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NSTX-U

Bifurcation to Enhanced Pedestal (EP) H-mode on NSTX

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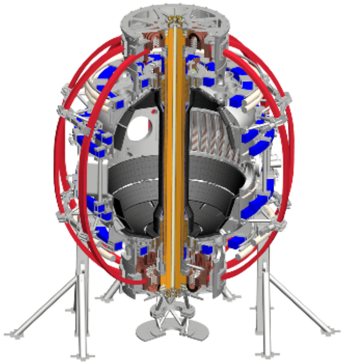
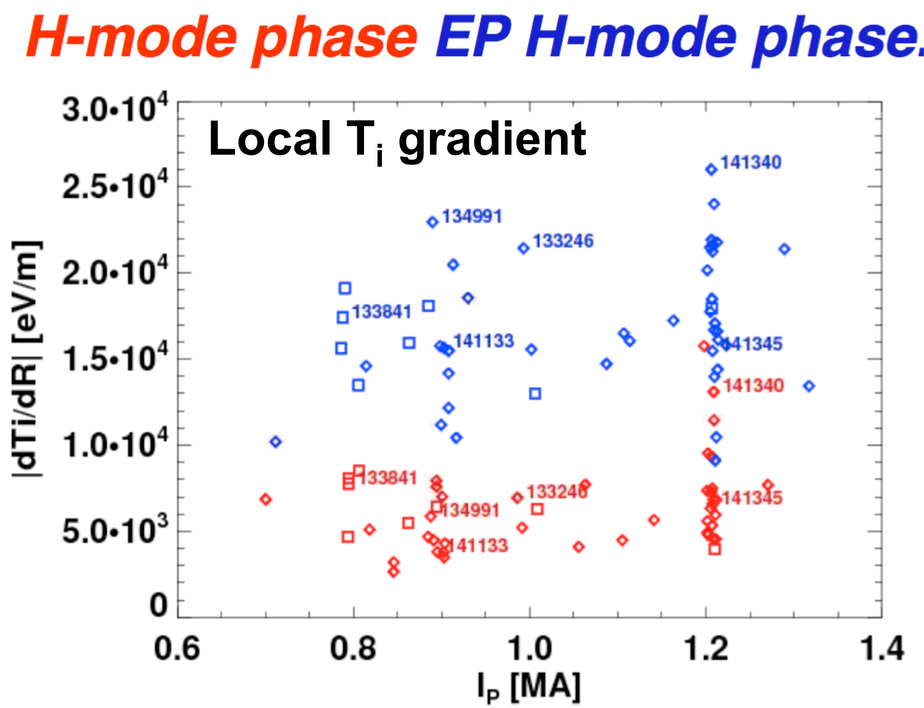


Outline

- Characteristics of the Enhanced Pedestal (EP) H-mode on NSTX
- Insights into bifurcation criteria from discharges near bifurcation
- Hypothesis: Reduction in low-frequency ion-scale transport reduces transport of high-energy main ions

EP H-mode: Bifurcation to large T_i and v_ϕ gradients on NSTX

- Enhanced Pedestal (EP) H-mode on NSTX:
  - Increased ion thermal and rotation gradients inside H-mode pedestal
  - Bifurcation triggered by a large ELM
  - More common with lithium wall conditioning



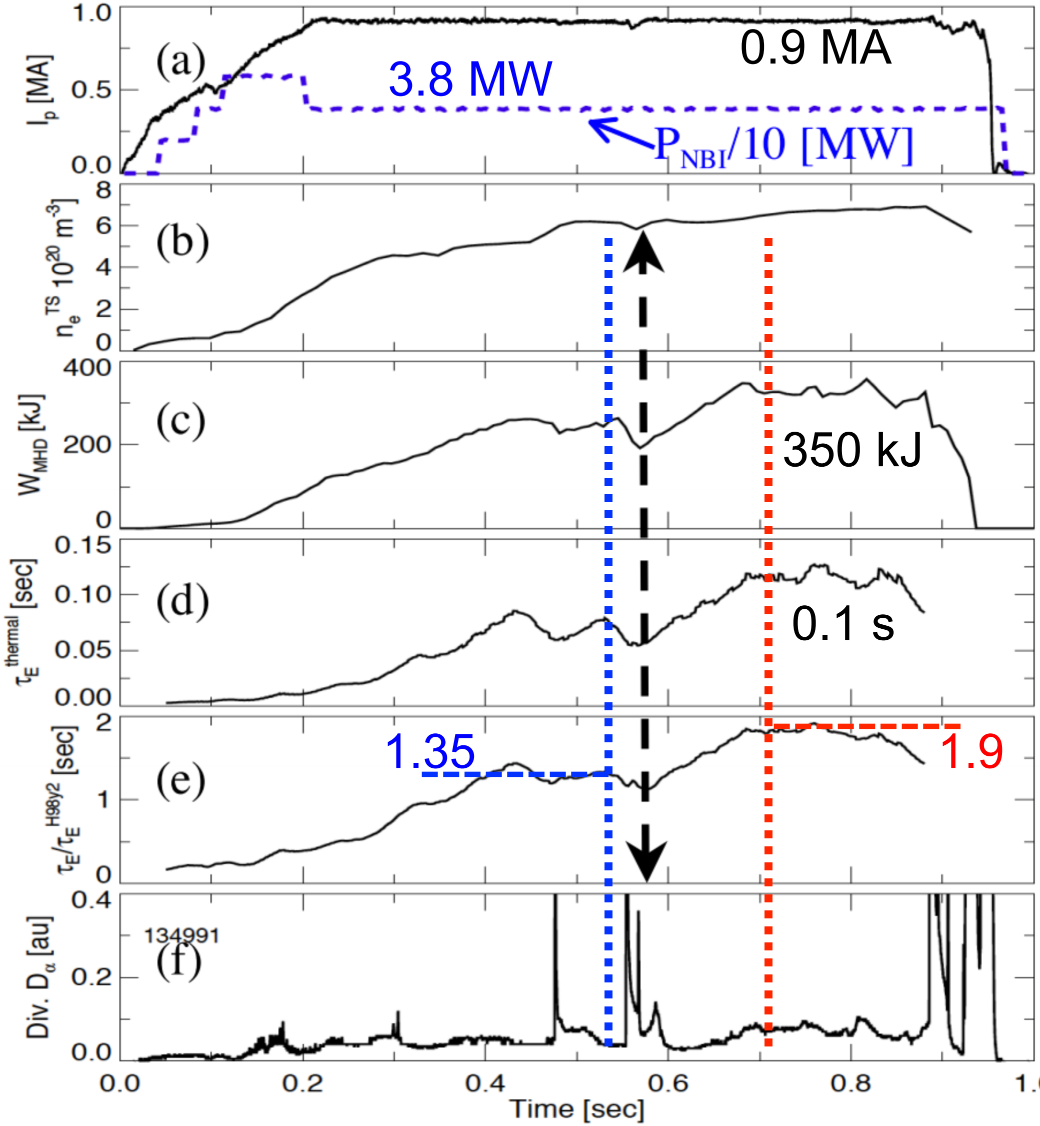
S. Gerhardt et al, NF **54**, 083021 (2014)

