NSTX

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Overview of L-H power threshold studies in NSTX

D.J. Battaglia[1*], S.M. Kaye[2], R. Maingi[1]
and the NSTX team

[1] Oak Ridge National Laboratory, Oak Ridge, TN
[2] Princeton Plasma Physics Laboratory, Princeton, NJ
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Oct. 22-Oct. 24, 2009

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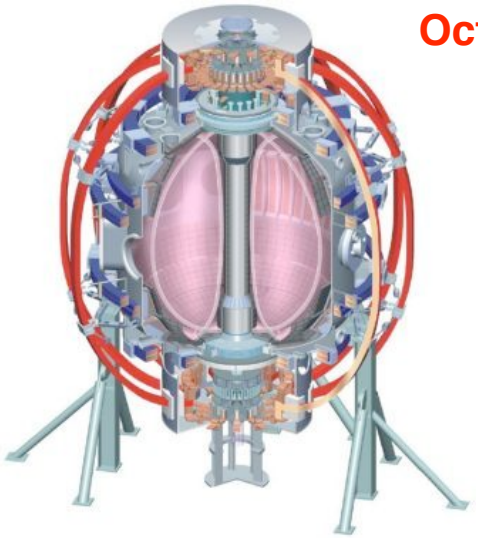

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NSTX actively contributes to the international P_{LH} research effort

- ITER modeling need: projection for P_{LH} and P_{HL}
  - Transition requirements
    - ITPA scaling database
    - First-principles model
  - Species dependence (D, H, He)
  - Effect of 3D fields prior to transitions

- NSTX has a wide range capabilities for L-H studies
  - Li pumping → effect of neutrals and collisionality
  - 3-D fields → rotation and edge magnetic field structure
  - Low-A → $B_\theta \sim B_\phi$ at outboard, high edge β, low B_T
  - Flexible shaping capability
  - State-of-the-art diagnostics with excellent access

Characteristics of the L-H threshold on NSTX

P_{LH} is observed to …

- Increase with n_e ($n_e > 1.5 \times 10^{19}$ m^{-3}) *
- Increase with $|\delta r_{sep}|$
- Not vary strongly with R_x *
- Not vary strongly with plasma rotation
- Increase with an applied n=3 external field *
- Increase with I_p *
- Not vary between deuterium and helium *
- Decrease with lithium evaporation

** Indicates dedicated experiments in 2009*

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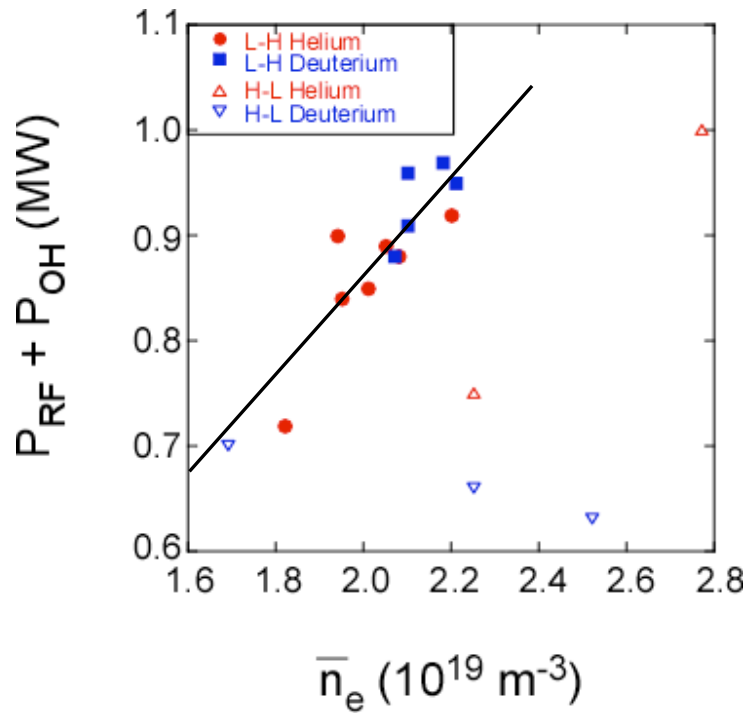
P_{LH} scales linearly with n_e at high density

- ITPA Scaling relation*

$$P_{LH} = 0.049\, n_{20}^{0.72}\, B_T^{0.8}\, S^{0.94}$$

- $P_{LH} \propto n_e$ above a critical density
  - Observed on a number of devices
  - P_{LH} linear with n_e on NSTX for $n_e > 1.5 \times 10^{19}\ m^{-3}$
  - Lock modes at lower density
- Normalize P_{LH} by n_e
  - n_e not actively controlled on NSTX



