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NSTX

Global Energy Confinement Scaling in NSTX and ITER Contributions

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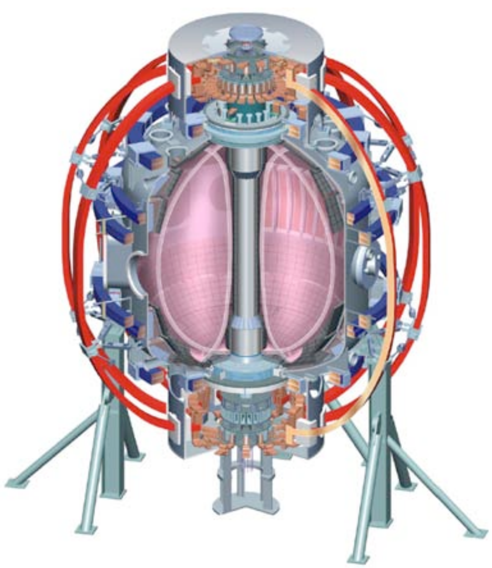

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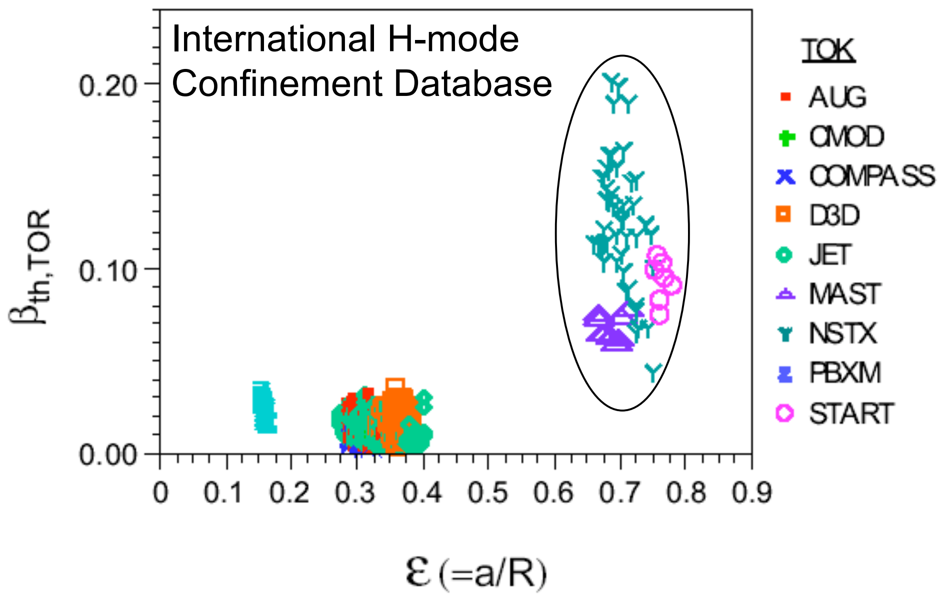
NSTX Addresses Global Confinement Issues Critical to ST Physics and Design of Future Devices

- NSTX operates in a unique dimensionless parameter space
  - R/a, β_T, & (ρ_*, ν_*) at high power (>3 MW)
  - Develop understanding of confinement trends specific to ST regime
    - Identify differences from conventional aspect ratio
- NSTX data crucial for establishing physics insight necessary for future devices (ITER, CTF and beyond)
  - Complements work done at conventional aspect ratio
  - Allows further development of confinement scalings
    - Notably in β, R/a (ITPA priority)
    - Greater confidence in parametric dependences
    - Better extrapolations

NSTX extends parameter space

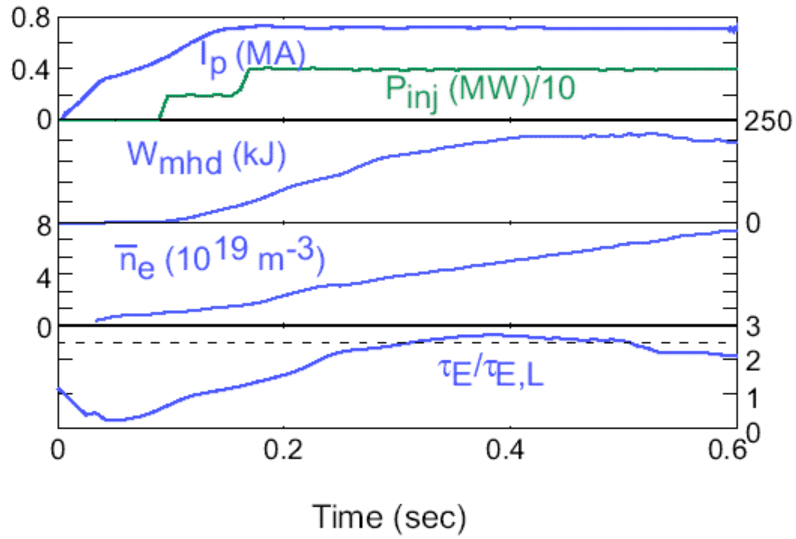
- Allows for exploration of confinement trends at high-β, low-ν_*
- Connect to conventional aspect ratio database for assessment of R/a