- Typically translates into improved τ_E (H_{98y2} ~ 1.3 – 2)
  - AND larger particle transport compared to ELM-free H-mode

Typical EP H-mode Bifurcation: Triggered by ELM with Lithium Wall Conditioning

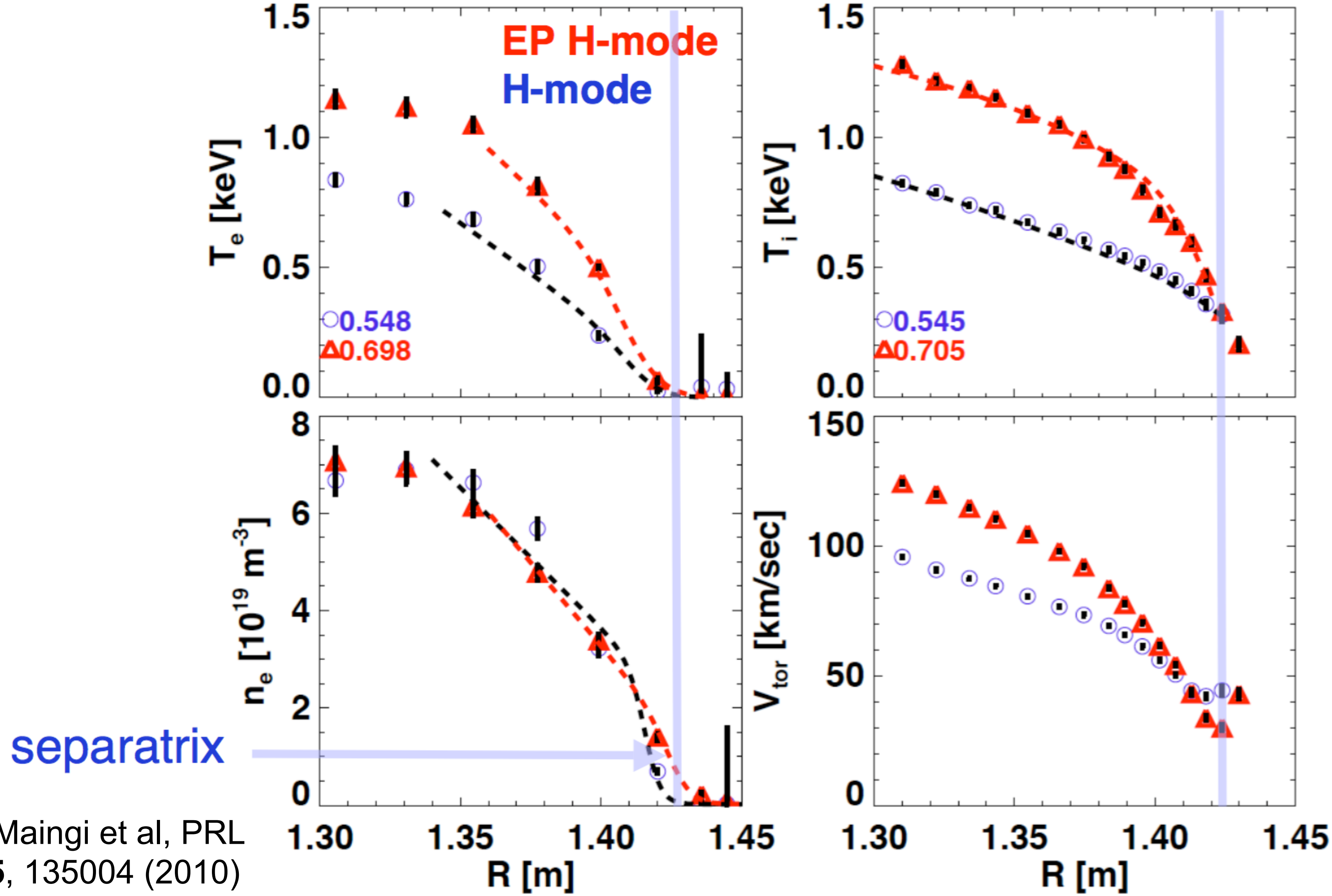
- Large infrequent ELMs with Li wall conditioning
  - EP H-mode begins after second ELM
  - Achieves H_{98y2} ~ 1.9
  - ELM and MHD quiescent

- Discharge terminates with core MHD



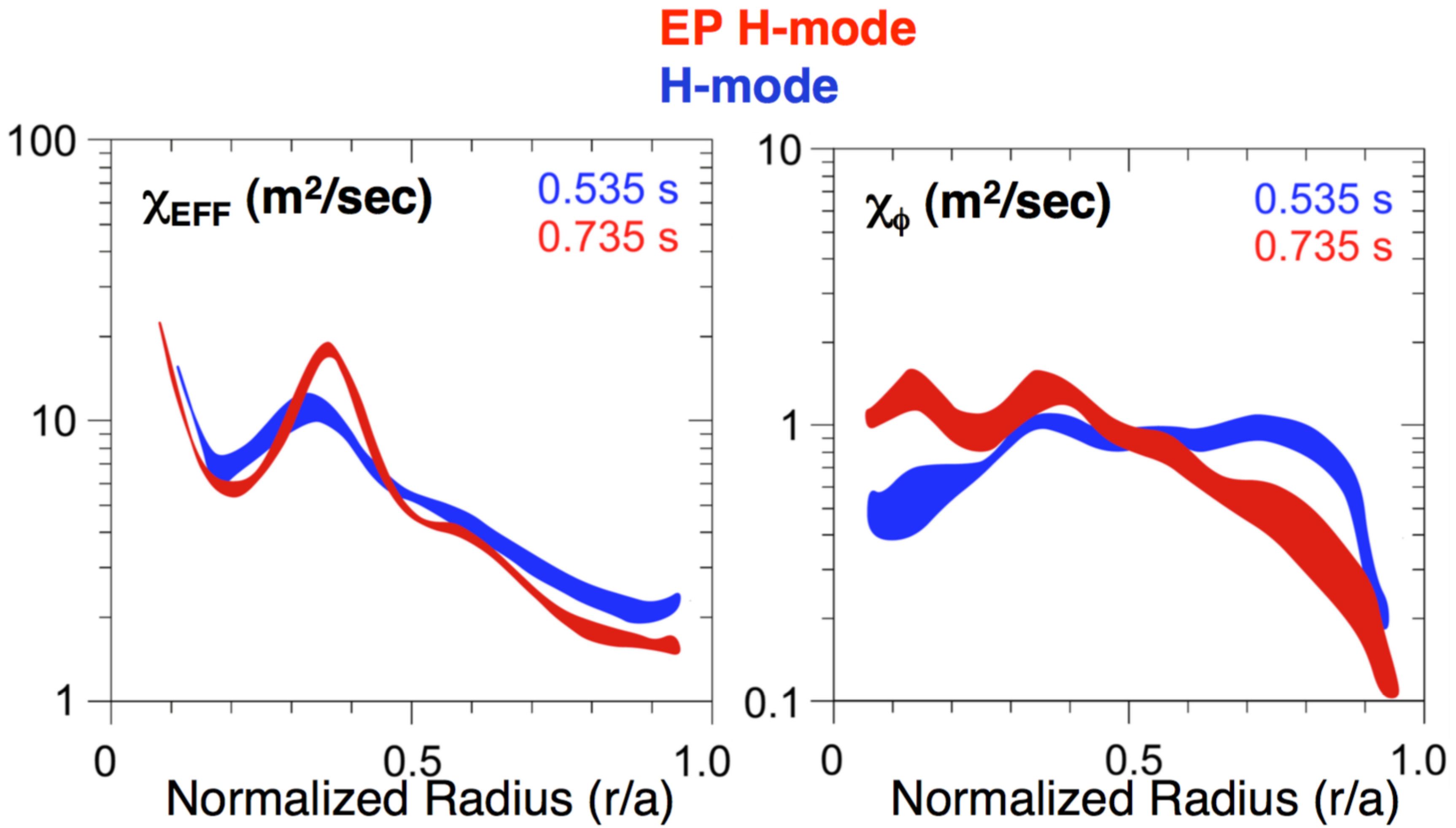
R. Maingi et al, PRL **105**, 135004 (2010)