* Y.R. Martin, et. al., J. Phys.: Conf. Ser. (2008) **123** 012033

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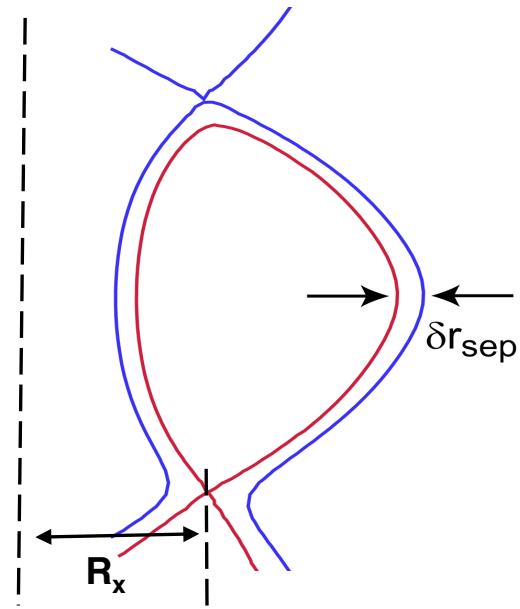
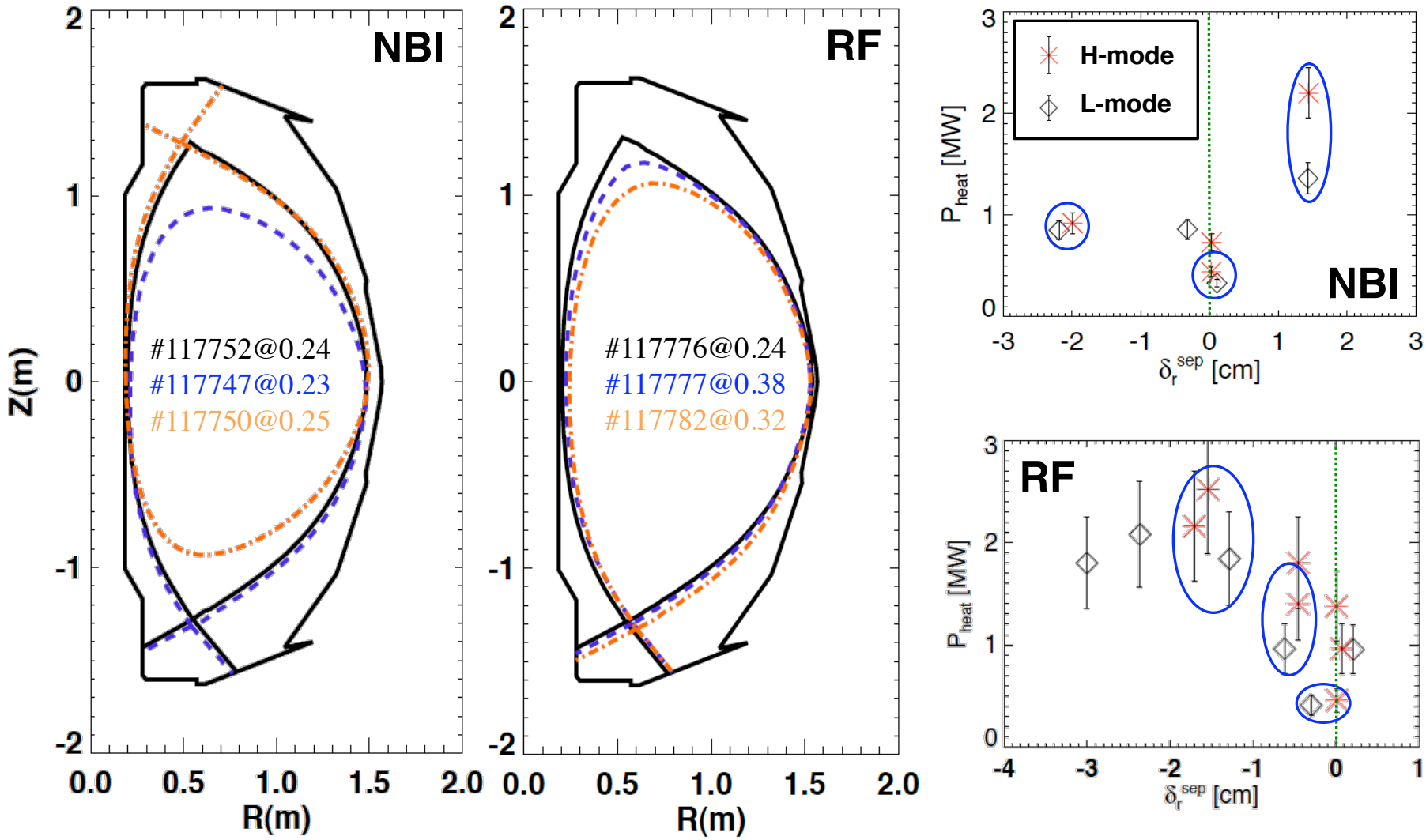


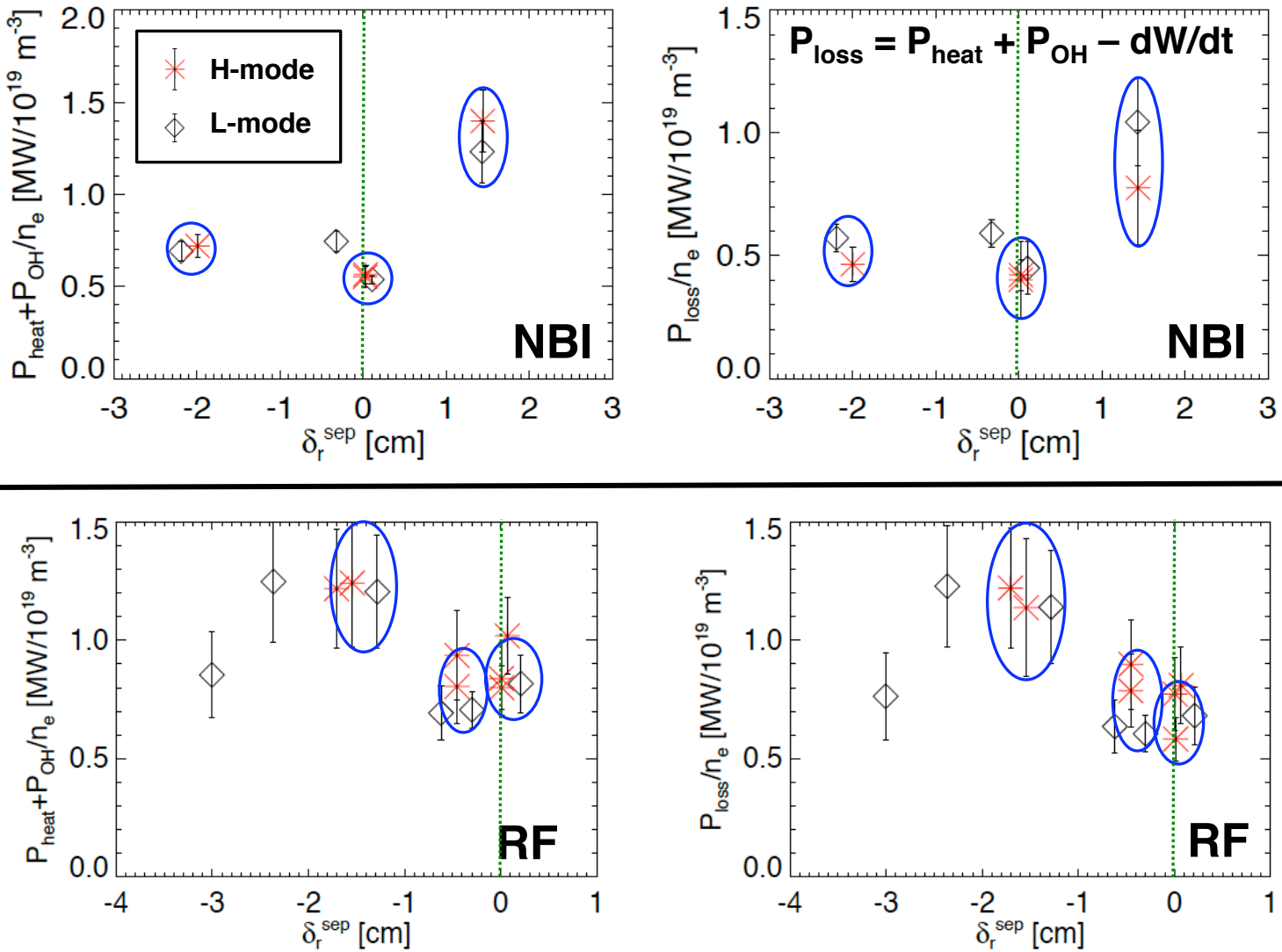
** Indicates dedicated experiments in 2009*