ε–β colinearity in ITPA dataset

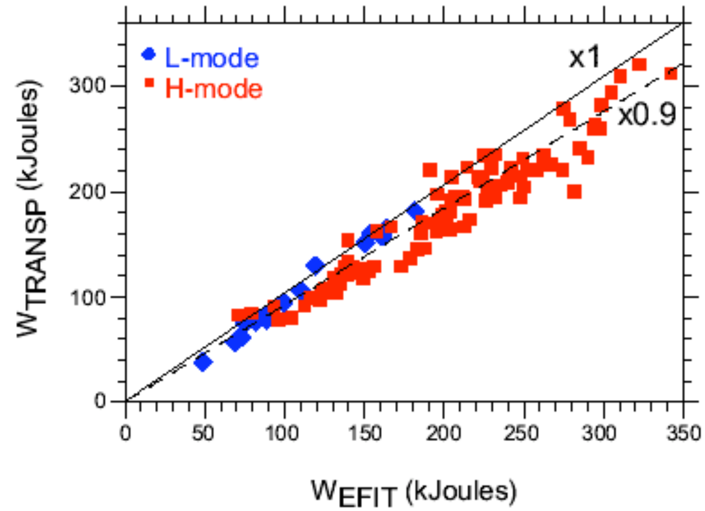
NSTX Accesses Good Confinement Regimes

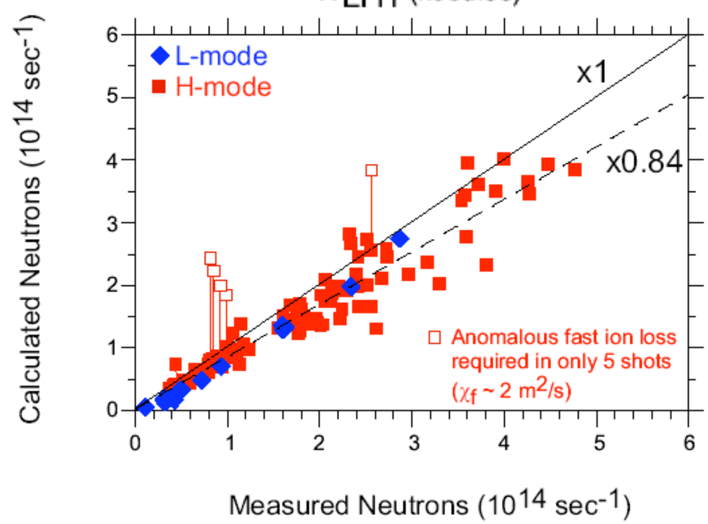
> 2.5 L-mode for ~ 4 τ_E



	W_{MHD}	τ_E^{global}	H_{97L}	$H_{98(y,2)}$
L-mode (transient)	up to 280 kJ	up to 110 ms	up to 2.5	up to 1.1
H-mode	up to 390 kJ	up to 85 ms	up to 2.7	up to 1.4

Good agreement between kinetics and magnetics





Results of Systematic Parameter Scans Indicate Some Scalings Similar to Those at Conventional R/a