Edge T_e, T_i increase with a reduction in n_e gradient and increase in v_ϕ shear



R. Maingi et al, PRL **105**, 135004 (2010)

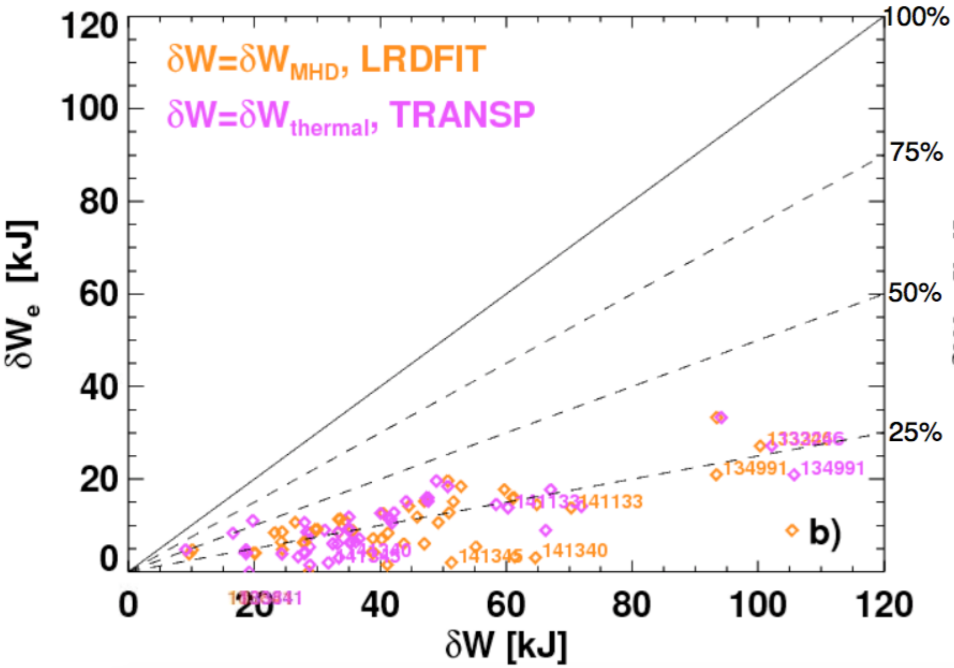
Thermal and angular momentum transport reduced in outer half of plasma



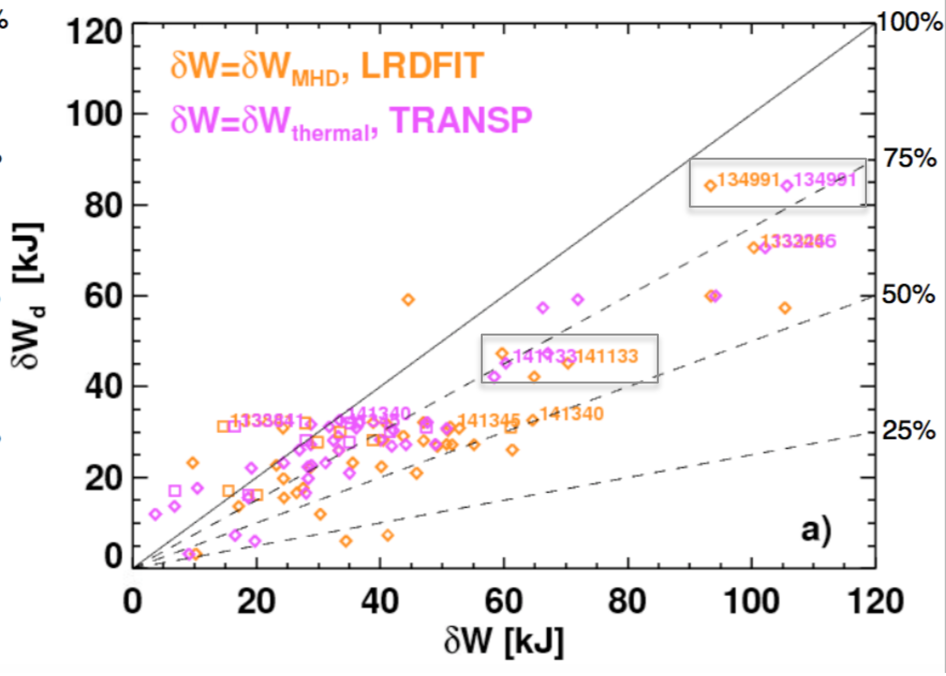
R. Maingi et al, PRL **105**, 135004 (2010)