L-H transition at lowest P_{heat} observed in DN



R. Maingi et. al., Nucl. Fusion, *submitted*

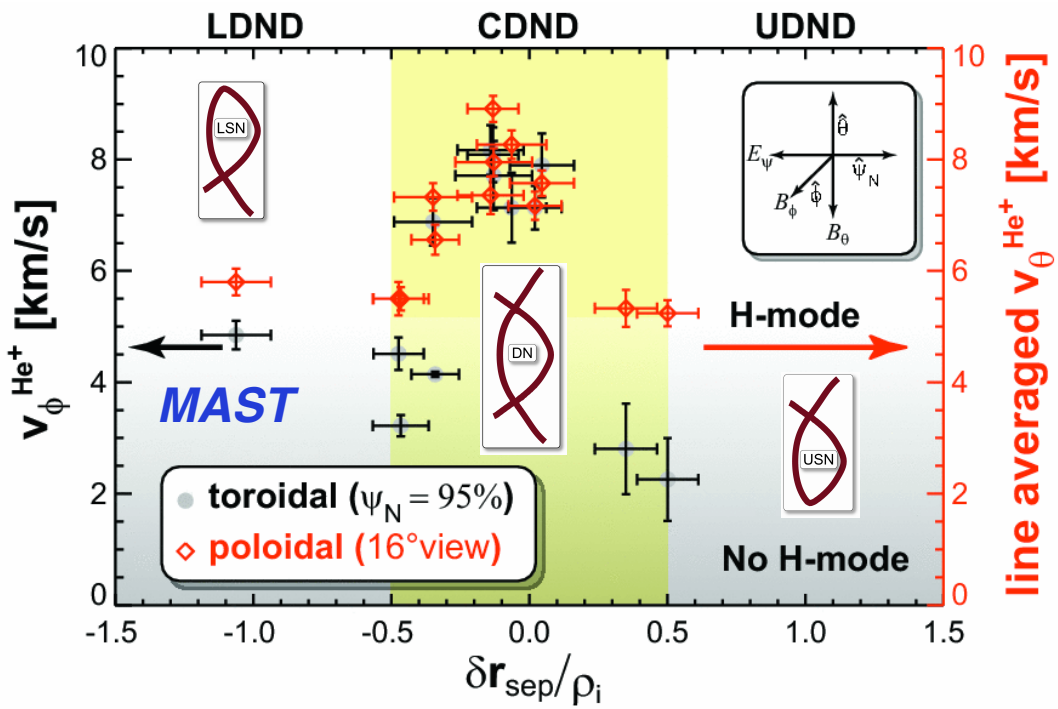
P_{LH}/n_e reduces the scatter in the relationship



R. Maingi et. al., Nucl. Fusion, *submitted*

DN configuration maximizes E_r

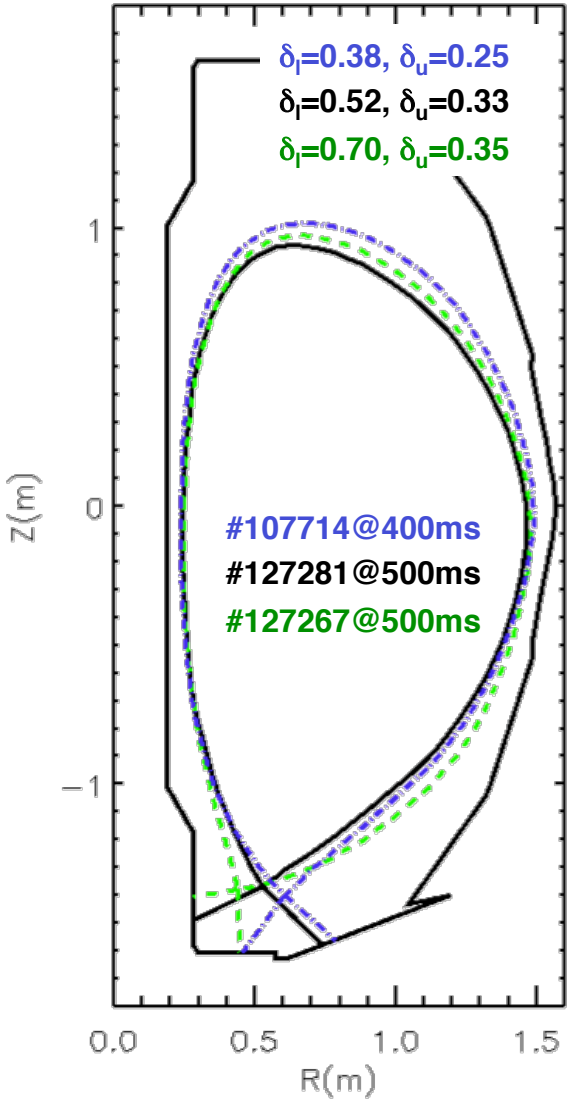
- E x B shear is thought to be important
  - Turbulence suppression
  - Typically increases prior to the formation of a pedestal
- Larger E_r in DN may describe lower P_{LH}
  - MAST: E_r is enhanced in DN configuration
  - Infers greater E x B shear



