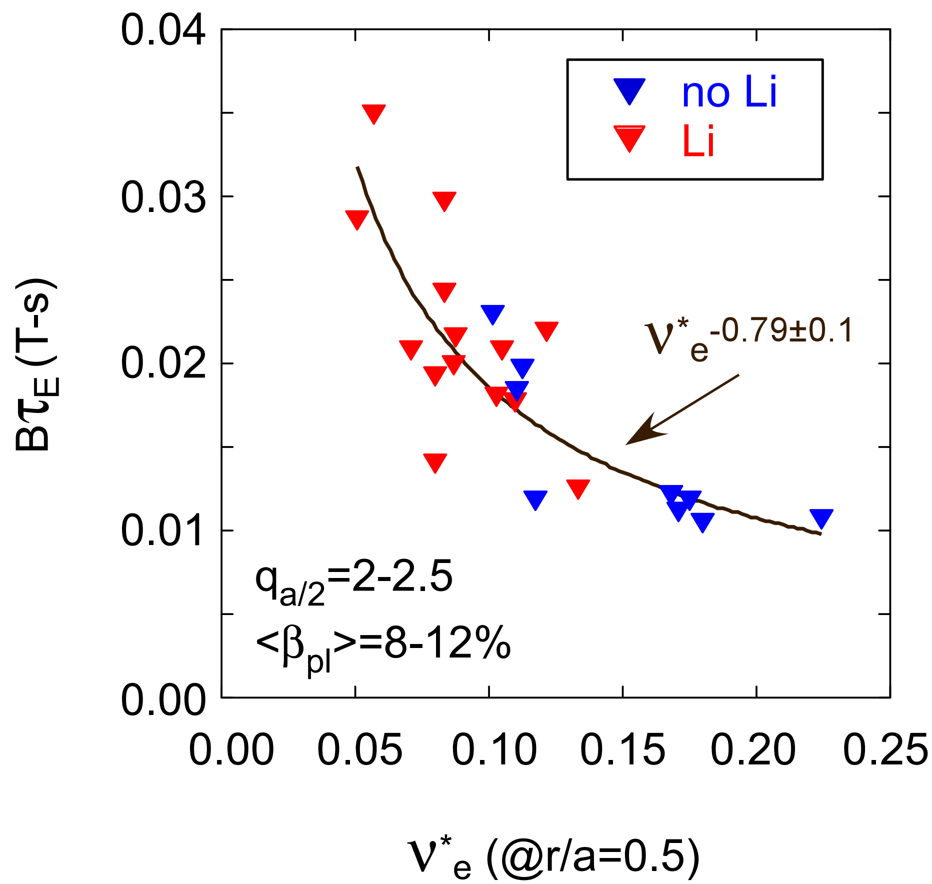




Changing q, β_T

At Fixed q, β_T, See Strong Favorable Dependence of Confinement on Collisionality

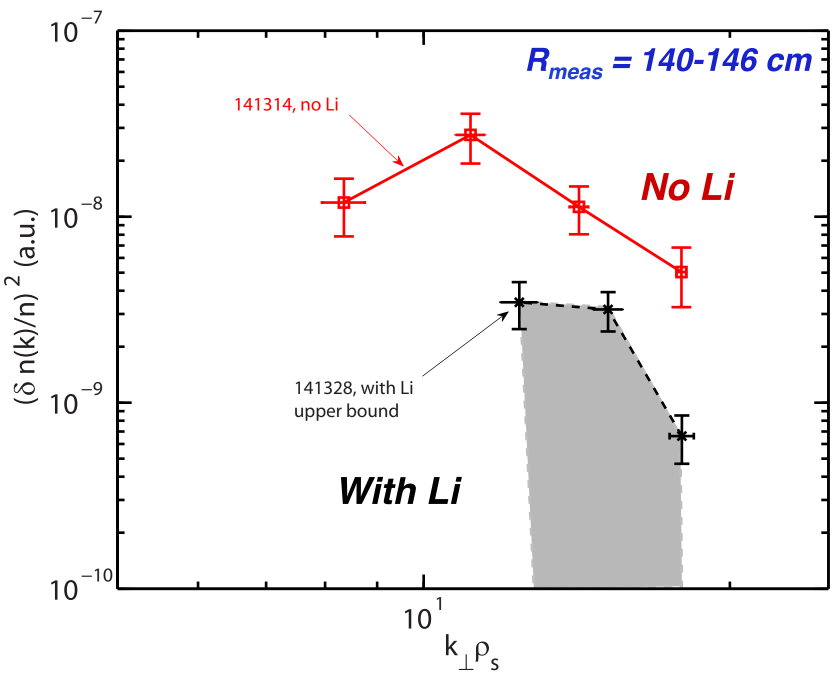
No-Li and Li discharges well ordered by and scale similarly with ν^*



