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Confinement Scaling and Transport Physics in NSTX

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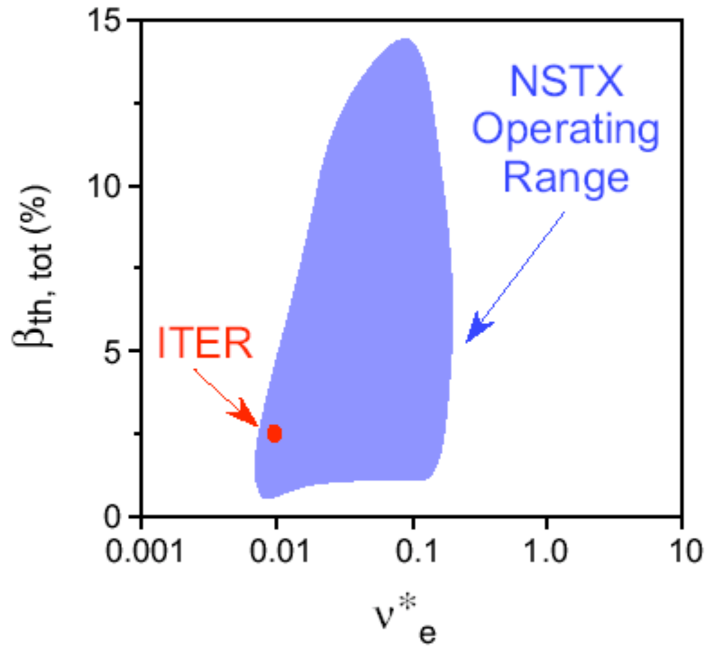
NSTX Addresses Transport & Turbulence Issues Critical to Both Basic Toroidal Confinement and Future Devices

- NSTX offers a novel view into plasma T&T properties
  - NSTX operates in a unique part of dimensionless parameter space: R/a, β_T, (ρ^*, ν^*)
  - Dominant electron heating with NBI: relevant to α-heating in ITER
  - Excellent laboratory in which to study electron transport: electron transport anomalous, ions close to neoclassical
  - Large range of β_T spanning e-s to e-m turbulence regimes
  - Strong rotational shear that can influence transport
  - Localized electron-scale turbulence measurable (ρ_e ~ 0.1 mm)



Major Radius R_0	0.85 m
Aspect Ratio A	1.3
Elongation κ	2.8
Triangularity δ	0.8
Plasma Current I_p	1.5 MA
Toroidal Field B_T	0.55 T
Pulse Length	1.5 s
NB Heating (100 keV)	7 MW
$\beta_{T,tot}$	up to 40%

This Poster Will Focus on Confinement & Transport Trends in NSTX and Their Underlying Processes

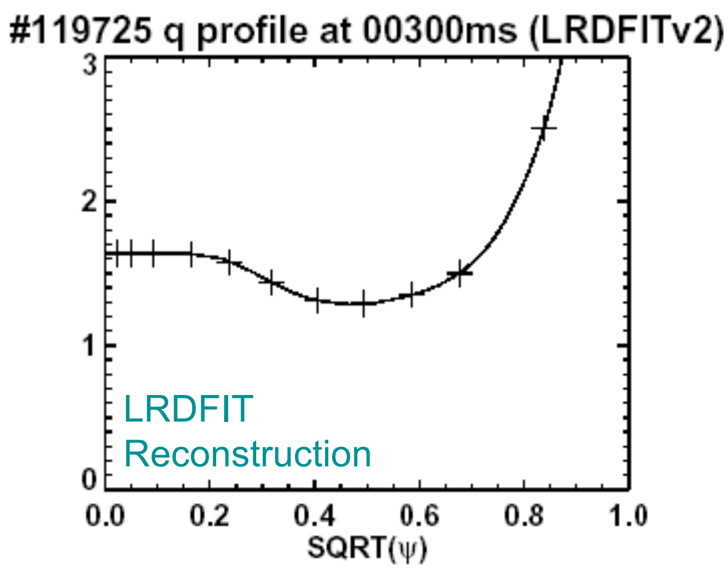
NSTX

- Key confinement and transport dependences established (B_T, I_p, β, $\nu*$, q(r),…)
  - Dedicated scans have isolated I_p and B_T dependences
- High priority ITPA tasks have been addressed
  - Dimensionless parameter scans in β_T, ν_e^*
  - Established more accurate ε (=a/R) scaling with NSTX (& MAST) data included in the ITPA database

    Localized turbulence characteristics being assessed across wide range of k (upper ITG/TEM to ETG)
- Theory/simulations have indicated ETG modes could be important in controlling electron transport

New Diagnostic Capabilities Have Facilitated Progress in Understanding Transport Processes

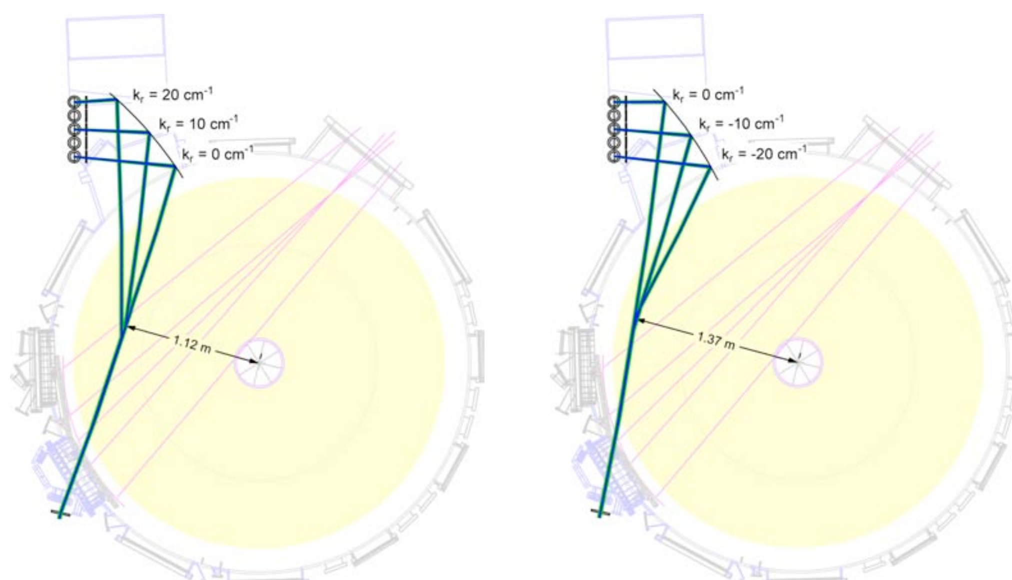
12 channel MSE [NOVA Photonics]



Important for equilibrium and microinstability calculations

Tangential micorwave scattering measures localized electron-scale turbulence

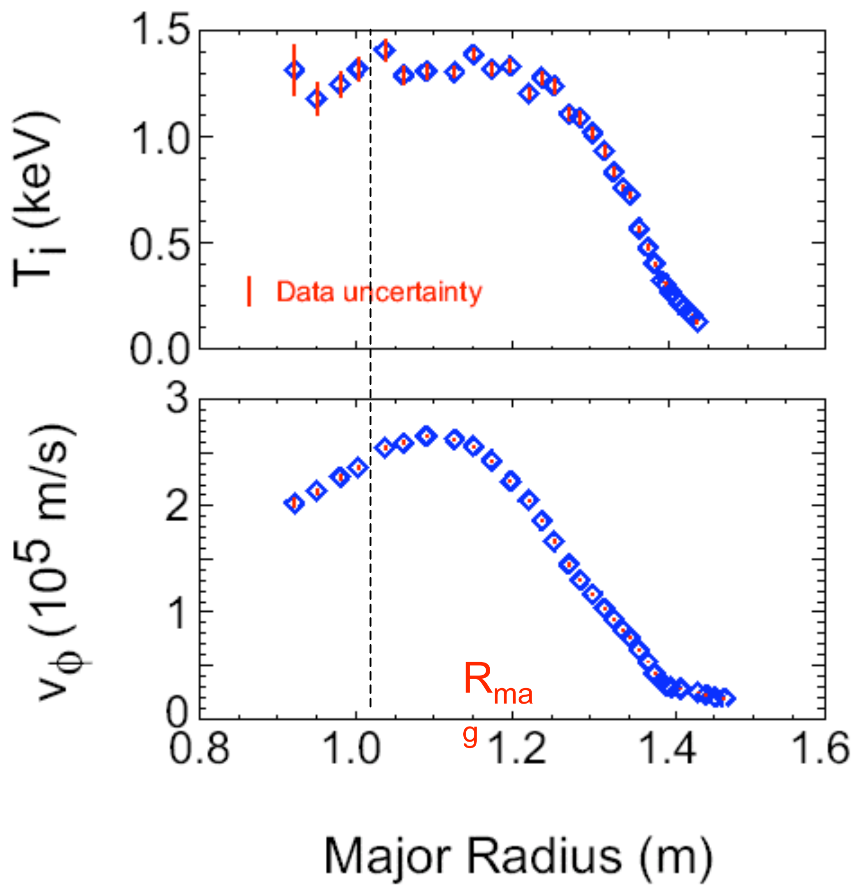
- k_r=2 (upper ITG/TEM) to ~24 (ETG) cm^{-1}
  - ρ_e ~0.01 cm
- Δr ~ 6 cm
- Δk ~ 1 cm^{-1}
- Can vary location of scattering volume (near R_{mag} to near edge)