$$E_r = v_\theta B_\phi + v_\phi B_\theta - \nabla_r (n_i T_i)/e n_i$$

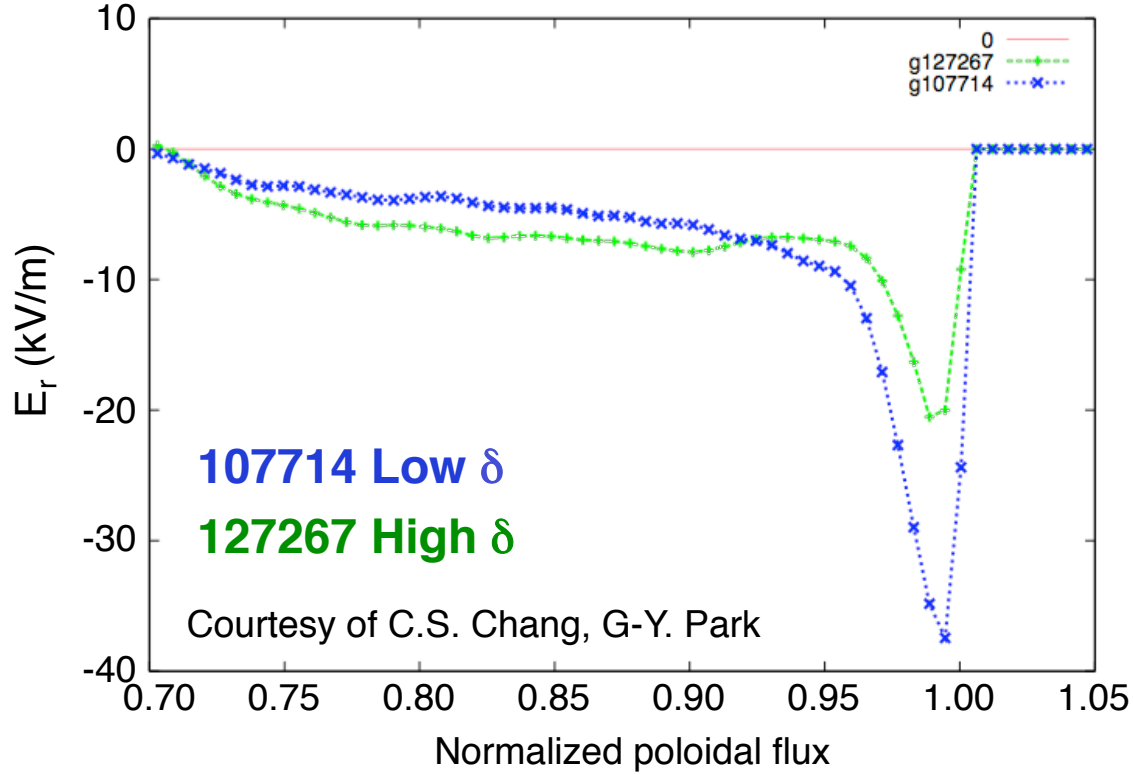
H. Meyer et. al., PPCF **47** (2005) 843-867

XGC calculations suggest enhanced E_r & E_r' with increasing R_x



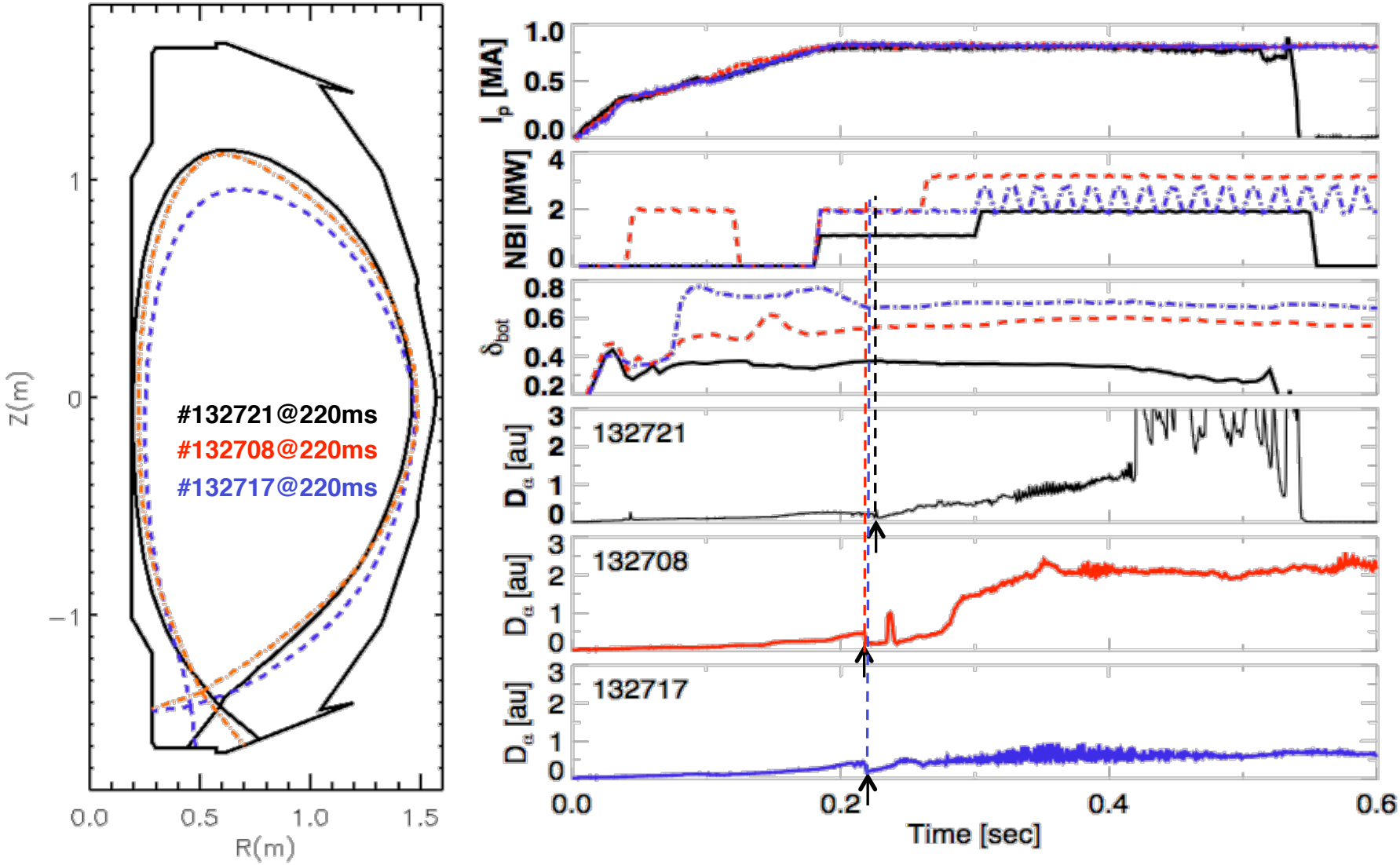
Enhanced E_r driven by ion loss near X-point

E_r profiles (anomalous D = 0.1 m^2/s in core, 0.2 m^2/s in SOL)