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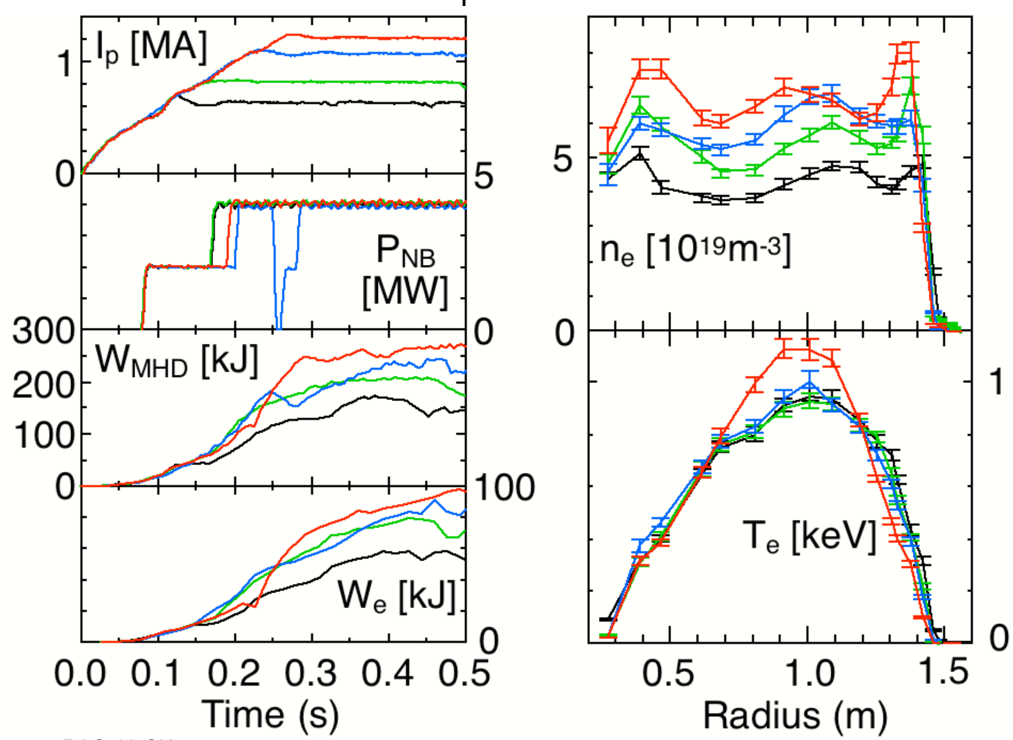
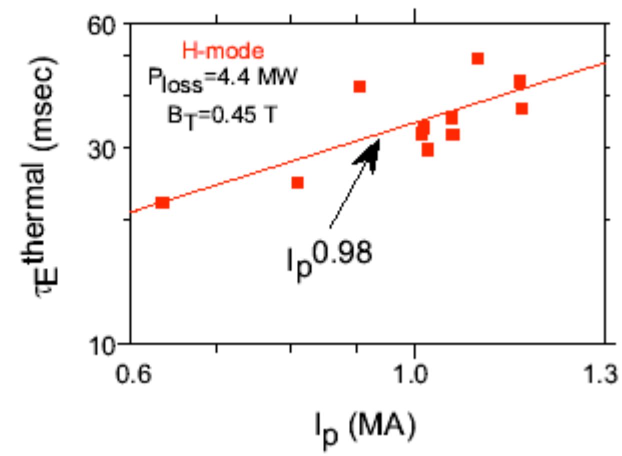
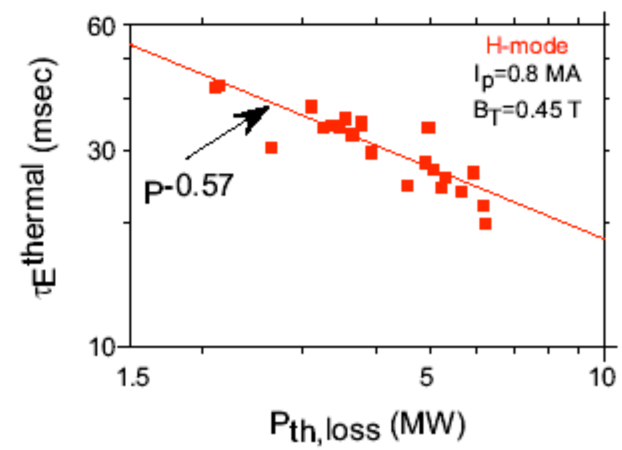
- H-Mode data from 2004 experiments (ELM-free and ELMy)
  I_p = 0.6 - 1.2MA, B_T = 0.3 - 0.45 T, n_e = 1.5 - 7e19 m^{-3}, P_{NBI} = 1.5 - 7 MW, κ = 1.6 - 2.4
- Linear current scaling
  - Need to control density to determine current scaling unambiguously
- Slightly weaker power degradation than ITER-PB(y,2)