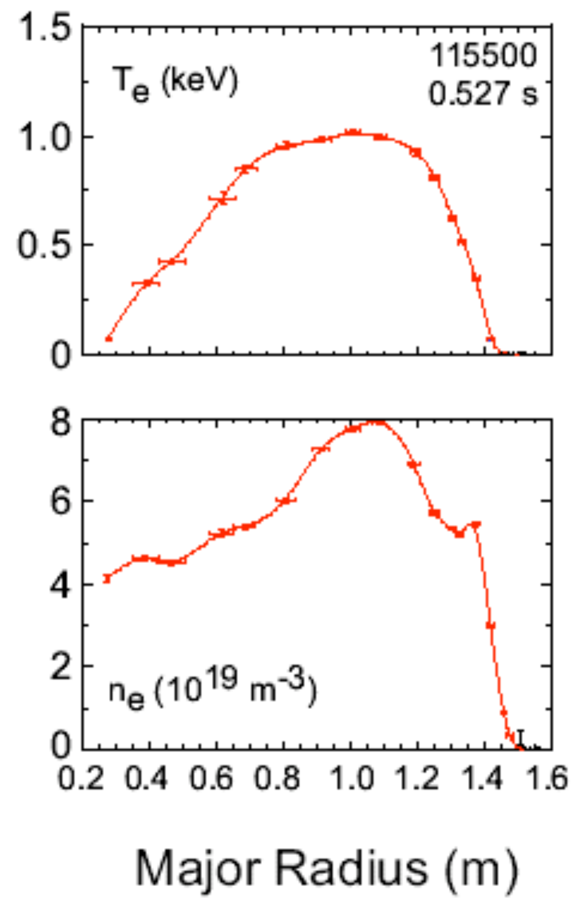
High Resolution Kinetic Profiles Enable Precise Transport Analyses

NSTX

51-point CHERS



20-point MPTS

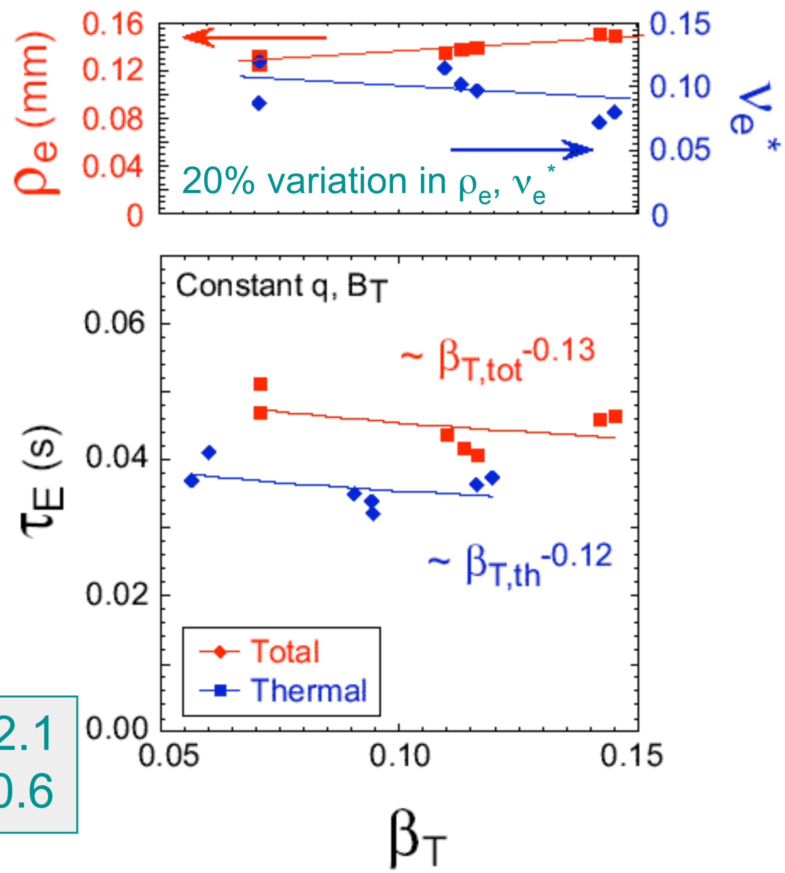


Dimensionless Parameter Scans Have Addressed High-Priority ITPA Issues

NSTX

β-scan at fixed q, B_T

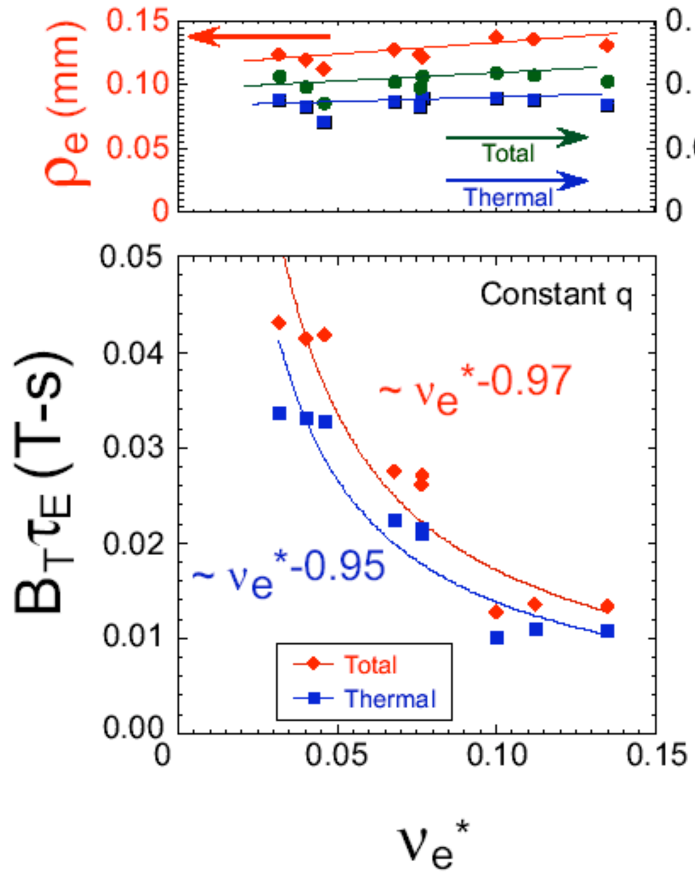
- β-dependence important to ITER advanced scenarios ($B\tau_{98y2} \sim \beta^{-0.9}$)
- Factor of 2-2.5 variation in β_T
- Degradation of τ_E with β weak on NSTX



κ=2.1
δ=0.6

ν_e^*-scan at fixed q

- Factor of >3 variation in ν_e^*
- Strong increase of confinement with decreasing collisionality