Stored energy increment is mostly due to improved ion confinement

~ 25% δW in electrons



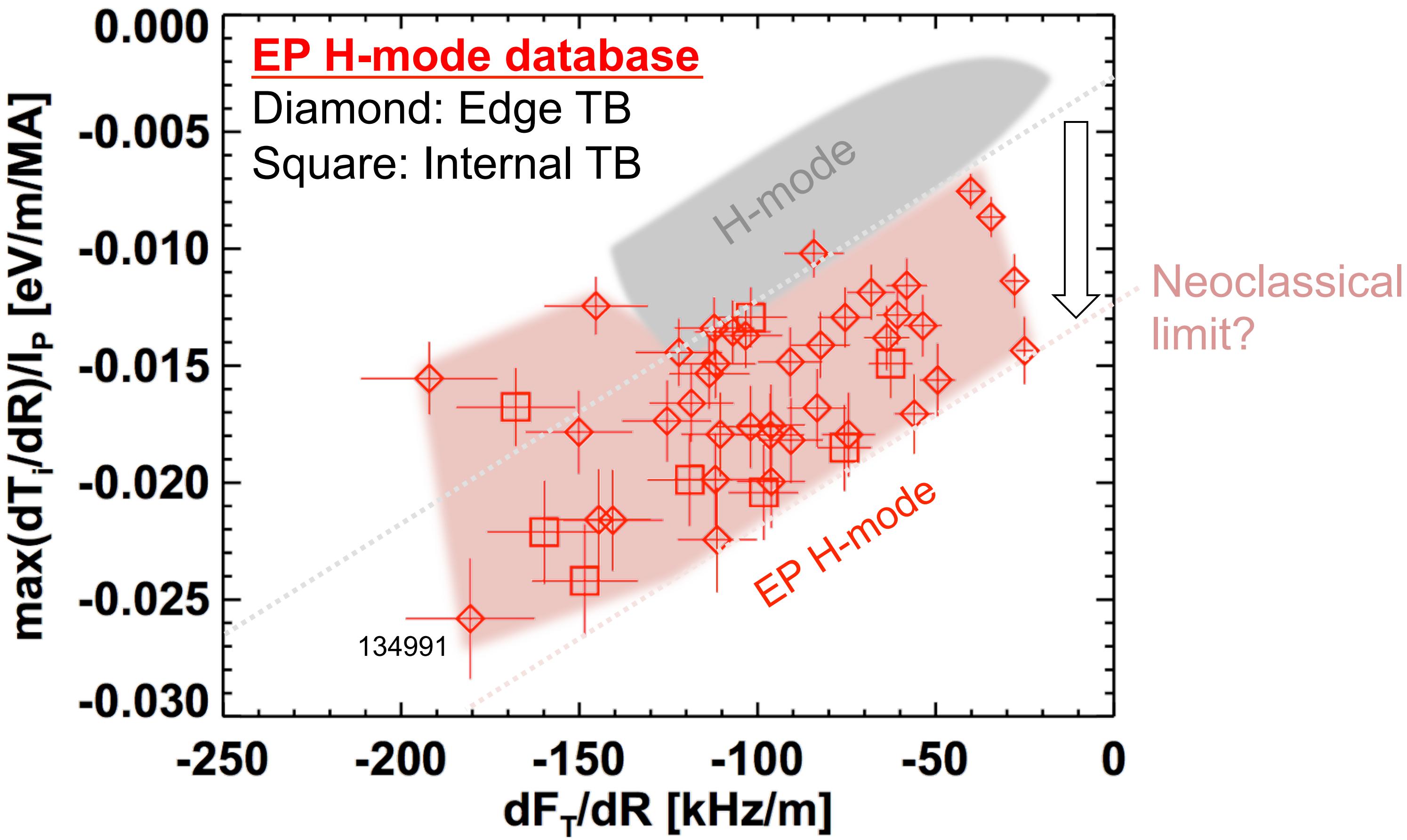
~ 75% δW in ions



Change in stored energy from H-mode to EP H-mode times

S. Gerhardt et al, NF **54**, 083021 (2014)

Max T_C gradient normalized to I_p scales with max rotation gradient in EP H-mode

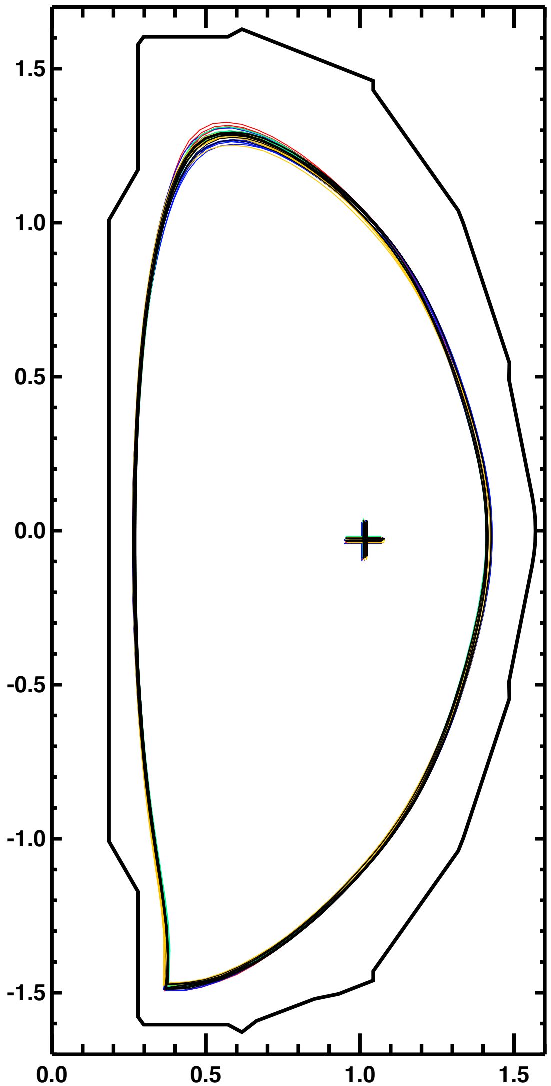


Maximum gradient across three edge CHERS channels for Carbon at outboard

What mechanisms improve ion thermal and momentum confinement in EP H-mode?

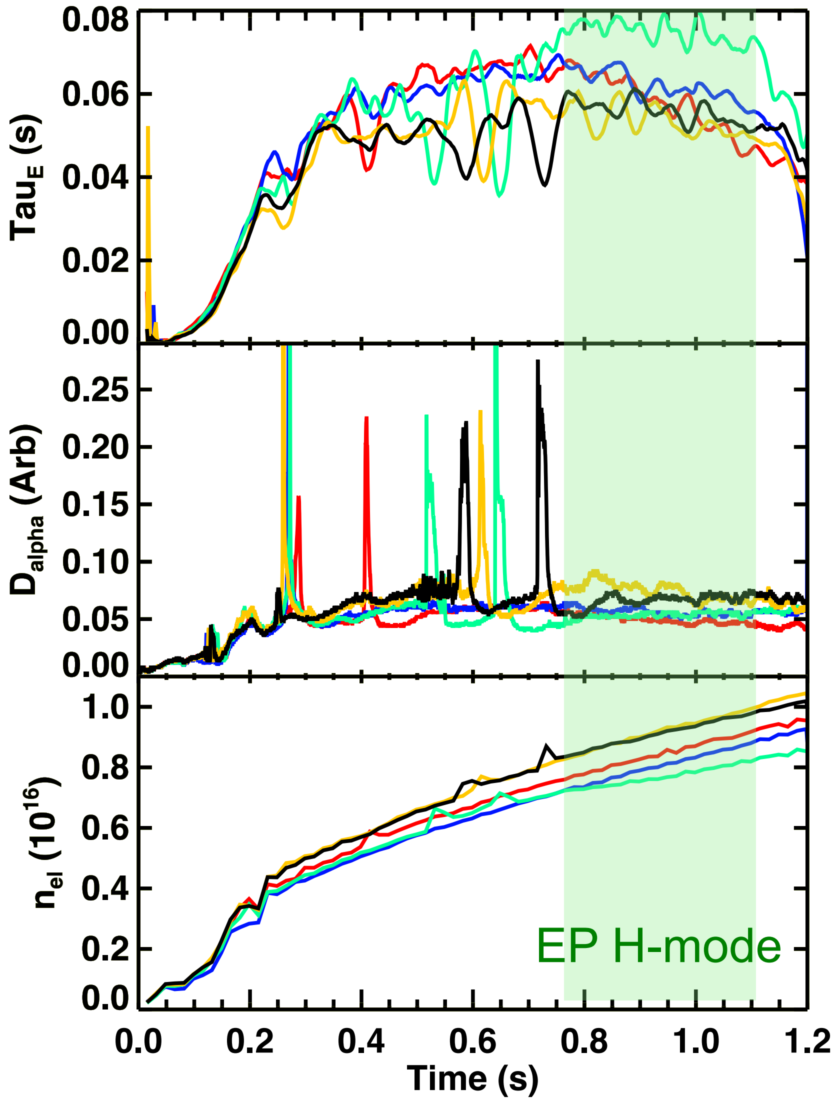
- H-mode ion thermal transport in outer half of NSTX is close to neoclassical
  - Is EP H-mode due to change in (kinetic) neoclassical transport?
- Is the bifurcation to EP H-mode driven by changes in the ion-scale anomalous transport?
- Why is the ELM important for triggering EP H-mode?
  - Localized rotation braking? 3D effects? Impurity flushing?
- Improved τ_E with increased particle transport very attractive for NSTX-U and future devices