B_T=0.45 T



$\tau_{E,thermal}$ calculated in TRANSP





Data Exhibits a B_T Dependence and Shot – Shot Variability

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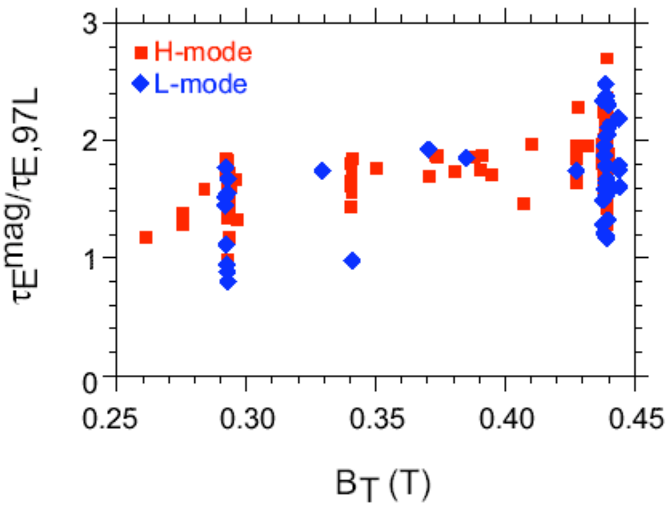
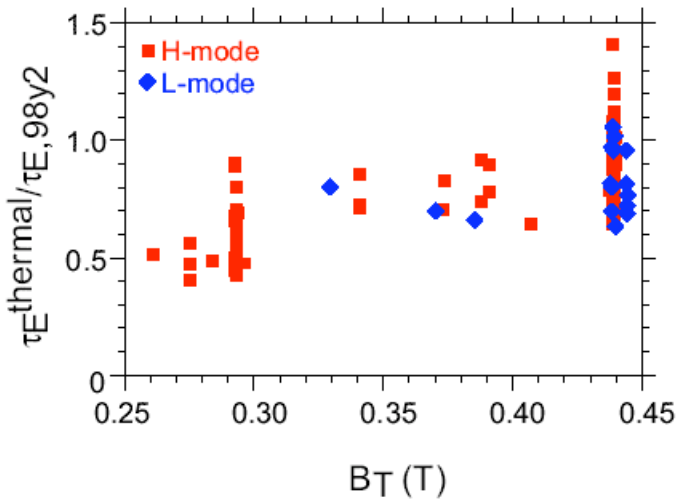
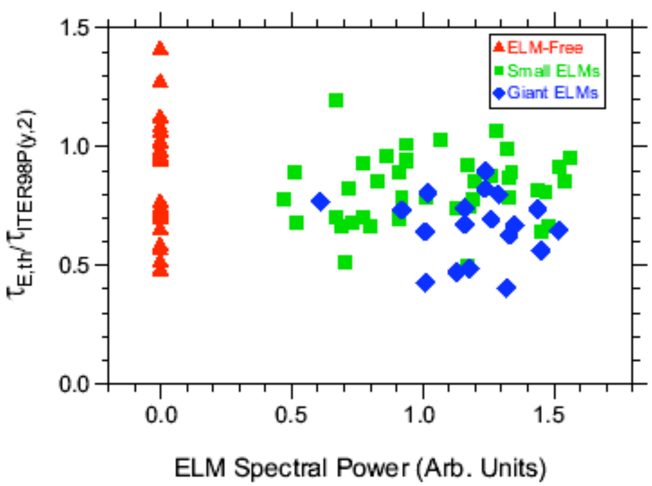
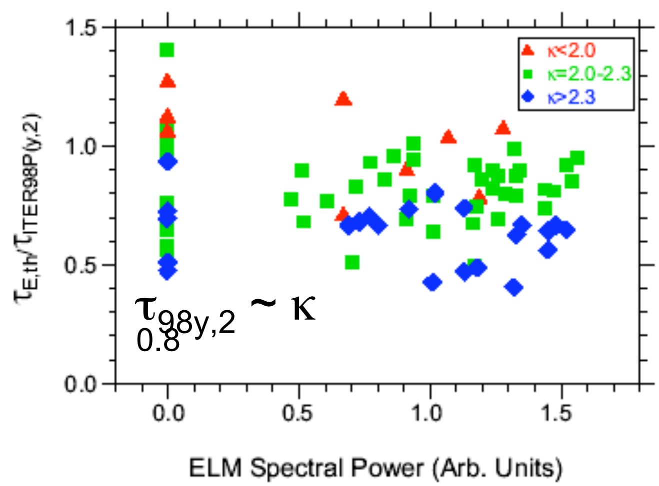
Degree of shot – shot variability consistent with that observed on other devices