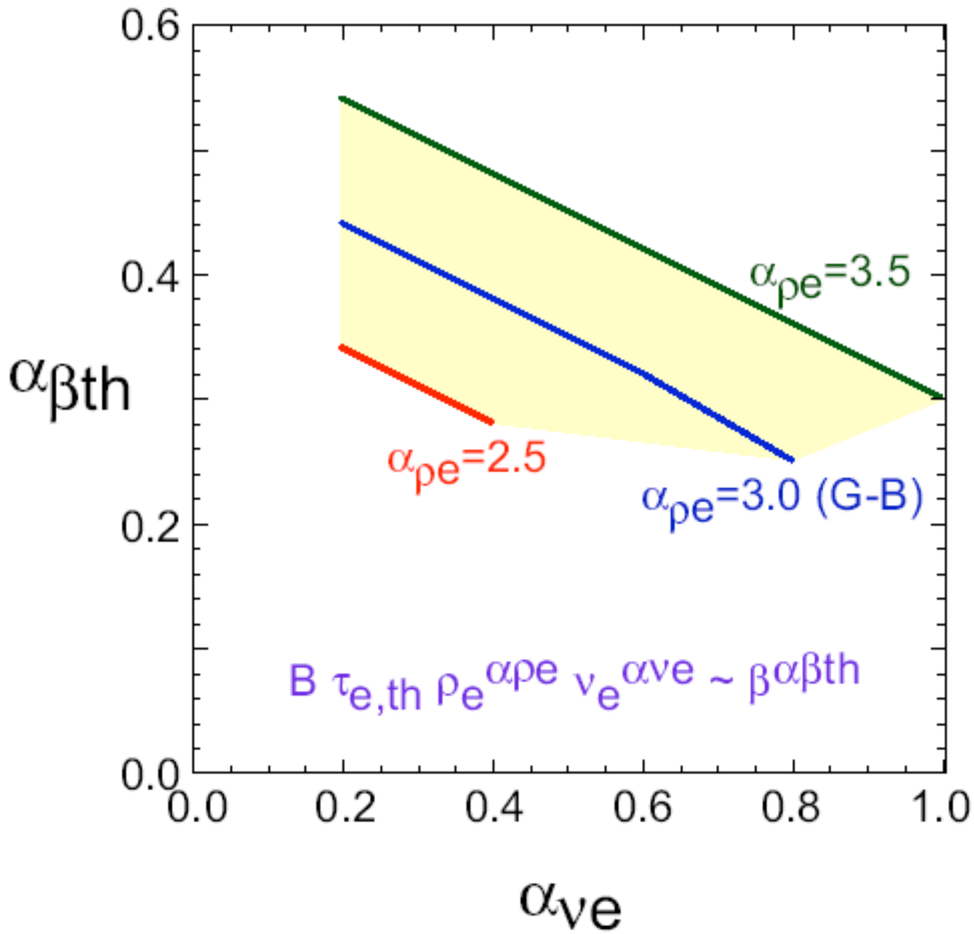


Examine β-dependence By Varying Assumed Fits To Other Parameters

NSTX

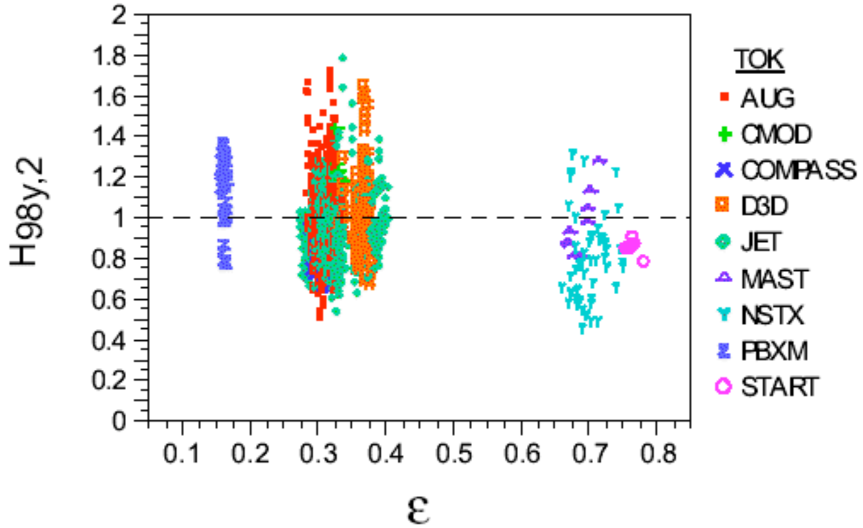
Use results with good fits only ($R^2>0.50$)

β-dependence can be positive

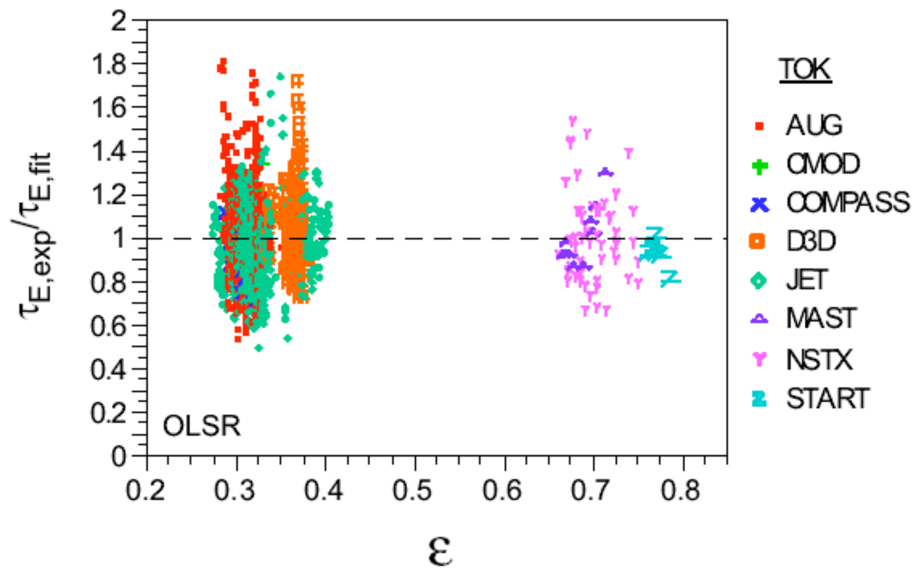


NSTX Data in ITPA Database Used to Establish More Accurate ε (=a/R) Scaling

ITER98PB(y,2) scaling does not represent low R/a data well



Scaling including NSTX & MAST data

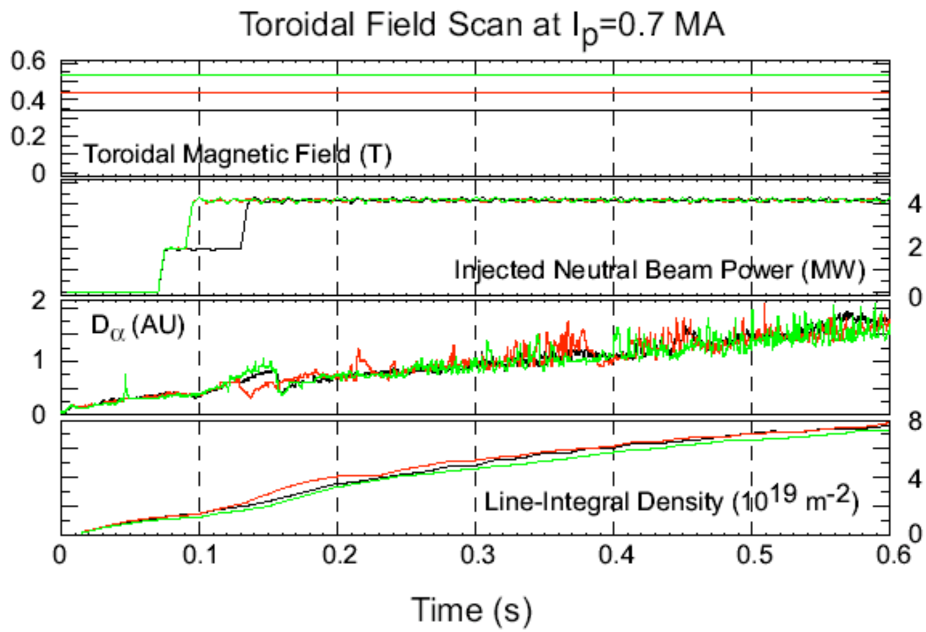


$$\tau_{98y2} \sim I_p^{0.93} B_T^{0.15} n_e^{0.41} P^{-0.69} R^{1.97} \boldsymbol{\varepsilon^{0.58}} \ldots$$

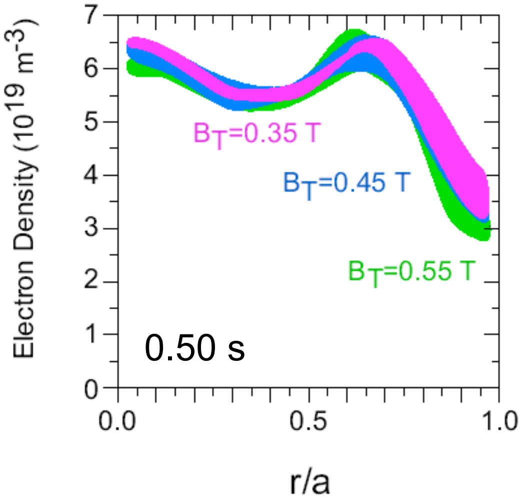
$$\tau_{new} \sim I_p^{0.73} B_T^{0.36} n_e^{0.39} P^{-0.62} R^{2.14} \boldsymbol{\varepsilon^{1.03}}$$

(Kaye et al., PPCF **48** [2006] A429)