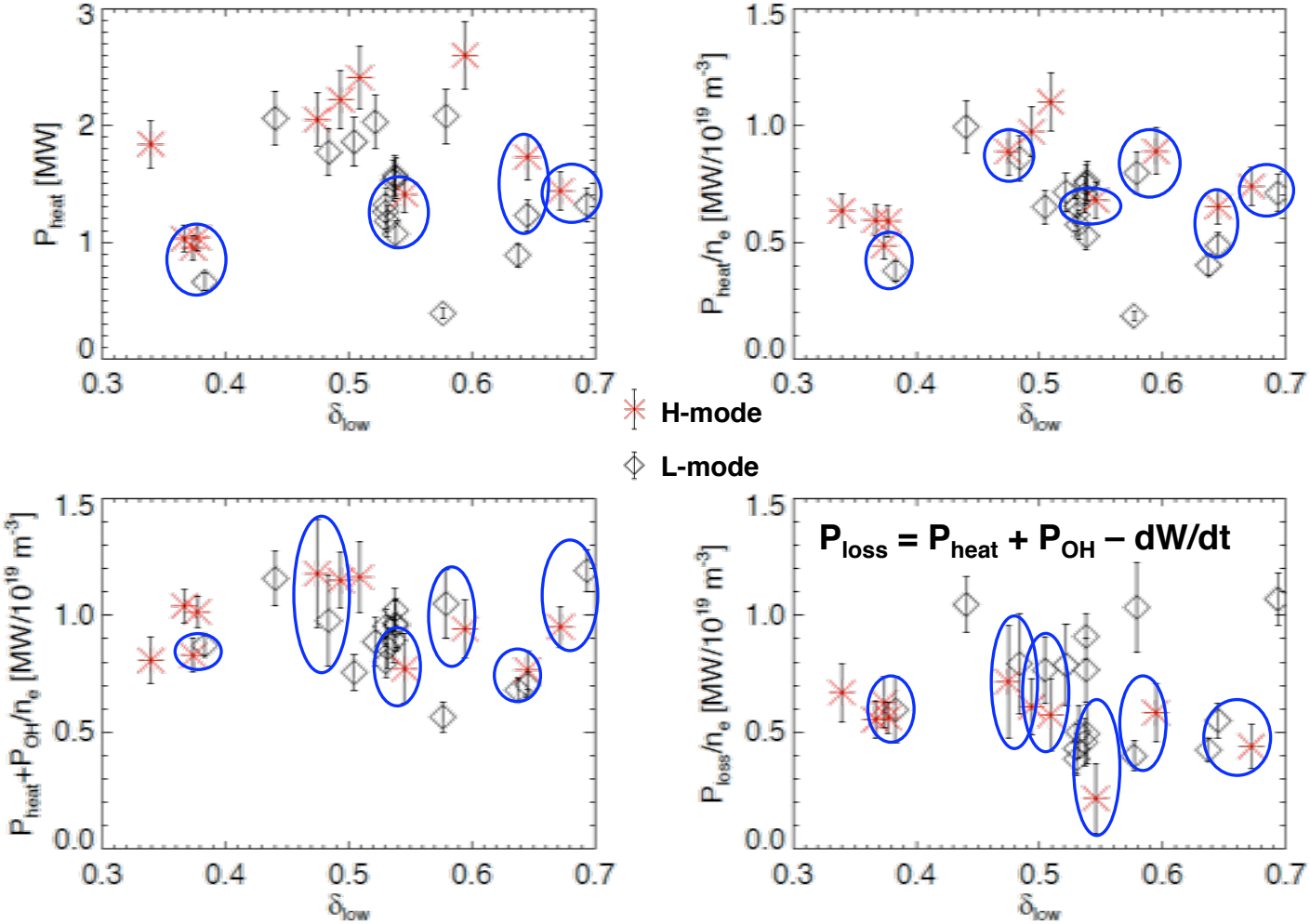
R. Maingi et. al., Nucl. Fusion, *submitted*

P_{NBI} lowest at largest R_x (lowest δ)



R. Maingi et. al., Nucl. Fusion, *submitted*

P_{in} & P_{loss} do not vary strongly with δ_{low} (i.e., R_x)



What is the correct normalization?

R. Maingi et. al., Nucl. Fusion, *submitted*

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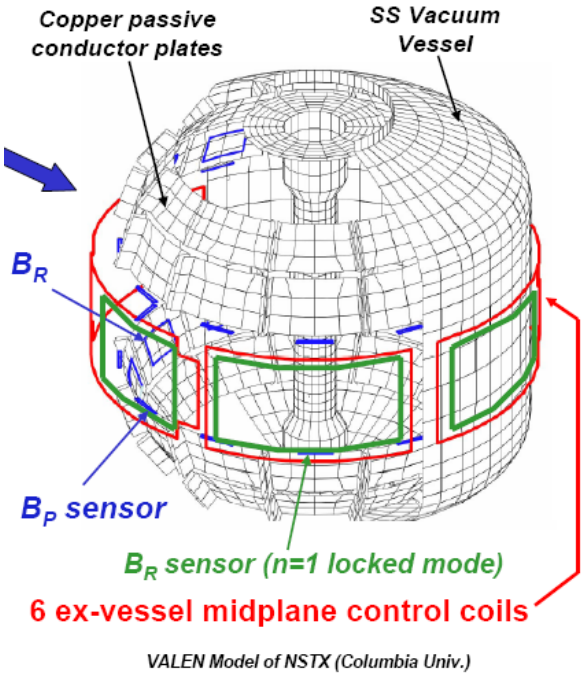
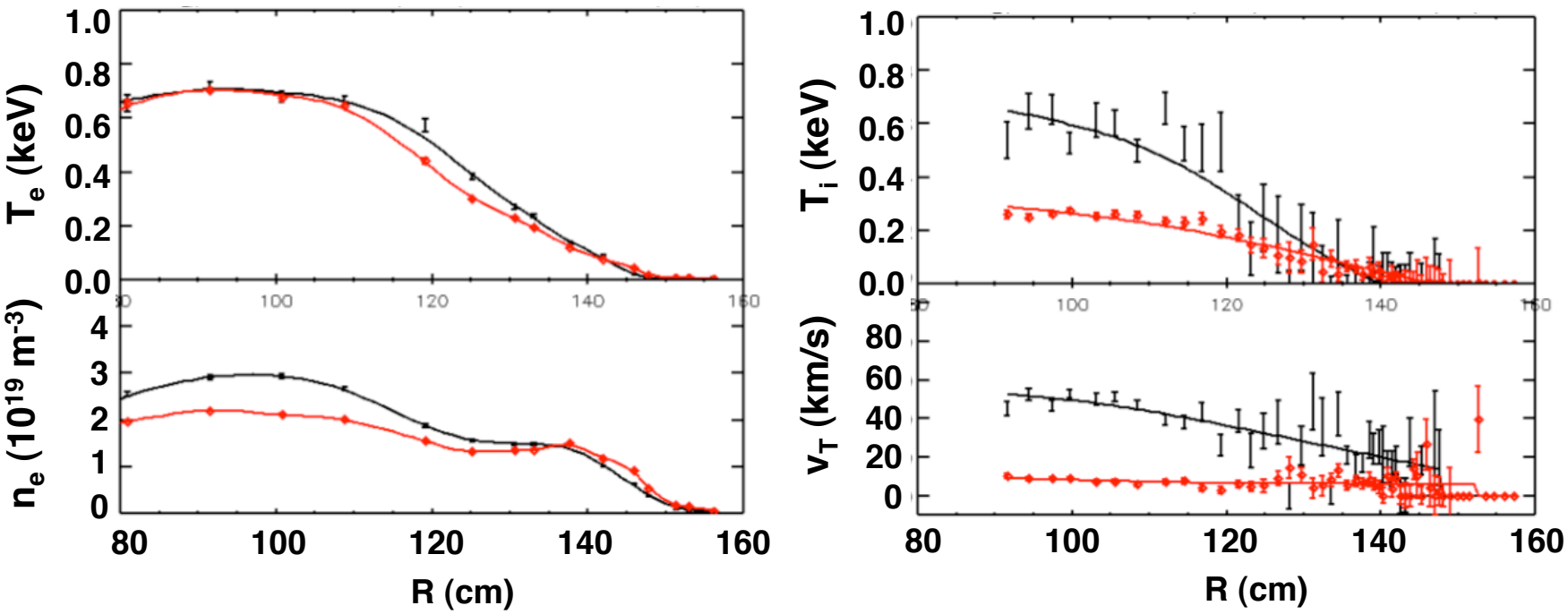