H-factor depends on ELM type, decreases with higher elongation

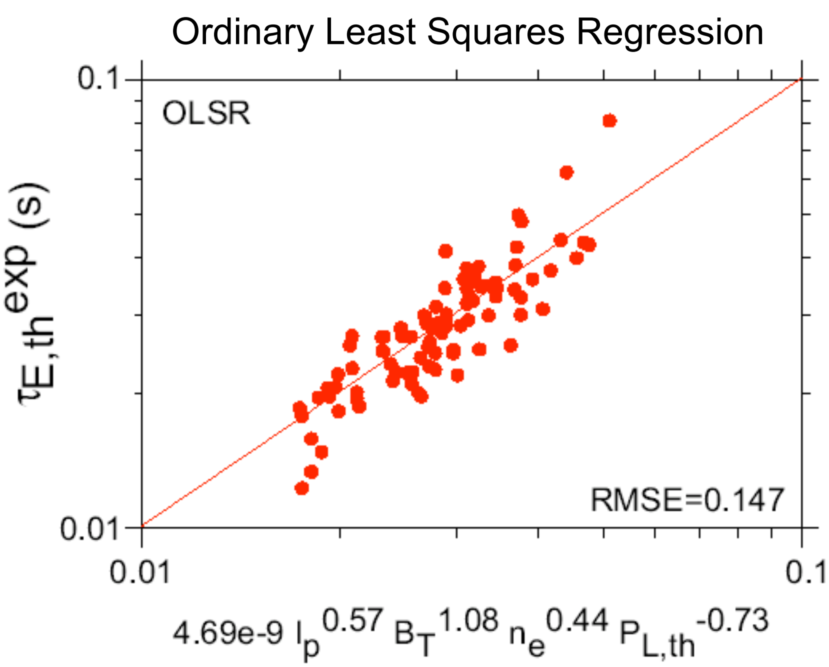




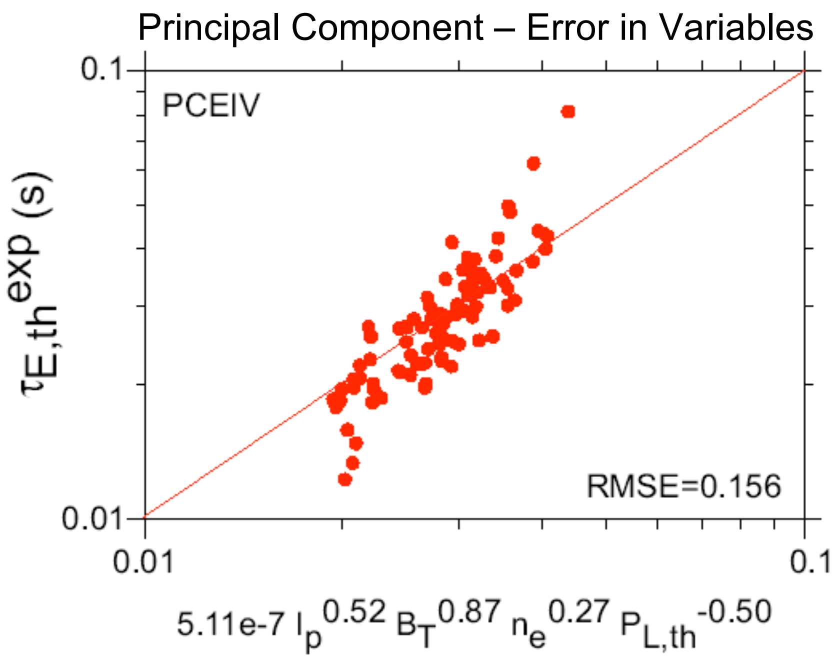
A Variety of Statistical Methods Have Been Used to Study Confinement Trends in NSTX

- Ordinary Least Squares Regression (OLSR)
  - Assume principal measurement error is in response variable ($\tau_{E,th}$)
- Principal Component Error-In-Variable (PCEIV)
  - Establish linear relation among predictor and response variables from PC with minimum eigenvalue ($\Sigma\alpha_i \log x_i \sim 0$)
    - Not zero in practice, but eigenvalue small
  - All variables normalized by their relative errors (assumed to be uncorrelated)
  - W_{th} (14% error) included in set of variables
- PCEIV-C
  - PCEIV with correlated errors taken into account
  - i.e., ε (=a/R), B_T (=B_0R_0/R_{geo}, "0" indicates value at centerstack)
- Bayesian
  - Use probability models to quantify data uncertainties and fits to the data
  - Gives similar result to OLSR (will not discuss further here)

Statistical Analyses Indicate a Stronger B_T but Weaker I_p Dependence Than Exhibited at Conventional Aspect Ratio



$B\tau \sim \rho_*^{-5.81}\ \boldsymbol{\beta}^{\mathbf{-0.65}}\ \nu_*^{-0.43}$



$B\tau \sim \rho_*^{-3.75}\ \boldsymbol{\beta}^{\mathbf{-0.01}}\ \nu_*^{-0.45}$

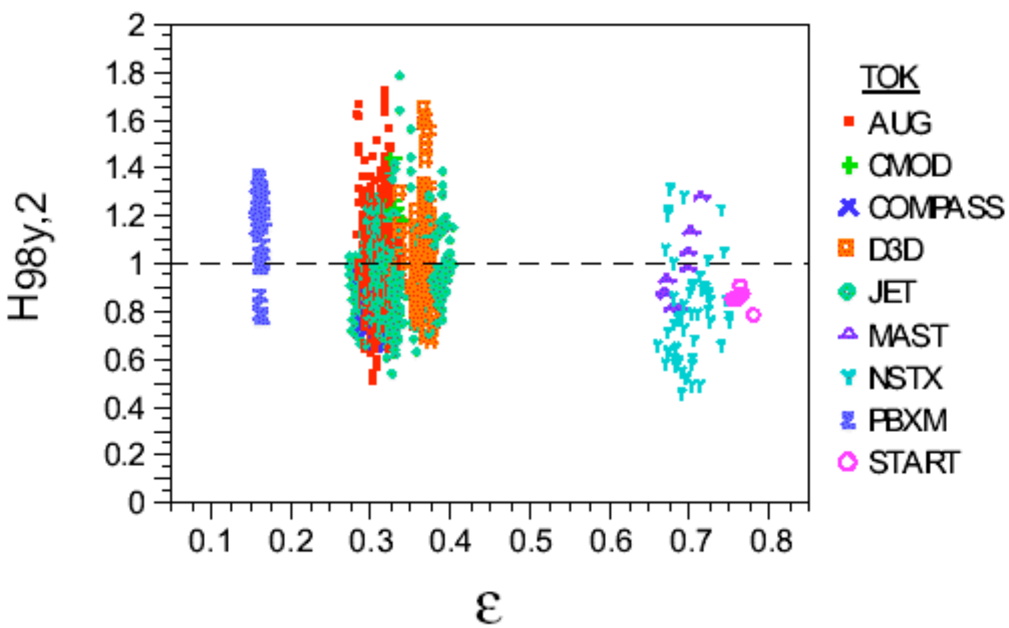
- Variation in power scaling exponents among methods leads to range of β-scaling dependences (from null to unfavorable)
- *B_T and β scaling to be studied in future experiments through dedicated scans*