Scanning applied 3D field produced discharges around EP H-mode threshold



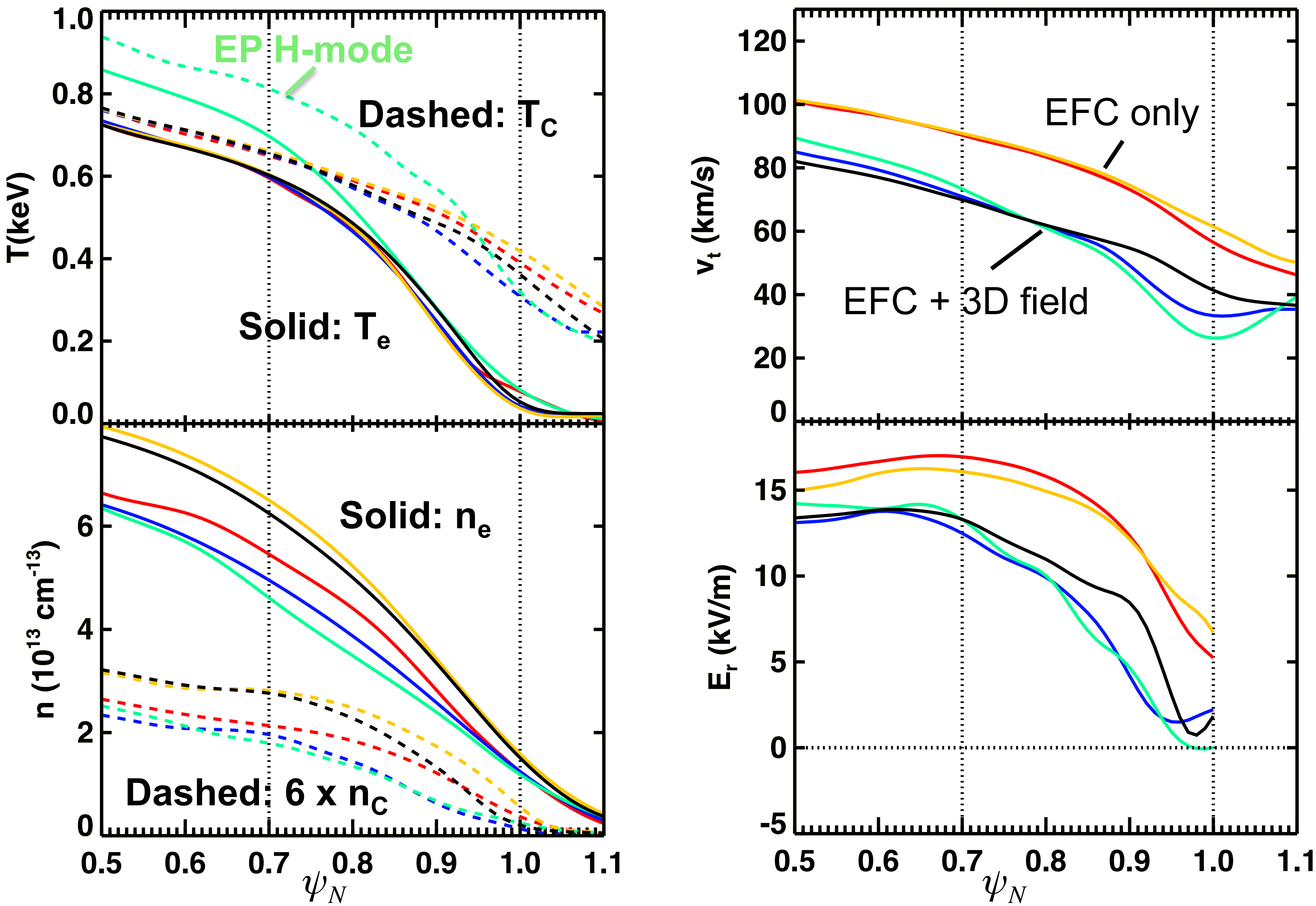
- Dataset of five shots
  - Matched high-triangularity shape
  - I_p = 900 kA, B_T = 0.45T, q_{95} ~ 9.5
  - Lithium wall conditioning
  - 100ms time windows for all profiles
- Experiment varied amplitude of n=1 field from RWM coils
  - Performed at different heating (and torque) from neutral beams

EP H-mode achieves larger τ_E compared to similar H-mode discharges



- All discharges have long quiescent period
  - No ELMs or MHD
- One EP H-mode shot
  - Larger τ_E
  - Triggered by 2nd ELM
  - Reduced density rise