Reduction in Electron Transport at Outer Regions Consistent with Reduction in High-k Turbulence, Microtearing

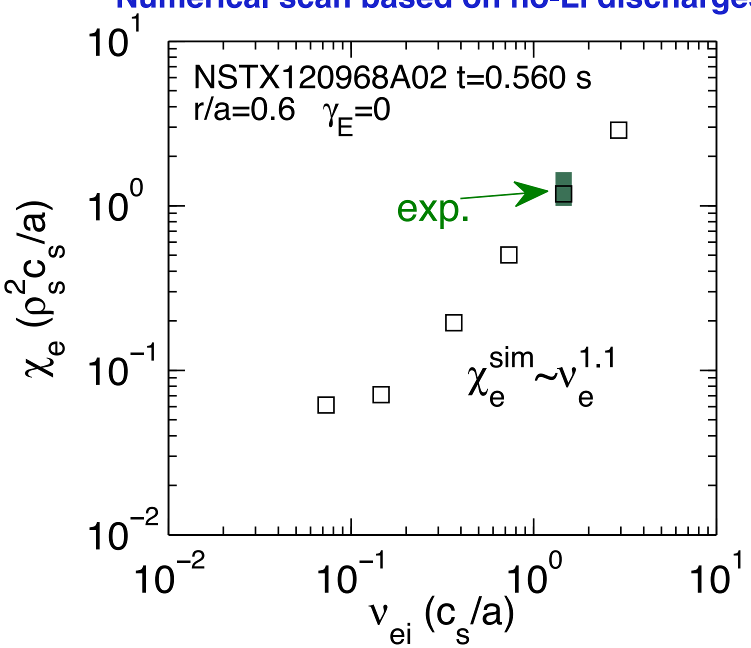
- Source of high-k turbulence consistent with ETG
- Due to increase in Z_{eff} with Li?
- Reduction in high-k⇔Reduction in transport (causal?)

- Non-linear GYRO sims show microtearing mode induced transport can be dominant
- Electron heat flux due to microtearing decreases with decreasing collisionality



Y. Ren, APS-DPP TI2:00002

Numerical scan based on no-Li discharges



W. Guttenfelder, APS-DPP TI2:00006

Regression Analysis Indicates Strong Dependence of Normalized Confinement on ν^* and Current Profile

$B\tau_E$	ν^* (1)	$\beta_{T,thermal}$	$q_{a/2}/q_a$ (2)	κ	R^2	RMSE
	-0.56	0.17			0.64	0.090
	-0.55			0.74	0.69	0.083
	-0.48		1.15		0.74	0.077
	-0.55	-0.49		1.30 (3)	0.72	0.081
	-0.45	-0.33	1.48 (4)		0.76	0.076

- Strong, positive dependence on $q_{a/2}/q_a$
  - Parameter is proxy for current profile, ~ $I_a/I_{a/2}$
  - Larger $q_{a/2}/q_a$ (smaller $I_a/I_{a/2}$) indicates broader current profile
  - Confinement improves with broader current profile (consistent with results of Ding et al., PPCF 2010)

  - (1) & (2): ν^* and $q_{a/2}/q_a$ have strongest influence on $B\tau_E$ of all parameters
  - (3): κ and $\beta_{T,thermal}$ have very high cross-correlation (0.77) => these parameters are not independent
  - (4): High cross-correlation between $q_{a/2}/q_a$ and both $\beta_{T,thermal}$ (0.56) and κ (0.78)

Summary

- Discharges with and without between-shot Li wall deposition reveal energy confinement scalings based on engineering parameters that differ
  - Strong B_T, weak I_p dependence without Li
  - Scaling closer to 98y,2 with Li (but slightly weaker I_p scaling)
- T_e profiles broaden with B_T for no Li case, not so with Li
  - Leads to decrease in ν^* with B_T for no Li, but increase in ν^* with Li
  - Decrease of ν^* with I_p for both Li and no-Li cases
- T_e broadens as a function of increased Li deposition, leading to decreasing ν^*
- Normalized confinement time is well ordered by, and shows strong increase with decreasing ν^* for both sets of data
  - Confinement time increases also with broader current profiles
- Collisionality dependence of τ_E consistent with dependence of microtearing-induced transport levels on this parameter (no Li cases)
- Decrease in high-k turbulence with Li consistent with improvement of confinement with increasing Li deposition

- NSTX-U will extend the range of collisionality to lower values (~one OOM)
  - Dependence on collisionality will be tested further