NSTX Data In the International H-mode Database Used to Determine β, ε Scalings

- *~100 NSTX Discharges From 2004 Contributed*
- IPB98(y,2) Scaling Overestimates Confinement at Low R/a (H<1)

$$\tau_{E,th}^{IPB98(y,2)} \sim I_p^{0.93} B_T^{0.15} n_e^{0.41} P_{L,th}^{-0.69} \kappa^{0.78} M^{0.19} R^{1.97} \varepsilon^{0.58}$$

$$B\tau \sim \rho_*^{-2.7} \beta^{-0.9} \nu_*^{-0.01}$$



Recent Scalings Also Fail to Describe Low R/a Data Adequately

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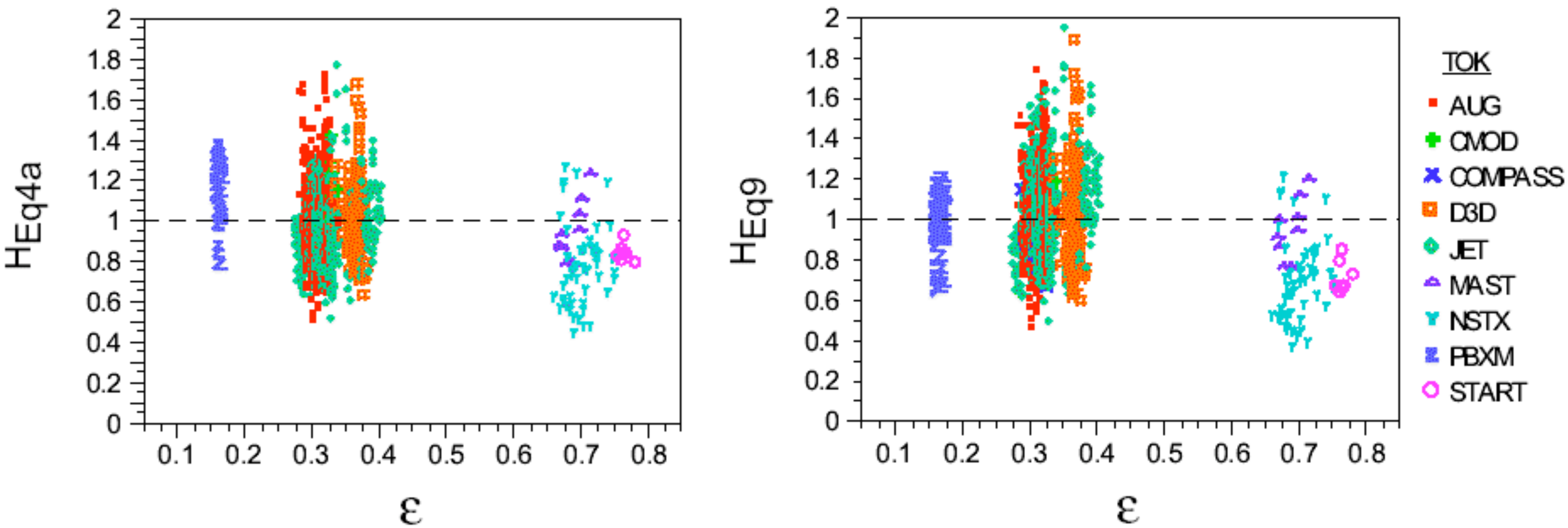
Using different statistical methods:

$I_p^{0.90} B_T^{0.19} n_e^{0.38} P_{L,th}^{-0.69} \kappa^{0.85} M^{0.13} R^{1.94} \varepsilon^{0.63}$