Dedicated Scan Performed to Isolate B_T Scaling

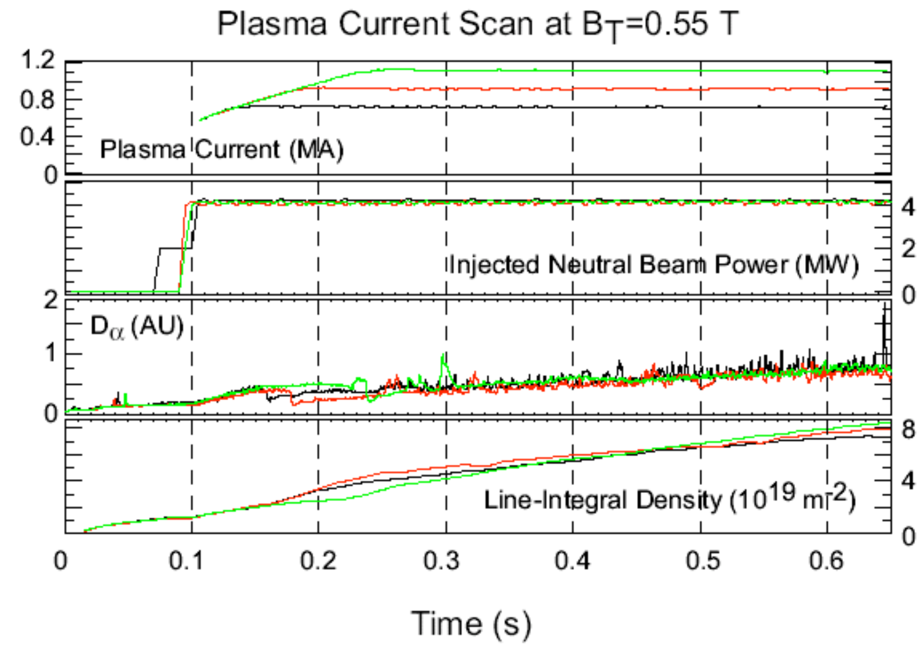


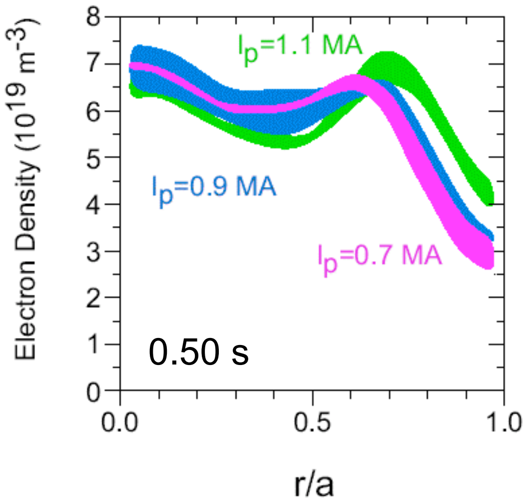
Scans carried out at constant density, injected power (4 MW)



Thickness of “profiles” represent envelope of individual profiles at each condition
- multiple discharges at each condition

Dedicated Scan Performed to Isolate I_p Scaling

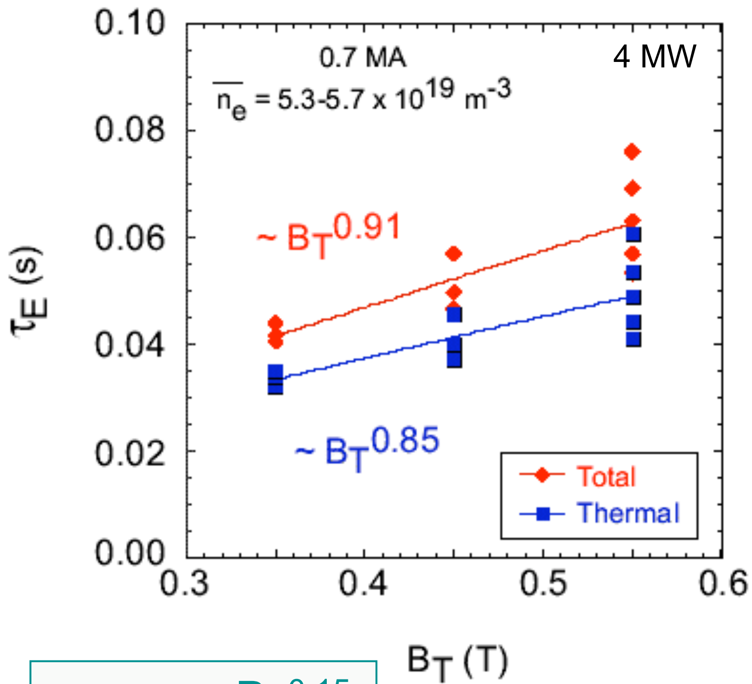




Dedicated H-mode Confinement Scaling Experiments Have Revealed Some Surprises

Strong dependence of τ_E on B_T

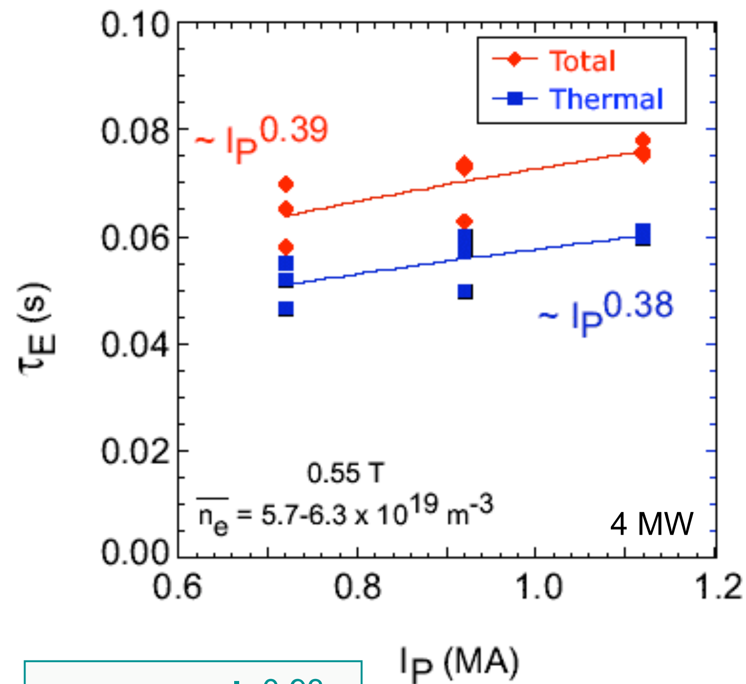
$H_{98y,2}$ ~ 0.9 → 1.1 → 1.4



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

Weaker dependence on I_p

$H_{98y,2}$ ~ 1.4 → 1.3 → 1.1



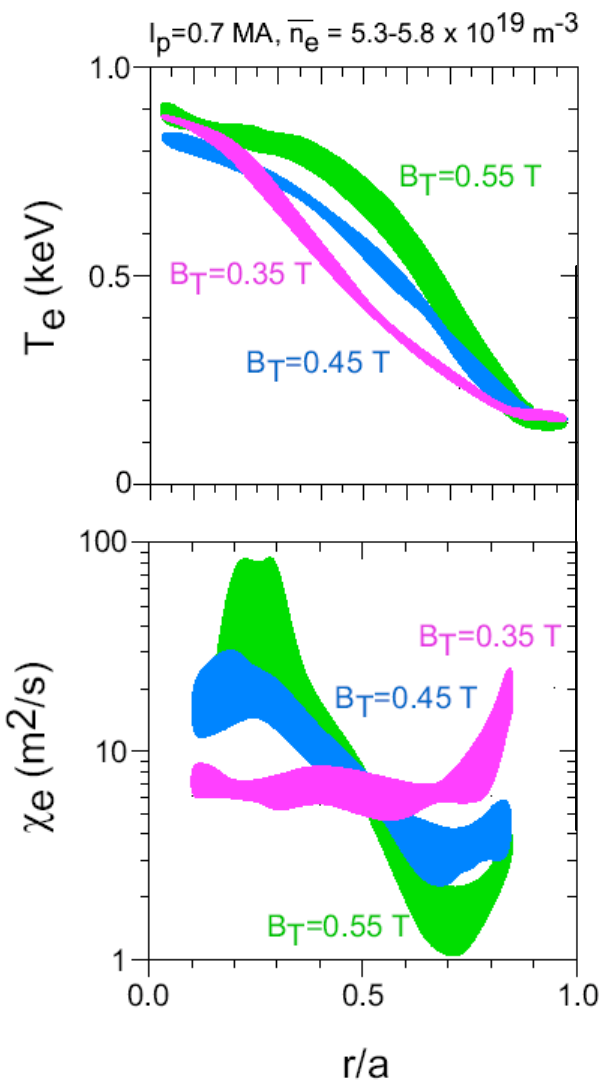
$\tau_{E,98y,2} \sim I_p^{0.93}$

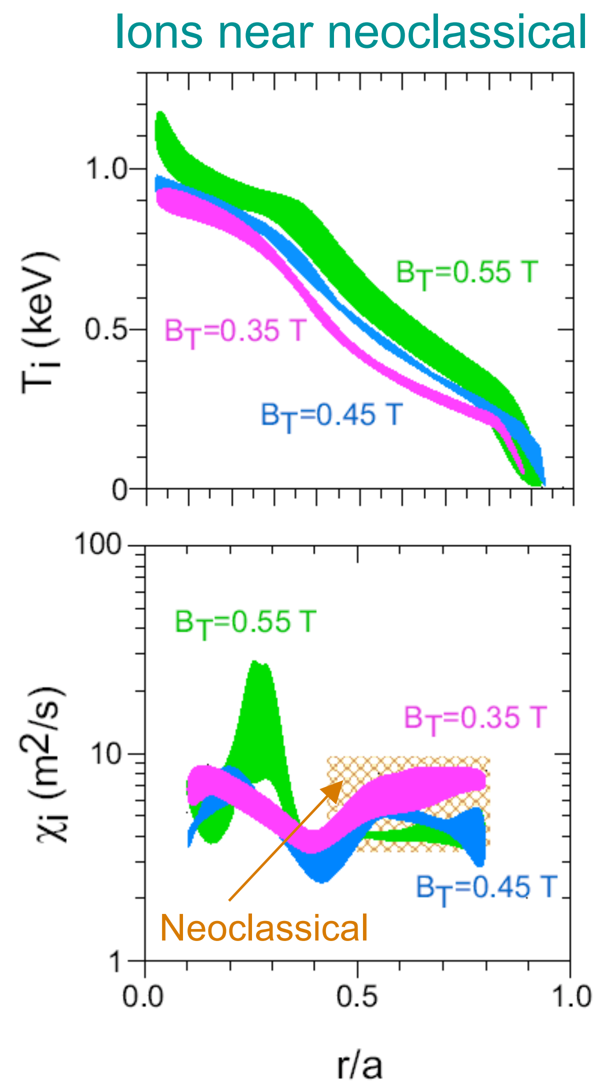
NSTX τ_E exhibits strong scaling at fixed q