Bifurcation to EP H-mode evident in temperature profiles

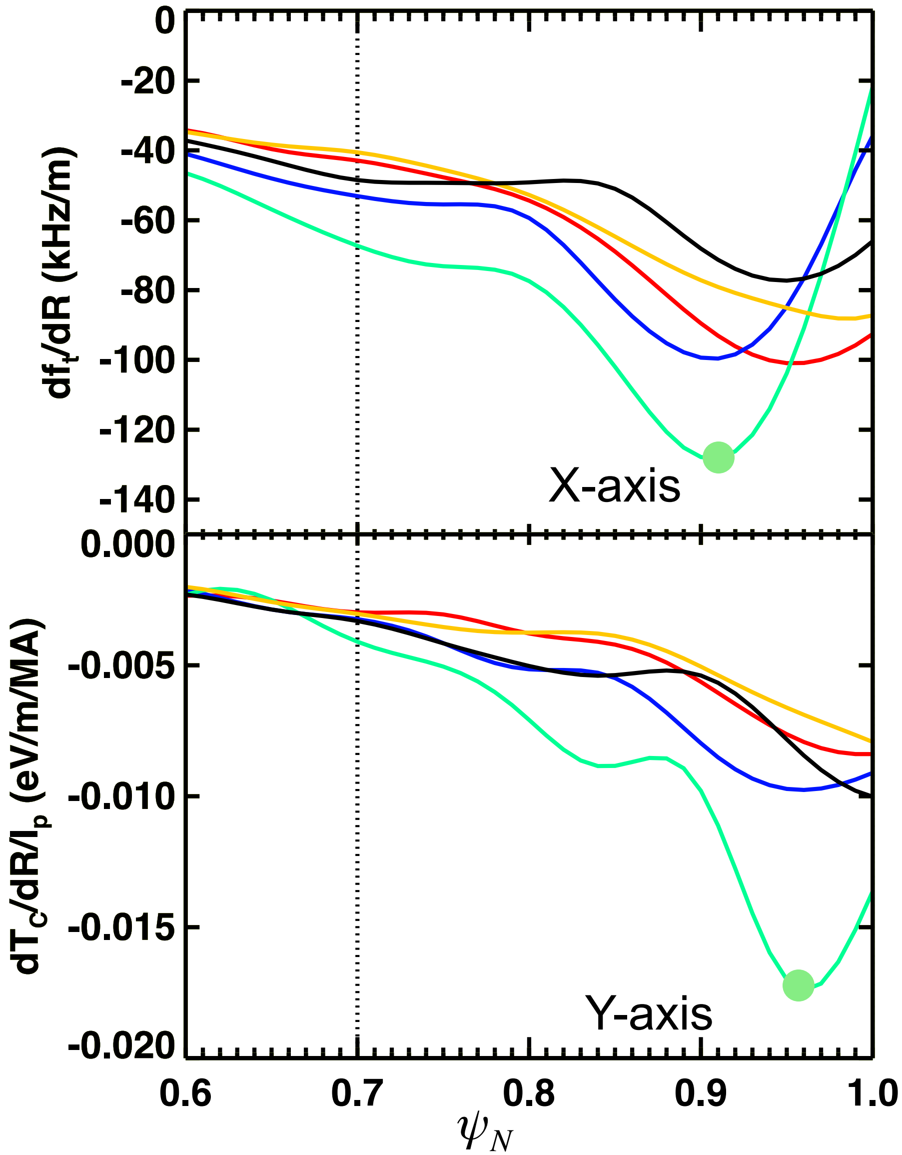


Edge T_i very different in EP H-mode despite smaller differences in other profiles

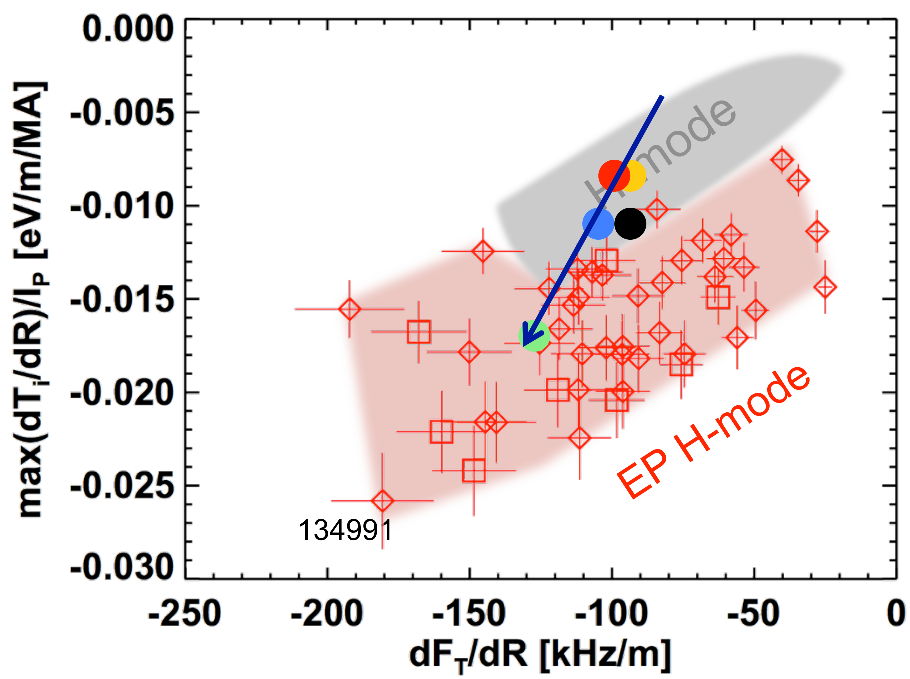
- Application of 3D field:
  - Reduces rotation: Edge v_ϕ shear increases
  - Reduces separatrix T_i: Edge T_i shear increases
  - Reduces n_e, n_C gradient and n_C pedestal shifts inward
  - Moves E_r minimum lower and inward

- EP H-mode edge has larger T_i gradient
  - T_e pedestal is wider and higher
  - Subtle changes in n_e, n_C, edge v_ϕ
  - E_r is similar to H-mode with 3D fields
  - "Flattening" of T_i, v_t, E_r from 0.85 to 0.9

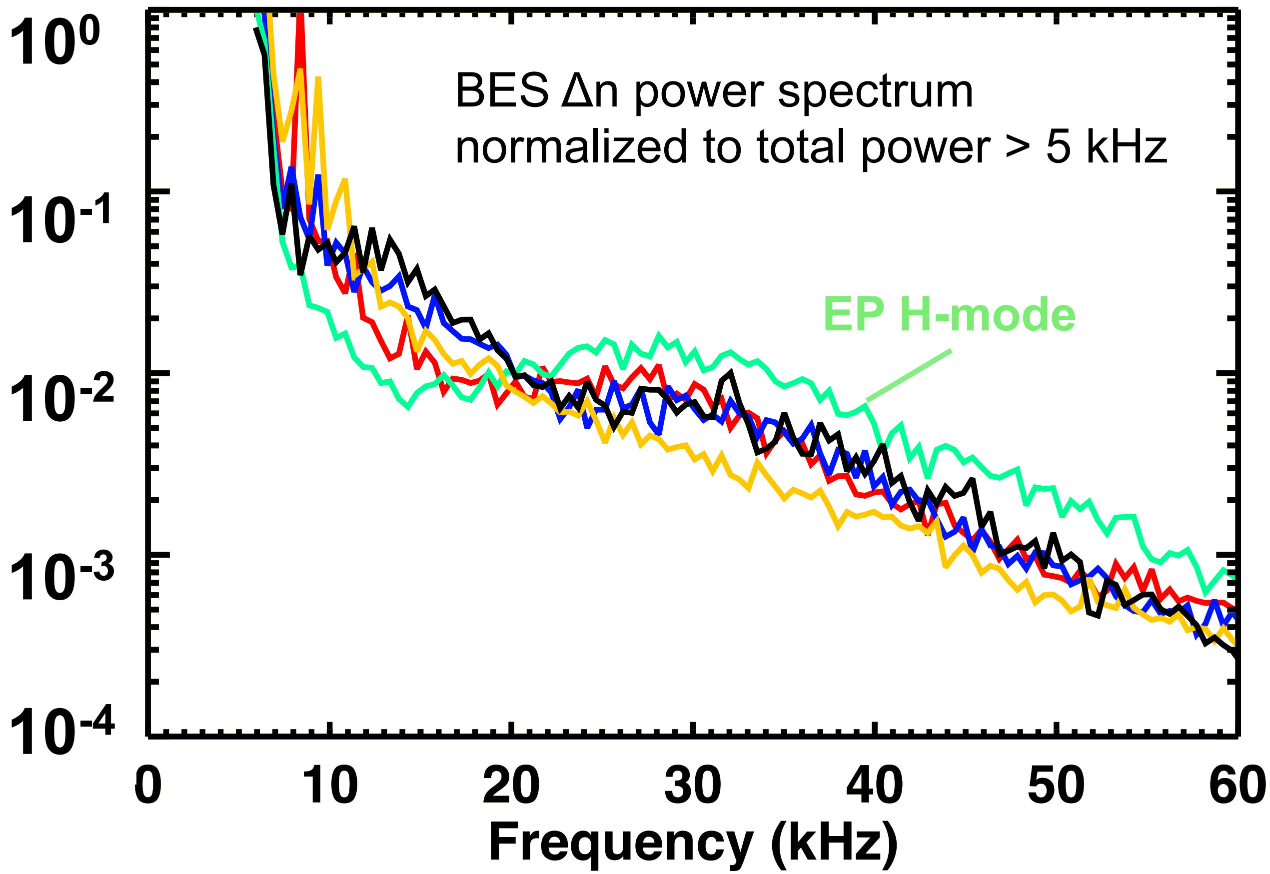
Gradients in T_i and rotation increase over entire pedestal region