$\sim \rho_*^{-2.6} \beta^{\mathbf{-0.97}} \nu_*^{-0.02}$

$I_p^{0.85} B_T^{0.17} n_e^{0.26} P_{L,th}^{-0.45} \kappa^{0.82} M^{0.11} R^{1.60} \varepsilon^{0.39}$

$\sim \rho_*^{-2.8} \beta^{\mathbf{0.00}} \nu_*^{-0.31}$

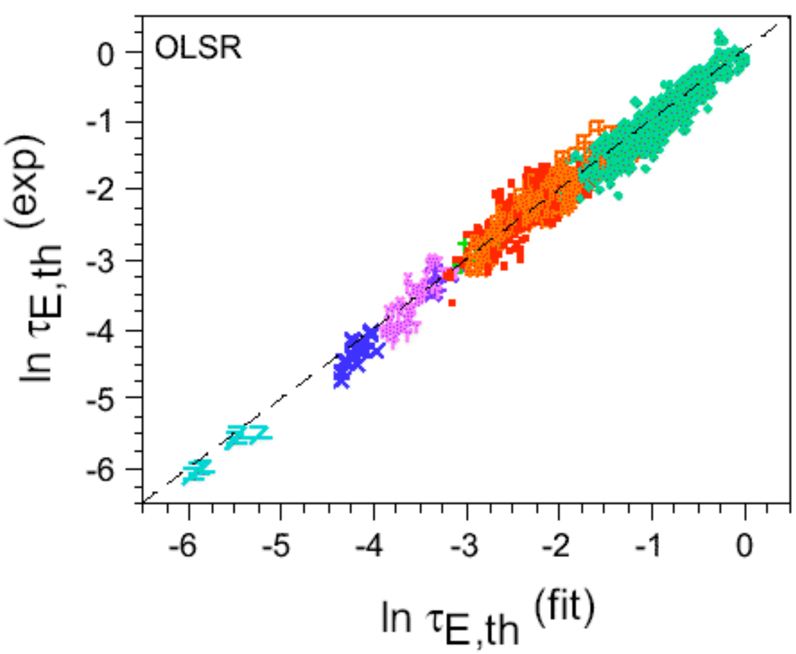


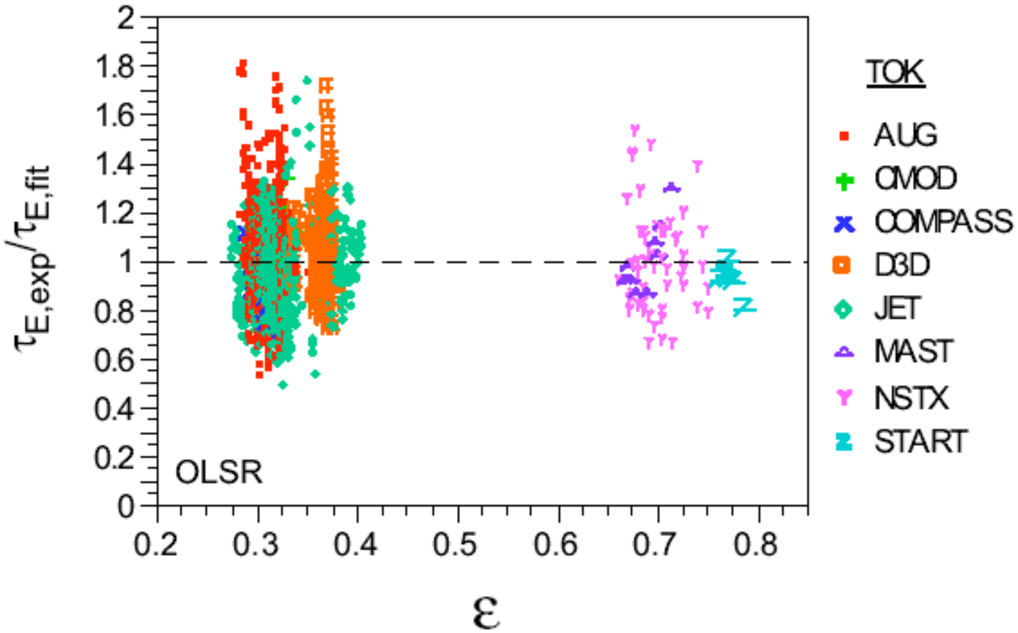
Cordey et al., IAEA 2004

NSTX Data Provides Leverage in Determining ε, β Dependences

$$\tau_{E,th}^{fit} \sim I_p^{0.80} B_T^{0.32} n_e^{0.39} P_{L,th}^{-0.66} R^{2.12} \varepsilon^{0.95}$$