$\tau_E \sim I_p^{1.3\text{-}1.5}$ at fixed q $\tau_{E,98y,2} \sim I_p^{1.1}$ at fixed q

Variation of Electron Transport Primarily Responsible for B_T Scaling

Broadening of T_e & reduction in χ_e outside r/a=0.5 with increasing B_T

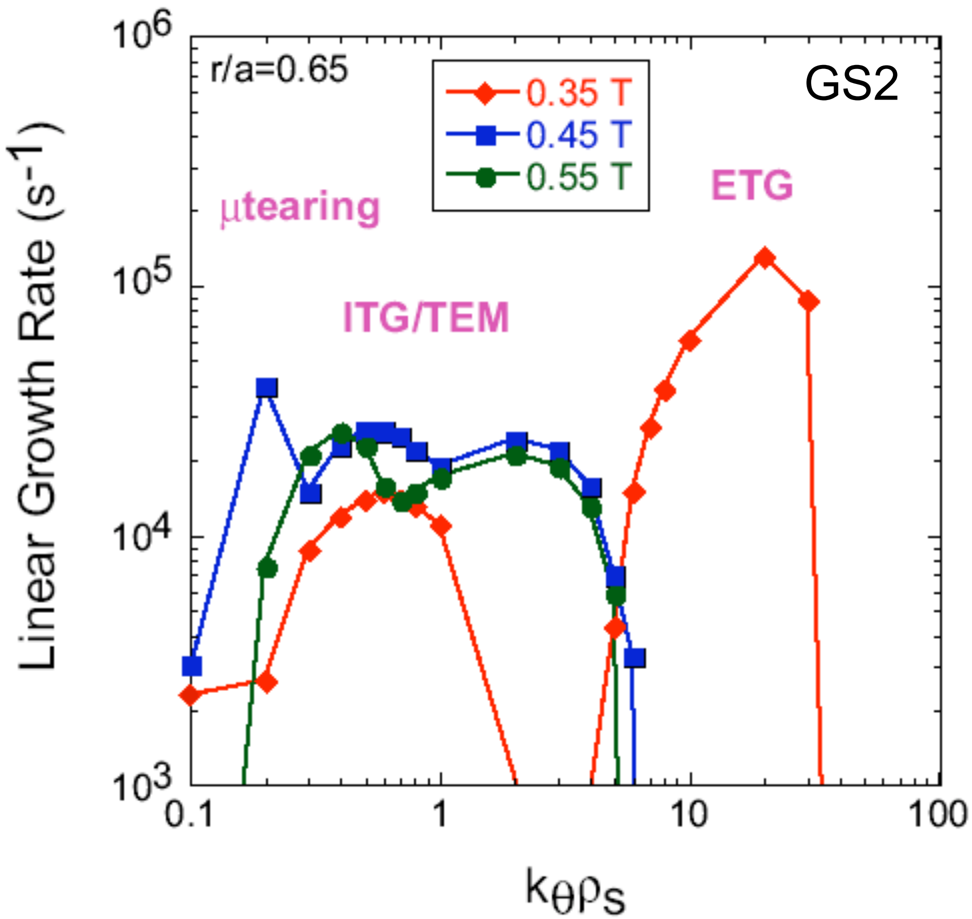




Theory/Gyrokinetic Calculations Suggest ETG May Play an Important Role in Determining Electron Transport at Low B_T

NSTX

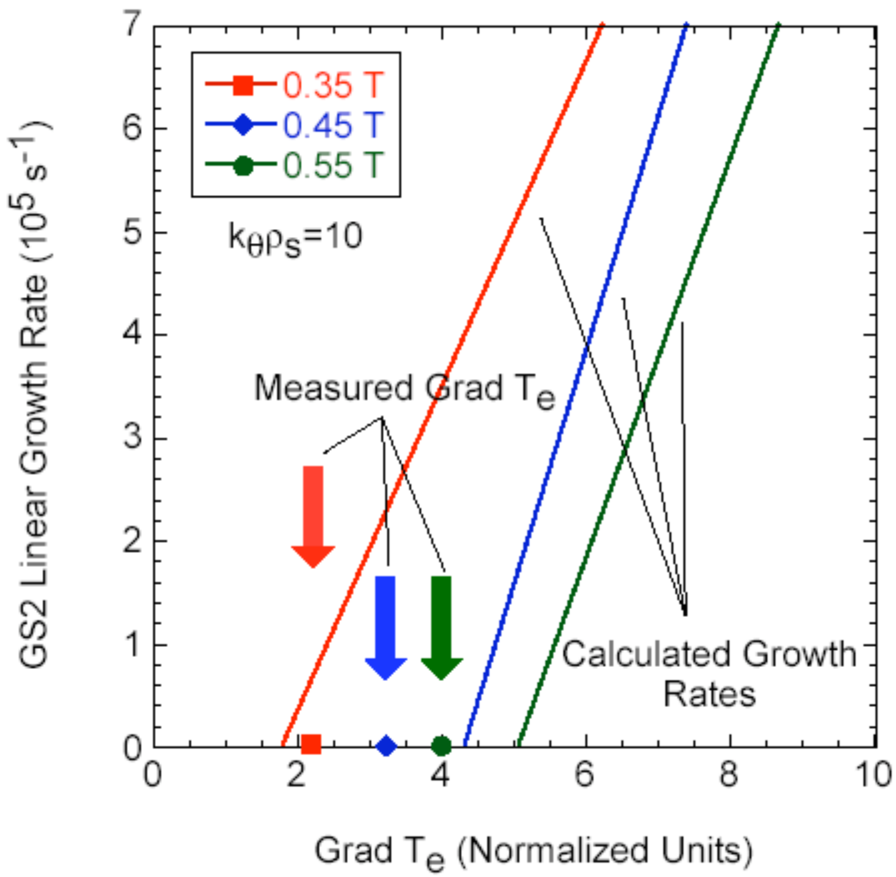
GS2 calculations show ETG linearly unstable only at lowest B_T