- Maximum rotation frequency gradient inside location of max T_i gradient



Ion-scale Density Fluctuations Below 20kHz are Suppressed in EP H-mode



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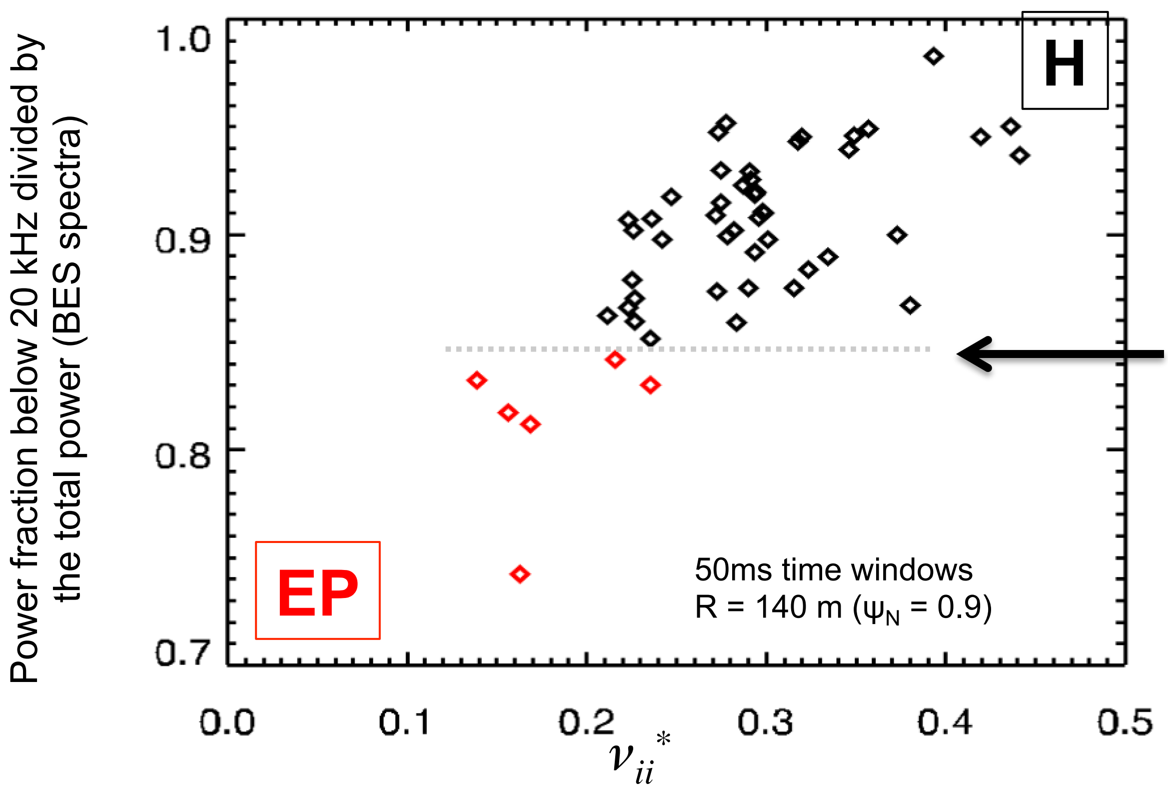
- Density fluctuations < 20 kHz decrease in EP times
  - Effect localized around BES chord at $\psi_N = 0.9$

Ion-scale Density Fluctuations Below 20kHz are Suppressed at Lower ν_{ii}

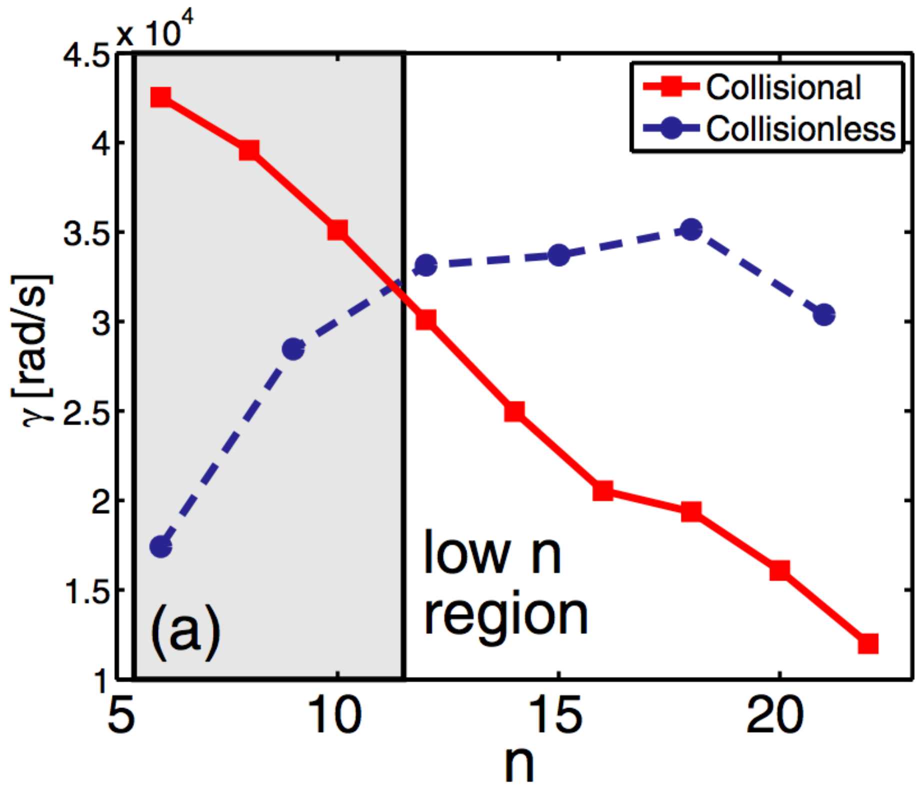
- EP H-mode observed at lowest ion collisionality (ν_{ii}^*)
  - Consistent with lower recycling with Li
  - Consistent with ELM flushing impurities in edge



Threshold in low-frequency fluctuation suppression organizes this limited dataset

Shift in Fluctuations to Higher Frequency Consistent with GEM Simulation

- GEM calculations: collisions stabilize high-n, destabilize low-n modes
  - Linear gyrokinetic simulations with NSTX pedestal profiles