** Indicates dedicated experiments in 2009*

P_{LH} insensitive to plasma rotation

Radial profiles for NBI and RF heated DN discharges prior to LH transition

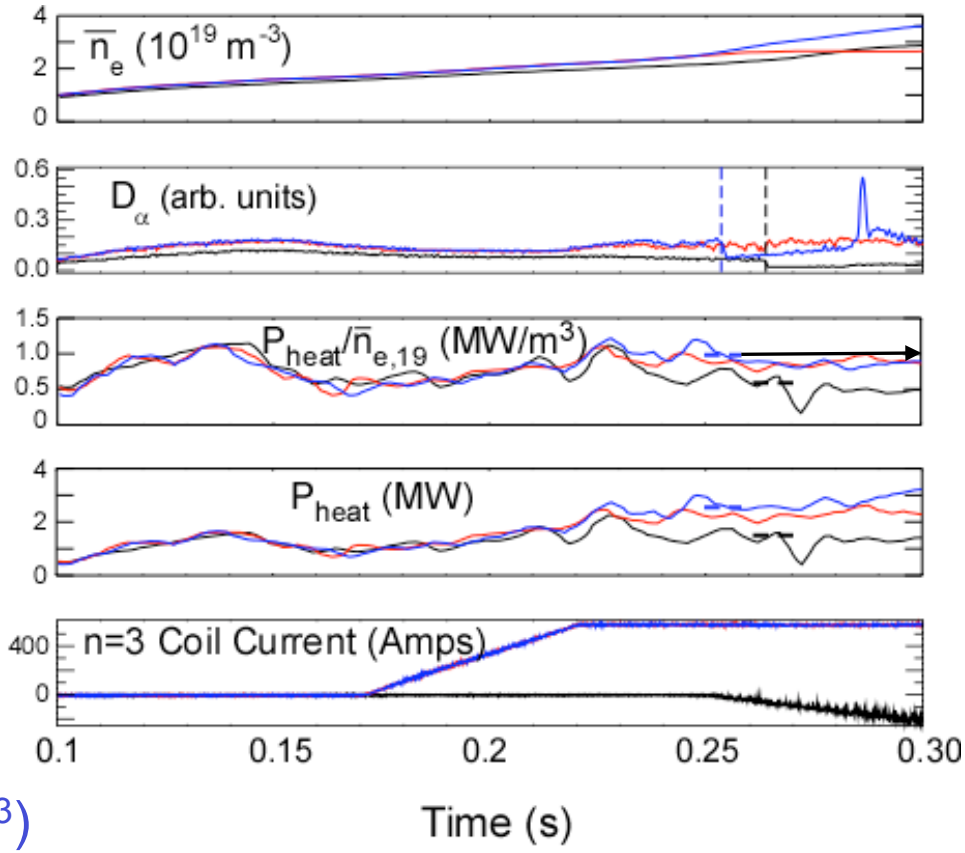


Both discharges transition when $P_{LH}/n_e \sim 0.5$ MW/10^{19} m^{-3} despite differences in core rotation and T_i/T_e

T.M. Biewer, et. al., EPS, Rome June, 2006

Application of n=3 fields results in larger P_{LH}

- Motivated by recent JET and MAST results
- Apply n=3 field in addition to error field correction
  - Applied prior to L-H transition
  - Only small change in toroidal rotation observed
- Found P_{LH}/n_e higher with larger applied n=3 field
  - P_{heat}: 1.5 → 2.6 MW
  - P_{heat}/n_e: 0.6 → 1.1 MW/(10^{19} m^{-3})



L-H Threshold Power Increases with I_p

- Observed over several years of operations
- P_{heat}/n_e almost a factor of 2 higher for 1 MA than for 0.7 MA
- Implies B_θ plays a role in the transition threshold

$$P_{LH} = 0.072\, n_{20}^{0.7}\, B_{out}^{0.7}\, S^{0.9}$$

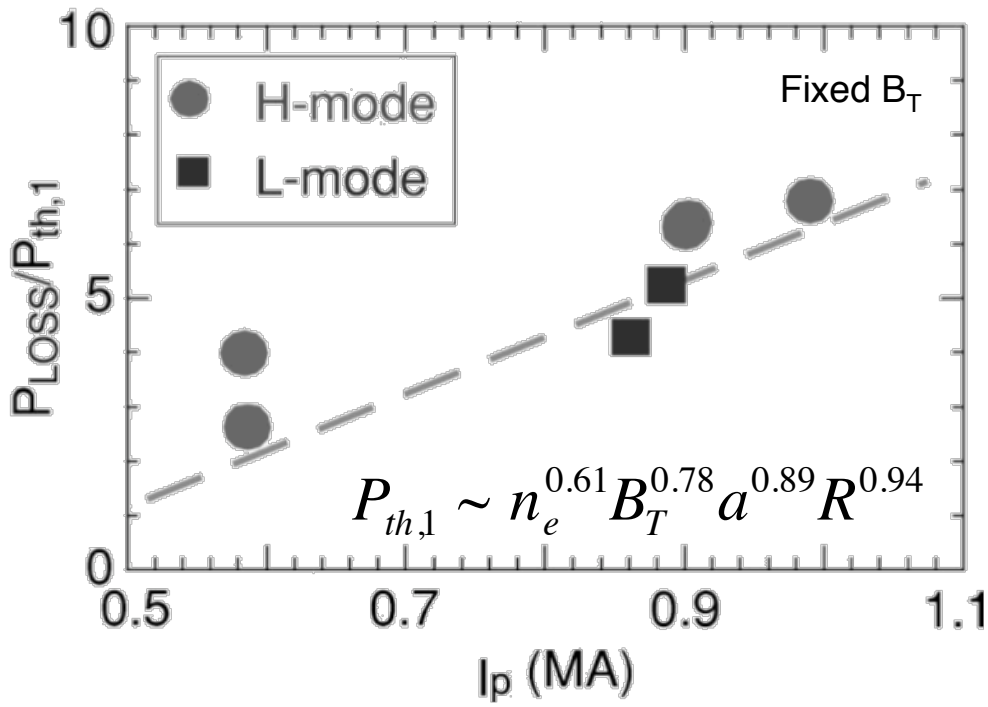
T. Takizuka et. al., PPCF **46** (2004) A227