T_e Profiles Near Critical Gradient for ETG

NSTX

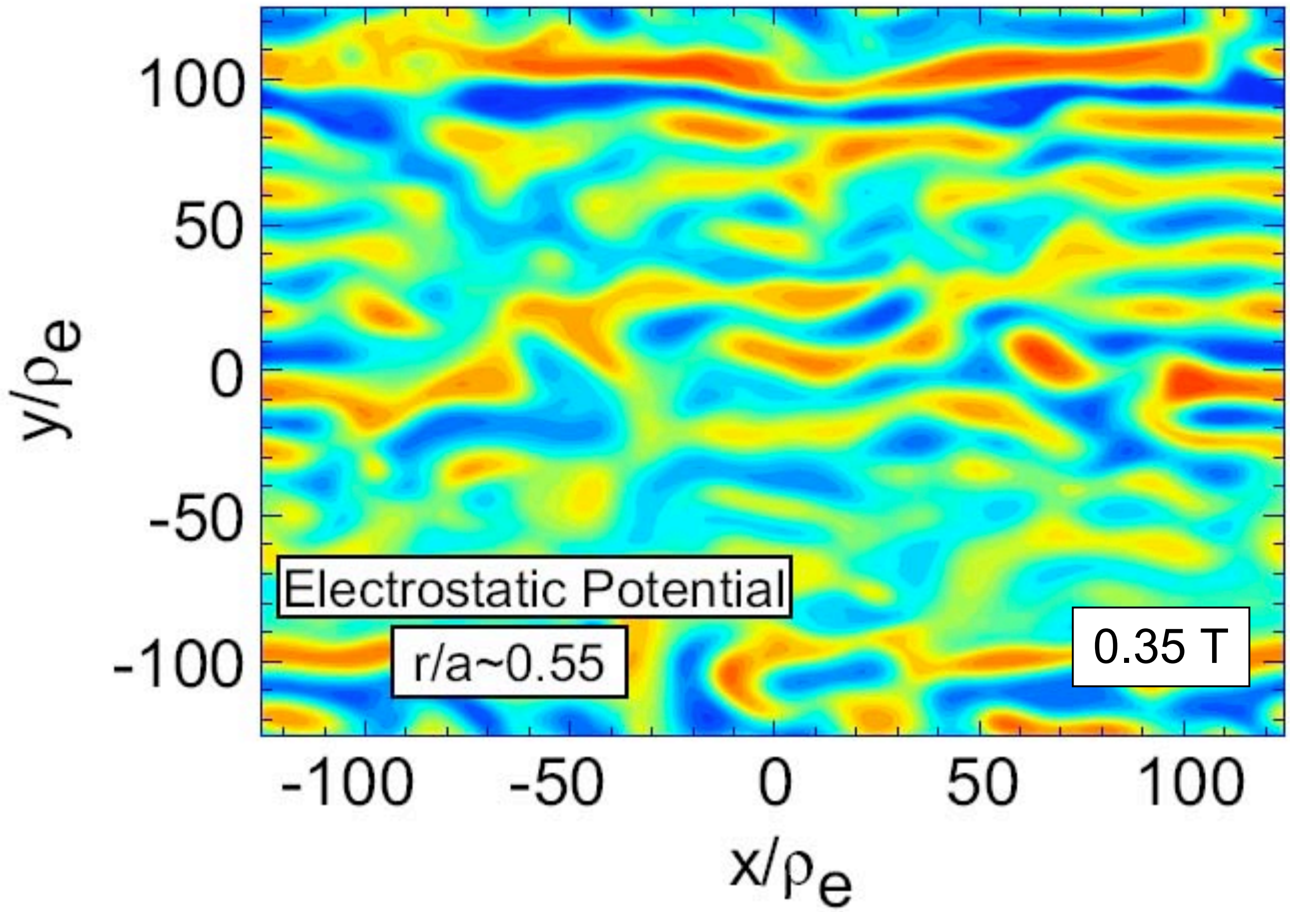
- 0.35 T: R/LTe 20% above critical gradient
- 0.45, 0.55 T: R/LTe 20-30% below critical gradient



Non-Linear Simulations Indicate Formation of Radial Streamers (up to 200ρ_e)

NSTX

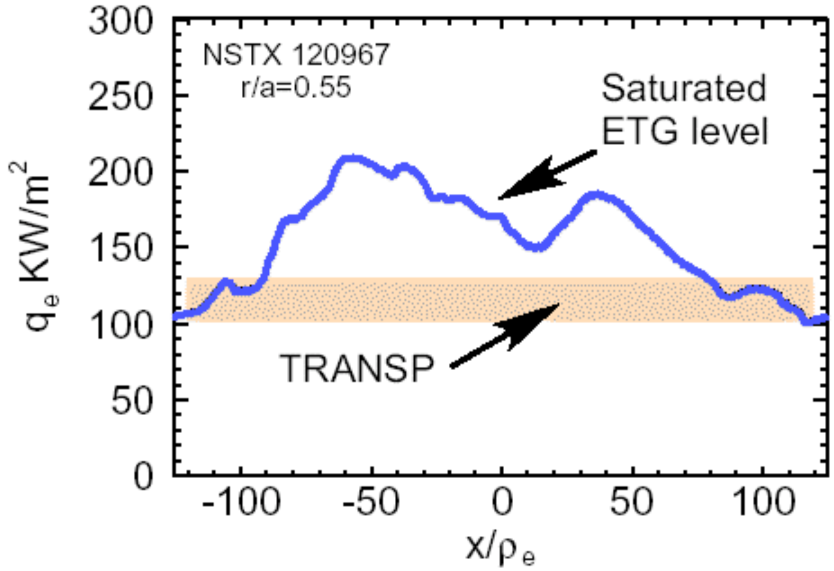
FLR-modified fluid code [Horton et al., PoP 2005]

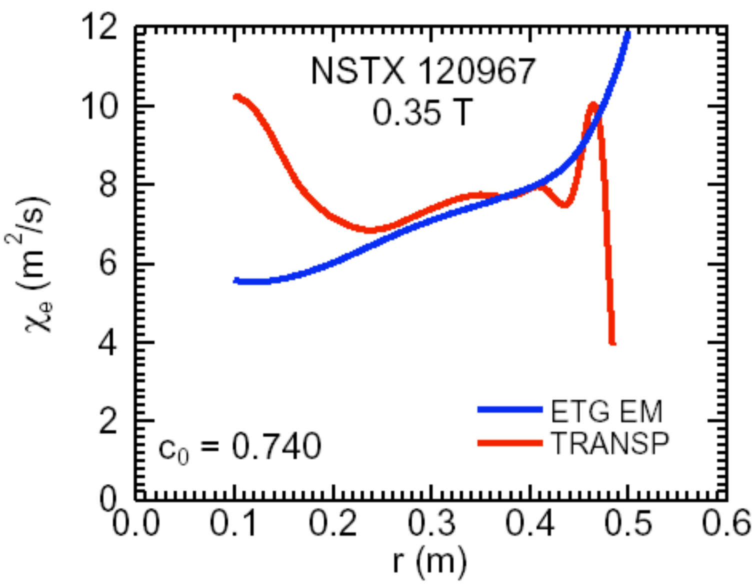


Kim, IFS

Inferred Transport Levels, χ_e Agree with Those From E-M ETG Theory at Low B_T

Good agreement between experimental and theoretical saturated transport level at 0.35 T

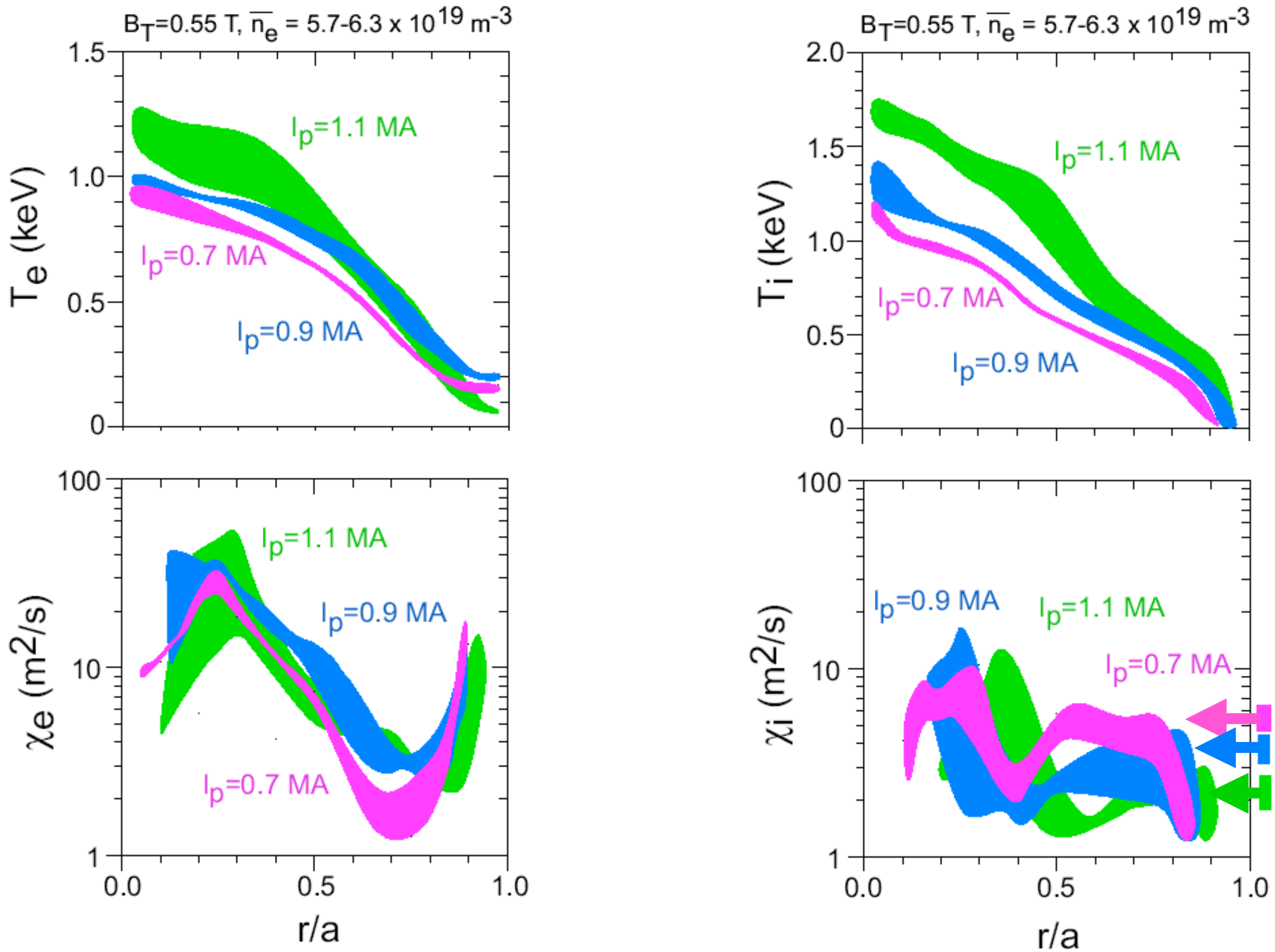




Experimental χ_e profile consistent with that predicted by e-m ETG theory [Horton et al., NF 2004] at 0.35 T