$$B\tau \sim \rho_*^{-2.86} \beta^{-0.70} \nu_*^{-0.09}$$





Range of Possible β-Dependence Reduced With NSTX Data Included in Analysis

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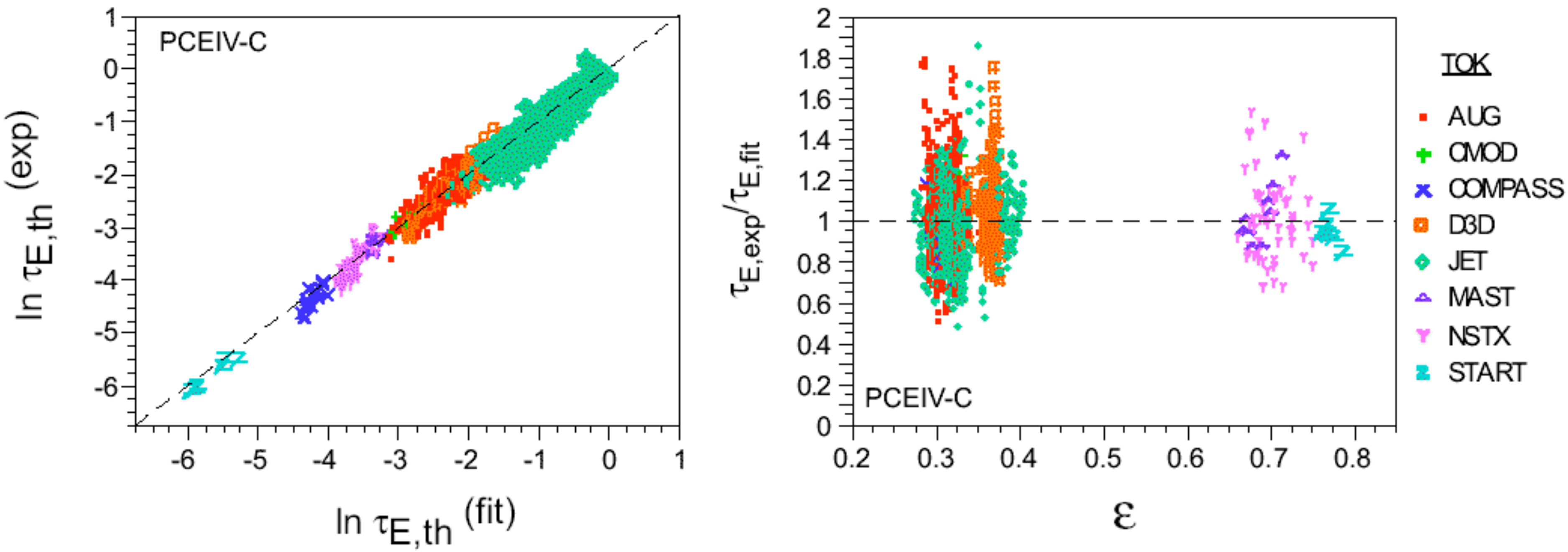
$$\tau_{E,th}^{fit} \sim I_p^{0.73}\, B_T^{0.36}\, n_e^{0.39}\, P_{L,th}^{-0.62}\, R^{2.14}\, \boldsymbol{\varepsilon^{1.03}}$$

$$B\tau \sim \rho_*^{-2.78}\, \boldsymbol{\beta^{-0.48}}\, \nu_*^{-0.12}$$



Further work needed to reduce effect of β – ε correlation in database (similarity experiments)

NSTX Confinement Studies Have Established Confinement Trends in STs and Have Been Important to ITPA/ITER Studies

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- Systematic scans indicate current, power scaling similar to those at higher aspect ratio
  - Density increases with plasma current
  - Weaker current scaling using statistical methods
  - Scalings show $B\tau \sim \beta^{0}$ to $\beta^{-0.65}$
- Data shows scaling with B_T and shot – shot variability
  - Some variability can be attributed to the effects of shaping, ELM amplitude, density fluctuation amplitude (weak)
- Including NSTX data in the ITPA database has aided in establishing the β and ε dependences with a higher degree of confidence
  - Weaker β degradation and stronger ε dependence than in scalings developed only from conventional R/a devices
    - Range of possible β-dependence reduced

Results of Analyses Have Identified Areas That Require Further Work (Both Experiments and Analysis)

- Experiments (related to ITPA priority tasks)
  1) Assess B_T dependence through dedicated scans (FY06)
     - At constant I_p and constant q (not simultaneously)
  2) Decouple density from plasma current (FY06)
     - Lithium conditioning
  3) Perform dedicated β, ν^* and shape (κ, δ) scans (FY06)

     Similarity experiments with MAST planned in FY06 for # 1-3
  4) Joint studies with DIII-D to determine R/a-scaling more precisely (FY06-07)
     - Overlap β range across aspect ratio
- Analysis
  - Further analysis of data required to identify sources of scatter
    - Profile shape, T_i/T_e, vessel conditioning, wall-plasma gaps, …..
  - Contribute recent H-mode data to ITPA confinement database (~170 discharges from FY05 presently being analyzed)
    - April timeframe