- Supported by recent MAST results

2009 NSTX

I_p = 0.7 MA: P_{LH} ~ 1.6 MW, $P_{heat}/n_{e,19}$ ~ 0.7 MW/m^{-3}

I_p = 1.0 MA: P_{LH} ~ 3.1 MW, $P_{heat}/n_{e,19}$ ~ 1.2 MW/m^{-3}



C.E. Bush, et. al., Phys. Plasmas **10** (2003) 1755

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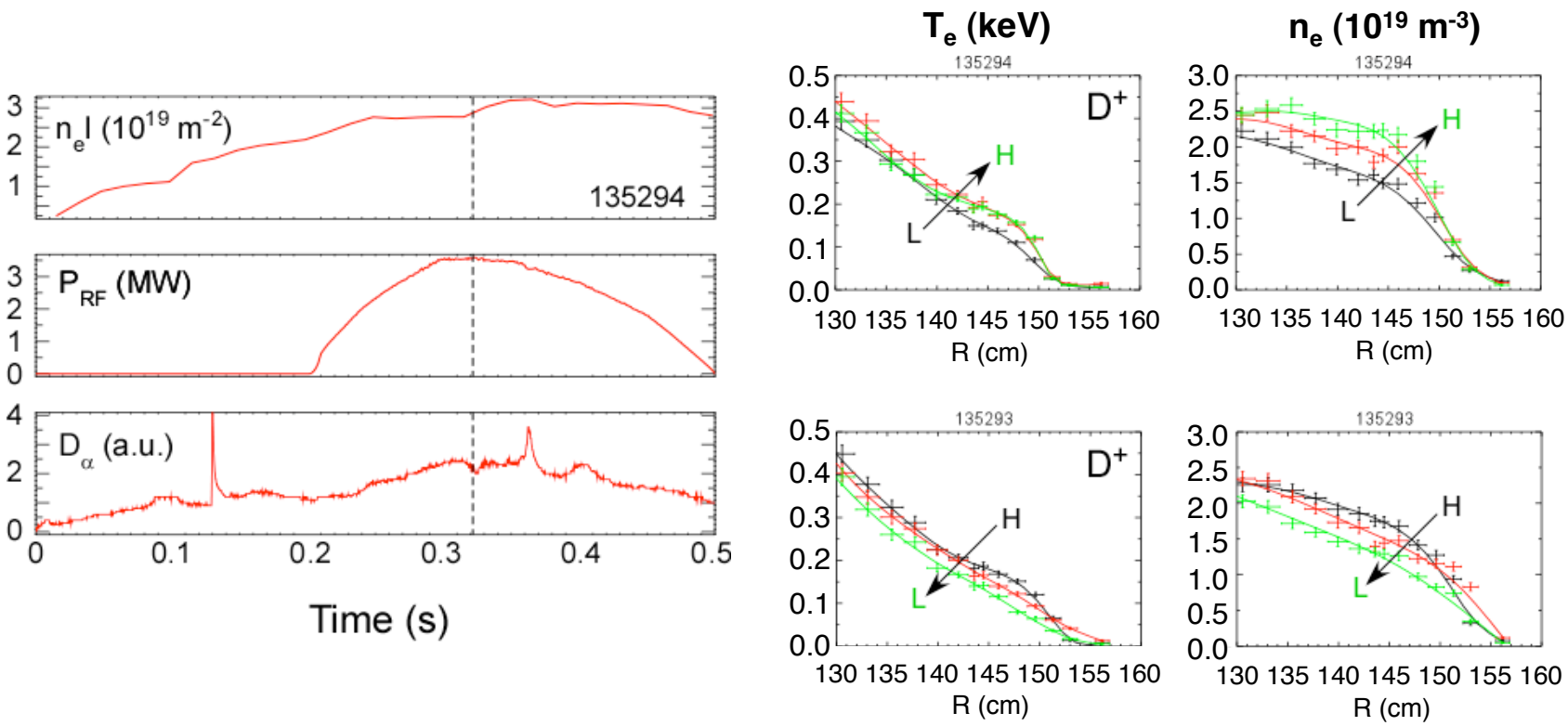
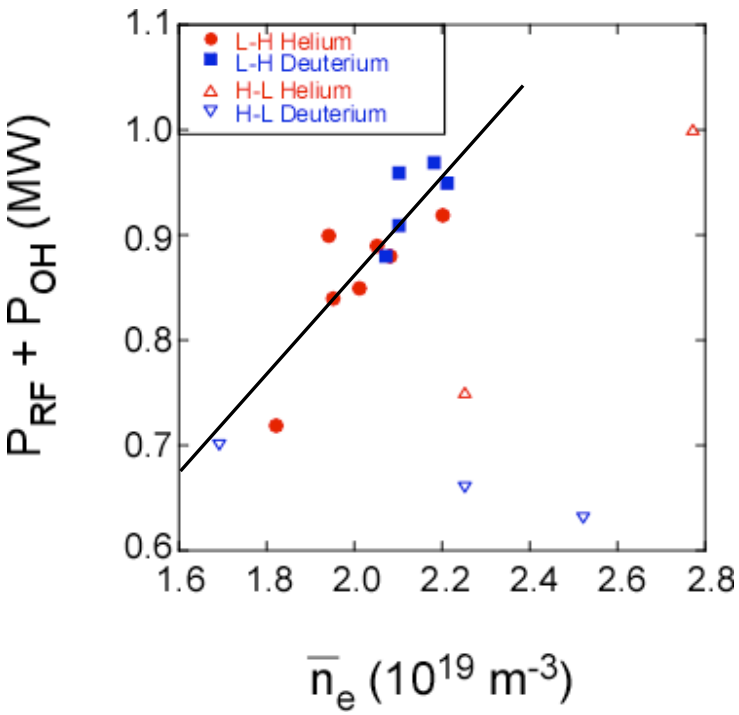
Slow scans of HHFW power used to measure the L-H/H-L thresholds in pure He and D plasmas