- Not at higher B_T

Ion Transport Primarily Governs I_p Scaling
- Ions Near Neoclassical Level -



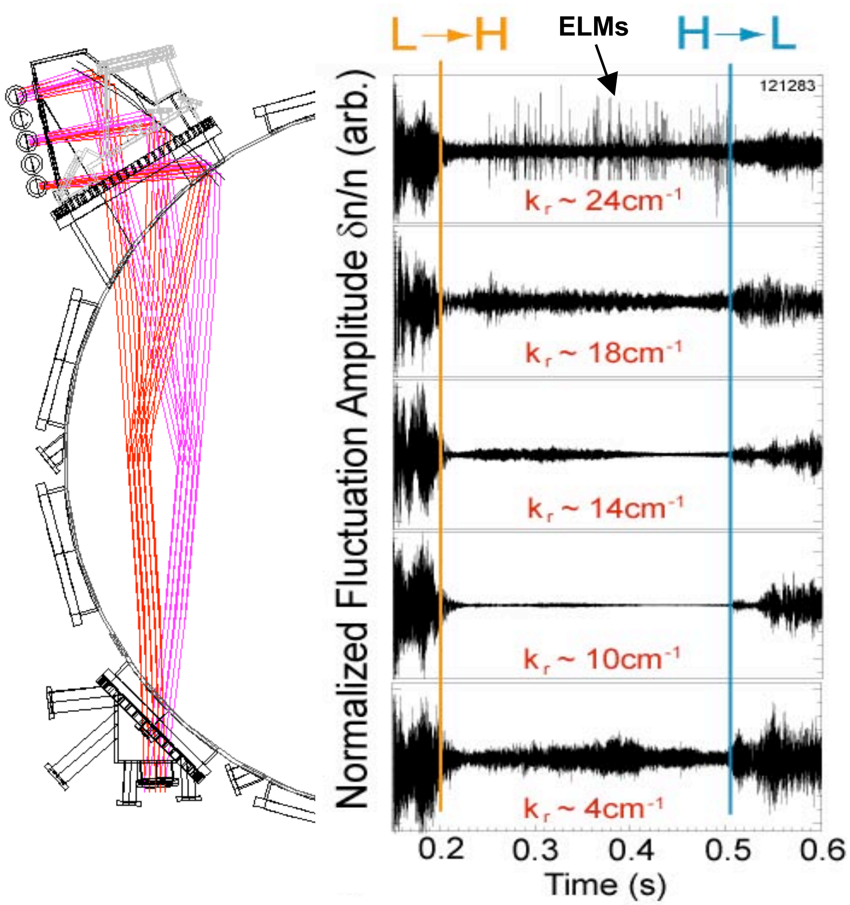
GTC-Neo neoclassical: includes finite banana width effects (non-local)

$\chi_{i,GTC\text{-}NEO}$ (r/a=0.5-0.8)

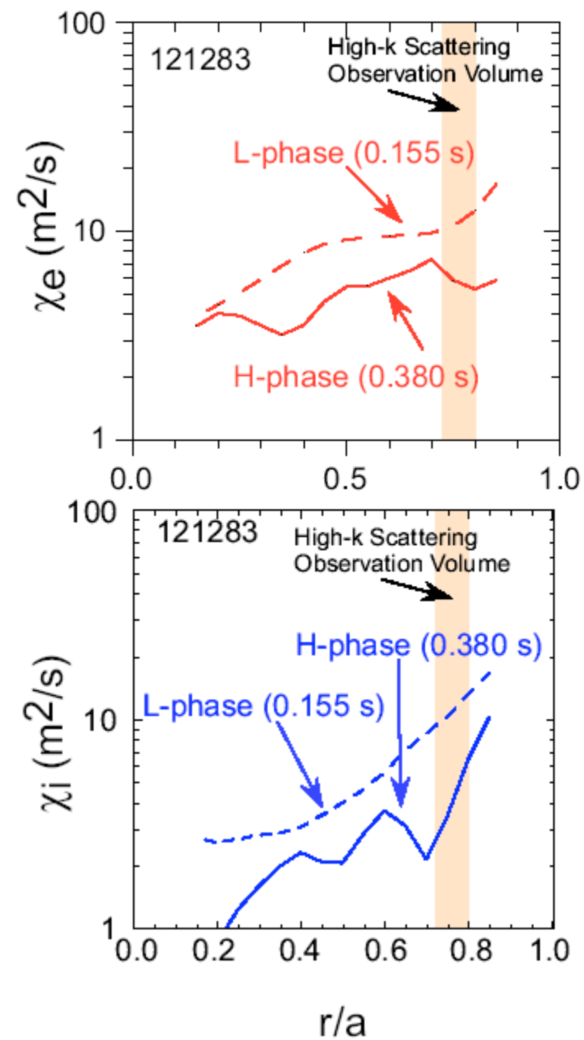
Turbulence Measurements + Gyrokinetic Calculations Have Helped Identify Possible Sources of Transport

NSTX

Microwave scattering system measures reduced fluctuations ($\tilde{n}/n$) in both upper ITG/TEM and ETG ranges during H-mode



Ion and electron transport change going from L- to H-modes



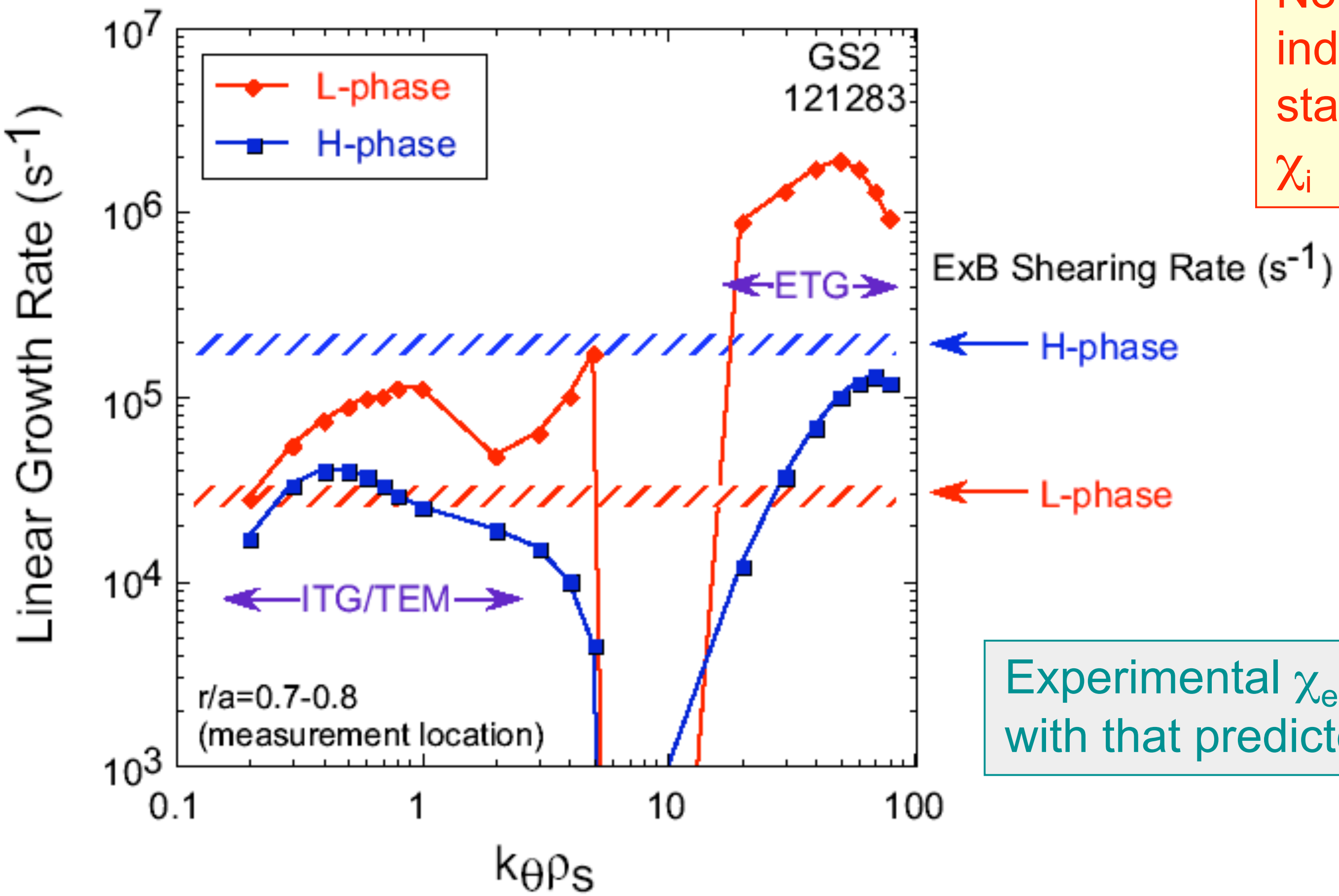
Electron transport reduced, but remains anomalous