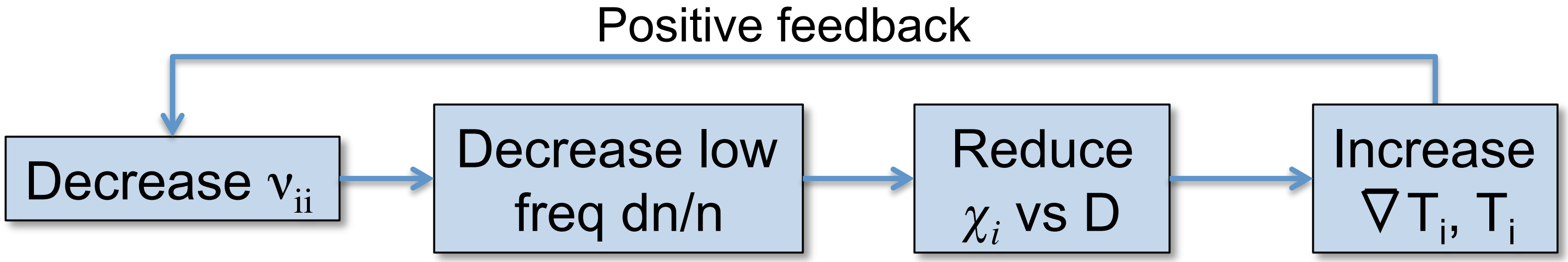
D.R. Smith et al, NF **53**, 113029 (2014)

Hypothesis: Bifurcation to EP H-mode driven by positive feedback loop

- Low ν_{ii}^* state achieved during ELM recovery
  - ELM flushes impurities
  - Rotation braking shifts n_Z pedestal inwards
  - Evidence for lower recycling early in recovery

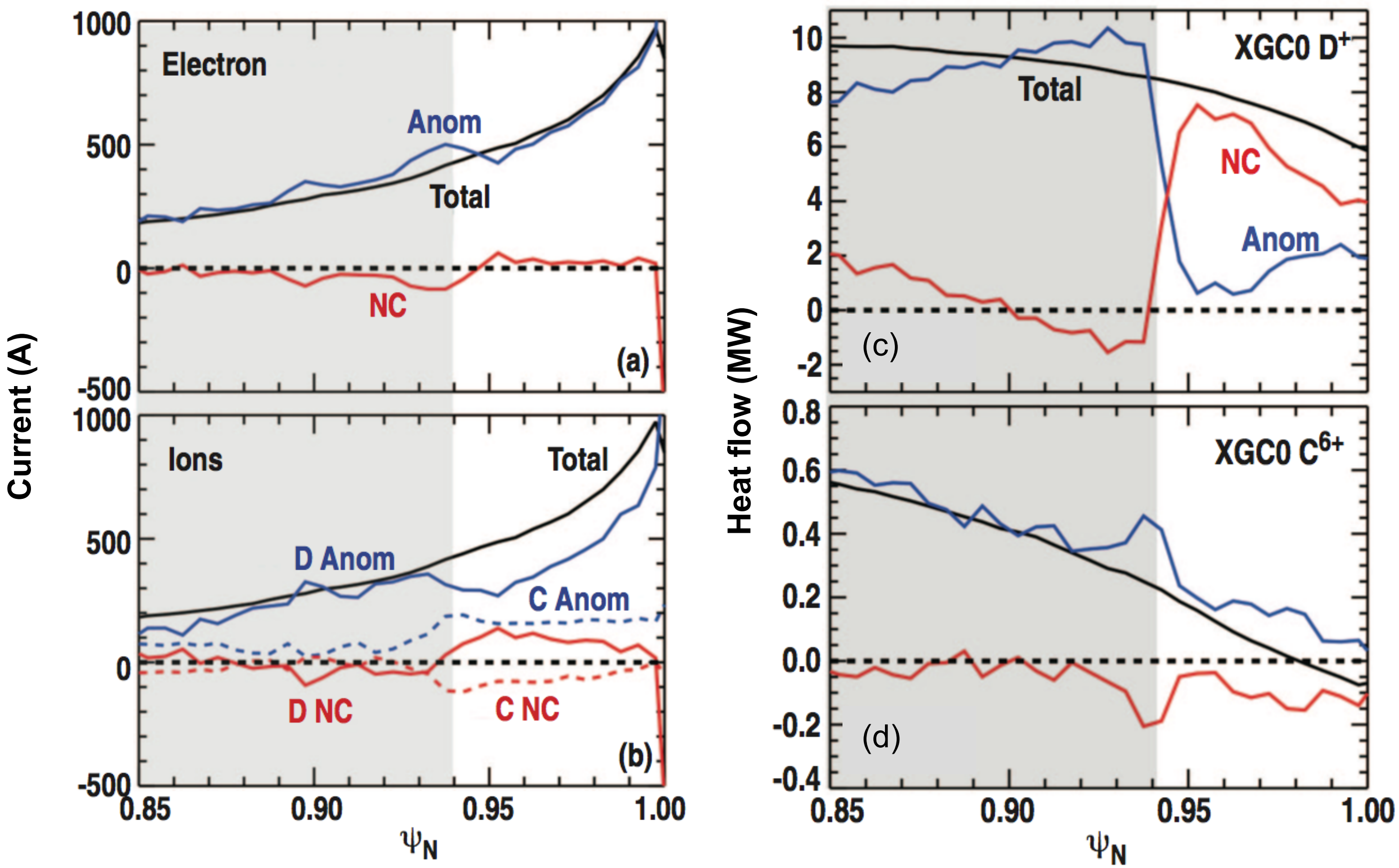
- Ion-scale turbulence shifts to higher-n, higher-frequency
  - Reduced radial transport of high-energy deuterium ions with wide gyro and banana orbits

- Improved ion and thermal momentum confinement drive ν_{ii}^* lower via larger T_i and v_t gradients



Consistent with total thermal transport set by tail deuterium ions at low ν_{ii}

XGC0 simulation of transport in a low collisionality QH-mode discharge on DIII-D



D.J. Battaglia et al, Submitted, PPCF

Particle transport (left column) dominated by anomalous transport, whereas energy transport (right column) dominated by kinetic neoclassical (NC) transport of deuterium ions via loss orbits of tail ions.

New capabilities on NSTX-U will advance understanding and utility of EP H-mode

- Edge rotation control with tangential NBI + 3D fields
  - Future: NCC coils provide additional edge rotation control
- ELM control with lithium pellet injector, 3D fields
- Expanded edge Thomson and BES capabilities
- Lower collisionality via higher fields
  - Also change in characteristic ion gyro and banana orbit size
- Edge instability characteristics at higher fields and aspect ratio

Summary

- EP H-mode is an attractive scenario for NSTX-U and future devices
  - Increase in energy and momentum confinement (H_{98y2} up to 2) with beneficial increase in particle transport
- Discharges near EP bifurcation indicate ion transport change during lowest ion collisionality following ELM
  - Bifurcation in T_i, little change in E_r, n_e compared to H-mode
  - BES shows shift in density fluctuations to higher frequency consistent with GEM prediction of larger-n instabilities at low v_{ii}^*
- Connection between ν_{ii}, frequency shift of dn/n and ion transport will be tested on NSTX-U
  - Develop control tools to access and sustain EP H-mode