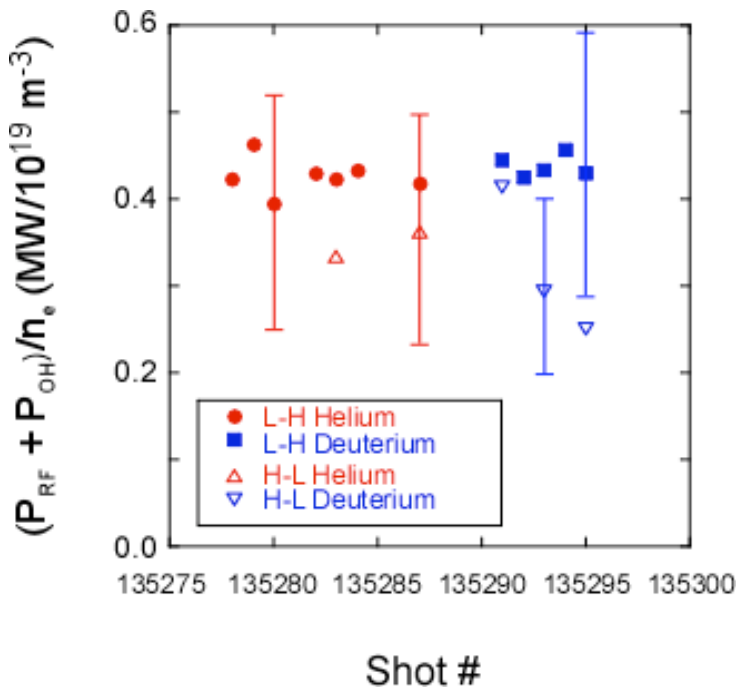
- Use change in edge profiles to determine transitions
  - Transitions not always obvious in D_α signal with slow power scan
  - No D_α signal in pure He plasmas



L-H power thresholds for He and D are similar

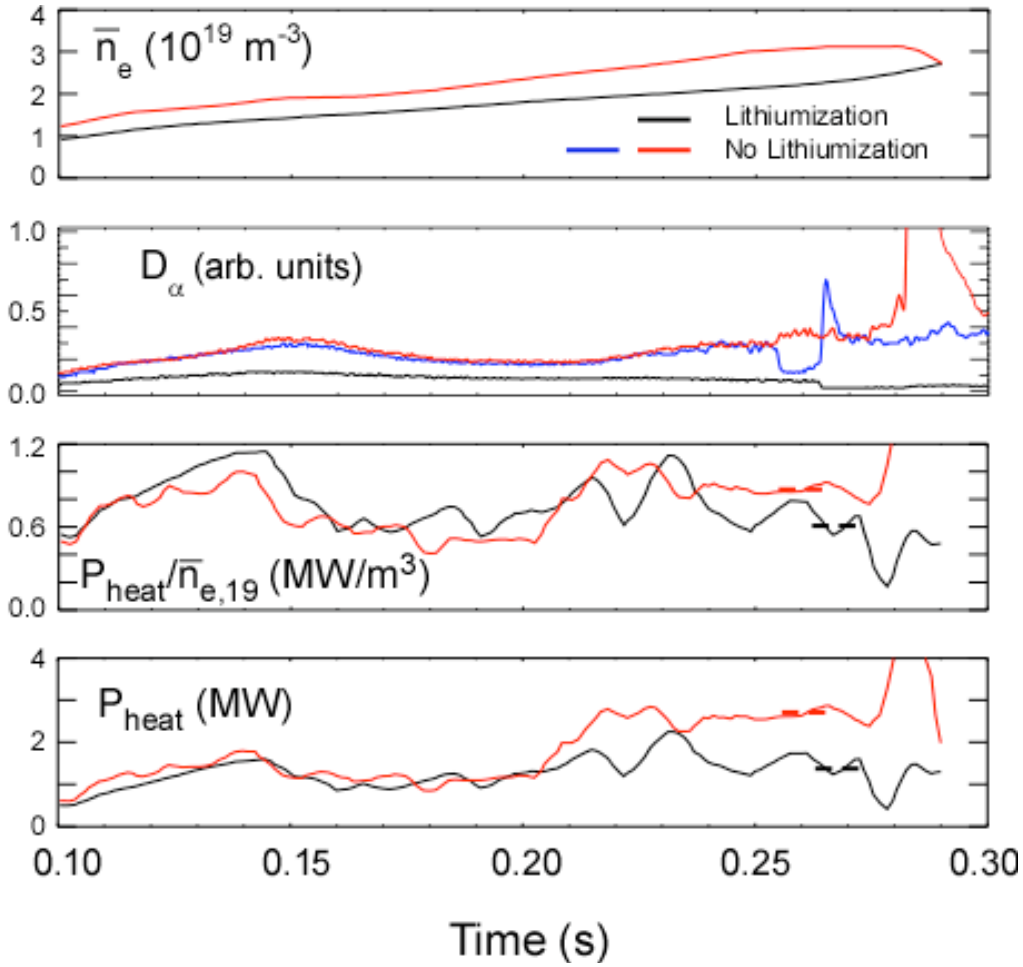
- $(P_{RF} + P_{OH})/n_e$ similar for P_{LH} thresholds with D and He
  - P_{HL} not effectively normalized by n_e
- H-L thresholds indicate some hysteresis
- Large error bars due to uncertainty in RF heating efficiency





Lithium evaporation led to a significant reduction in L-H power threshold

P_{LH} ~ 2.7 MW NBI without Li evaporation (P_{heat}/n_e~0.9 MW/10^{19} m^3)
~ 1.4 MW NBI with Li evaporation (0.6 MW/10^{19} m^3)



Summary: P_{LH} dependences observed on NSTX

- Dependence on density
  - P_{LH} has linear dependence above 1.5 x 10^{19} m^{-3}
- Lowest P_{LH}/n_e near DN
  - P_{LH}/n_e ~ 0.5 MW/10^{19} m^{-3} for both RF and NBI heated plasmas
- No discernable scaling of P_{LH}/n_e with R_X observed
  - May require discharges with similar P_{OH} and reduced dW/dt to cull out dependence
- Strong dependence on I_p
  - Recently observed on MAST
  - May imply outboard B strength is important (B_θ ~ B_φ in an ST)

Summary: P_{LH} dependences observed on NSTX

- P_{LH} independent of plasma rotation
  - Elucidated using similar discharges with pure RF or NBI heating
- Applying an n=3 field increases P_{LH}
  - Past results imply rotation braking is not the root cause
  - Suggests edge magnetic field perturbation alters L-H dynamics
- No variation in P_{LH} with He compared to D
  - Considered $(P_{RF} + P_{OH})/n_e$
  - Reported $P_{LH,He}$: 1 - 1.8 times $P_{LH,D}$ in database
- Lithium wall conditioning lowers P_{LH}