Ion transport during H-phase is neoclassical

Theory/Gyrokinetic Calculations Indicate Both ITG/TEM and ETG are Possible Candidates for Electron Transport

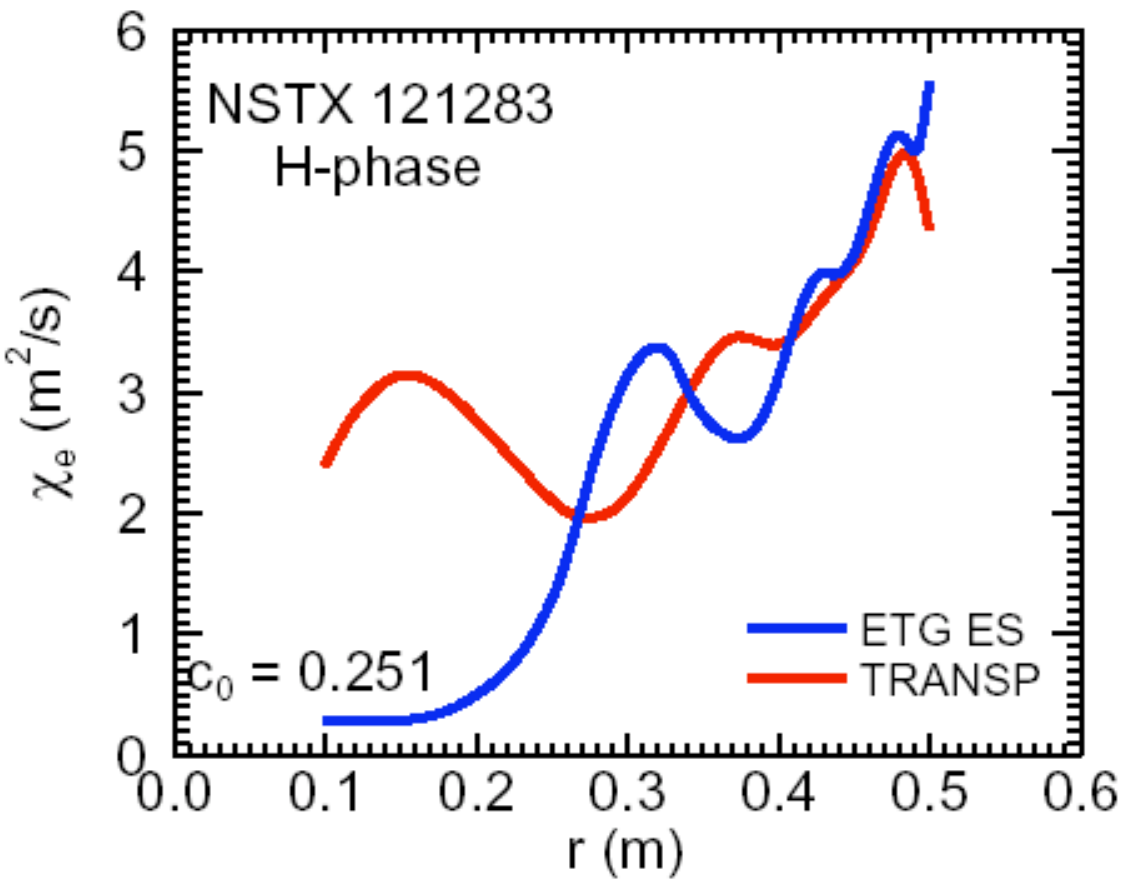
GS2 calculations indicate lower linear growth rates at all wavenumbers during H- than during L-phase: *ETG unstable*

Non-linear GTC results indicate ITG modes stable during H-phase; χ_i ~ neoclassical



Experimental χ_e profile consistent with that predicted by e-s ETG theory

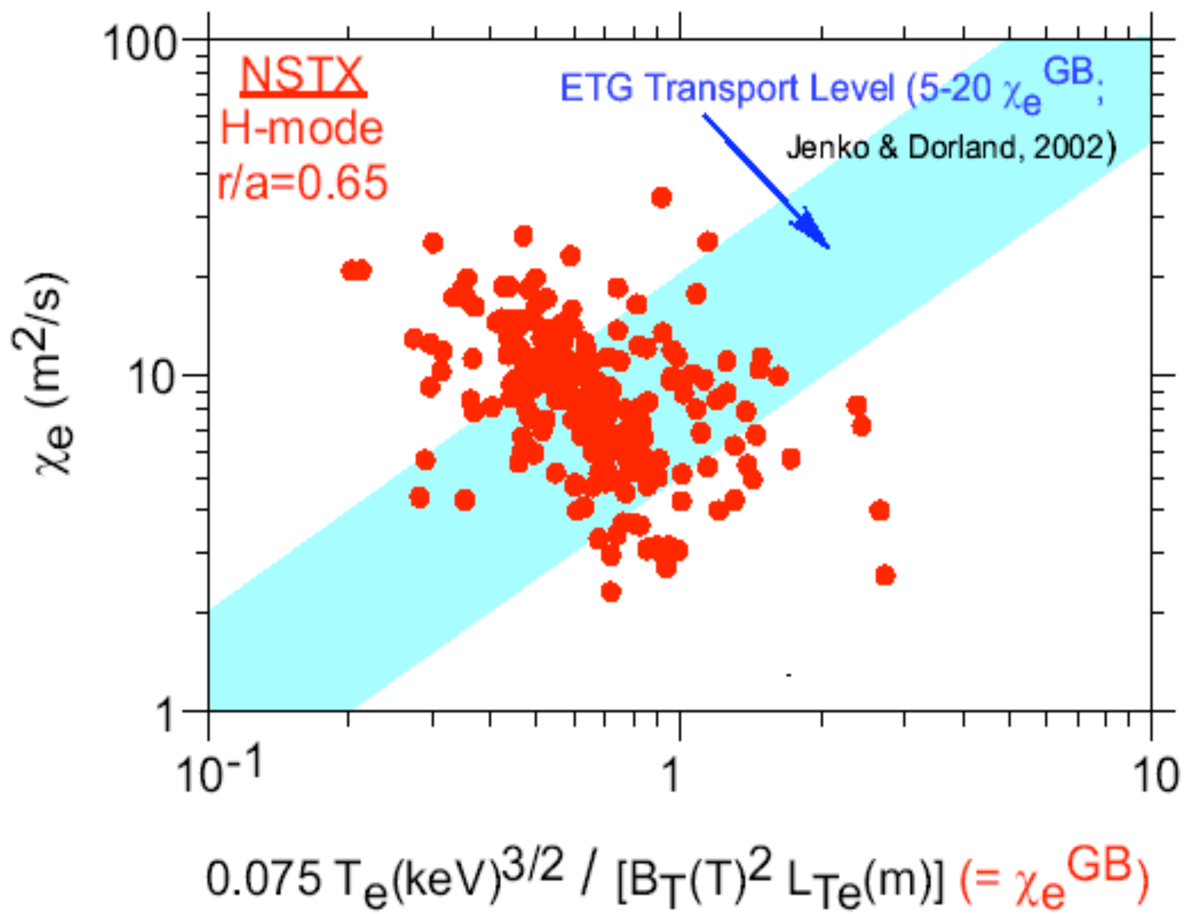
Experimental χ_e Profile Consistent With That Predicted by E-S ETG Theory



(Horton et al, Phys. Plasmas [2004])

A Significant Number of NSTX Discharges Have χ_e Values Consistent With ETG Expectations

NSTX



NSTX Plays a Key Role in Multi-Scale Transport & Turbulence Research

NSTX

- Confinement and transport trends found to differ from those at higher R/a
  - Strong B_T, weaker I_p scaling
    - Electron transport variation primarily responsible for B_T scaling
    - Ions near neoclassical; primarily responsible for I_p scaling
    - *Understand the source of the difference in confinement trends at different R/a (low vs high-k turbulence dominant at different R/a, B_T?)*
- Data provided to ITPA H-mode database for R/a and β_T scalings
  - No degradation of $B\tau_E$ with β_T
- $\tilde{n}/n$ decreases from L- to H-phase for k_r=2 to 24 cm^{-1} (upper ITG/TEM to ETG range)
  - Associated with reduction in transport
- Linear and non-linear theory have indicated ETG modes could be important
  - Need also to consider lower-k modes (microtearing, ITG/TEM)