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NSTX

2009-2013 Research Plan for Multi-Scale Transport and Turbulence Physics in NSTX

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For the NSTX Team

Tokamak Planning Workshop
PSFC, MIT
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NSTX Can Address T&T Issues Critical to Both Basic Toroidal Confinement and Future Devices

- Critical issues for future (including Burning Plasma) Devices (NHTX, CTF; ITER)
  - Scaling of L-H threshold power, confinement, rotation to larger I_p, B_T, P_{heat}, …., in sustained discharges
  - Predictive understanding of local transport trends
  - Profile control to optimize performance, stability and non-inductive current drive to achieve integrated performance goals
- NSTX can make important contributions and bring new perspectives to these issues
  - Dominant electron heating with HHFW & NBI: relevant to α-heating in ITER
  - Strong rotational shear that can influence transport
  - Anomalous electron transport can be isolated: ions often close to neoclassical
  - Large range of β_T spanning e-s to e-m turbulence regimes
  - Localized measurements of electron-scale turbulence (ρ_e~0.1 mm)
  - Lithium plasma facing components

Transport and Turbulence Studies Are Multi-Faceted

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Facility and diagnostic upgrades will aid achieving T&T goals

Density control: Lithium plasma facing components

Additional power, current/density profile control: 2nd NBI, D pellet injector

Magnetic braking to change ExB shear: Internal non-axisymmetric control coils

Long-pulse discharges: OH/TF sub-cooling

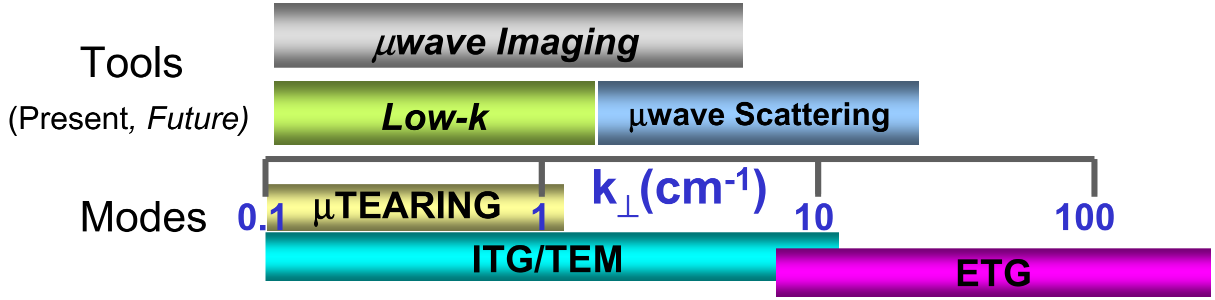
Heating profile measurements for power balance: FIDA, neutron collimators

Rotation measurements: poloidal CHERS, Edge Rotation Diagnostic upgrade, imaging X-ray crystal spectrometer

Perturbative energy transport – EBW for localized heating (350 kW→1 MW), High resolution edge and core SXR

Fluctuations: internal δB using MSE, microwave scattering upgrade to measure high k_θ in addition to high k_r, Microwave Imaging Reflectometer for low-to-medium k, low-k (developing options)

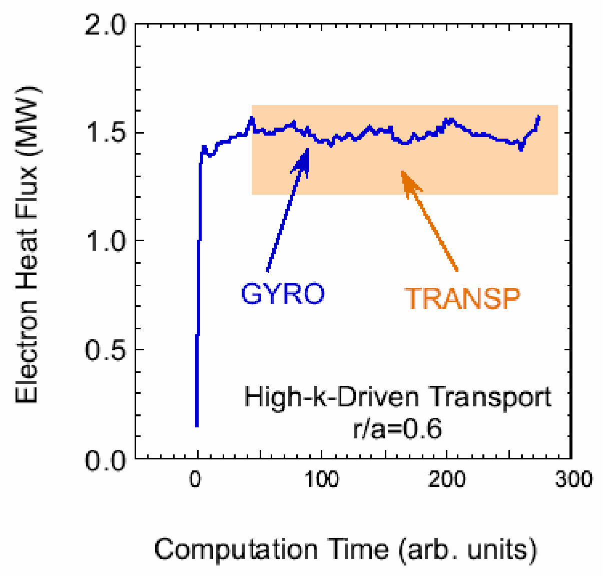
Full complement of turbulence measurements will cover a wide k-range



Strong Coupling of Experiment to Theory

Experiment coupled to gyro-kinetic theory/simulation results

- TRANSP: transport analysis
- GTC-NEO: non-local neoclassical
- GS2, GYRO, GTC, GEM: linear and non-linear gyrokinetic codes for turbulence-driven transport
- pTRANSP (+ TGLF): predictive simulations



NSTX operating regimes will yield results that will test and extend theory

Verification and validation of theory and models at all levels

- Synthetic diagnostics in gyro-kinetic codes
- Fluctuation spectra, mode structure
- Transport fluxes, χ's, D's

Ultimate goal: Comprehensive Understanding ⟷ Predictive Tool

Global Studies Have Established Dependences for Confinement and L-H Threshold Power

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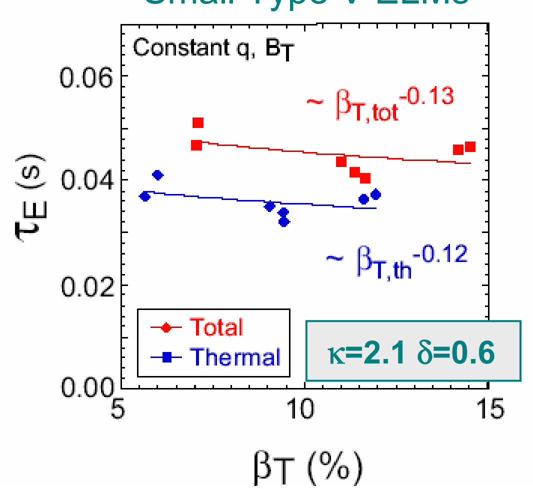
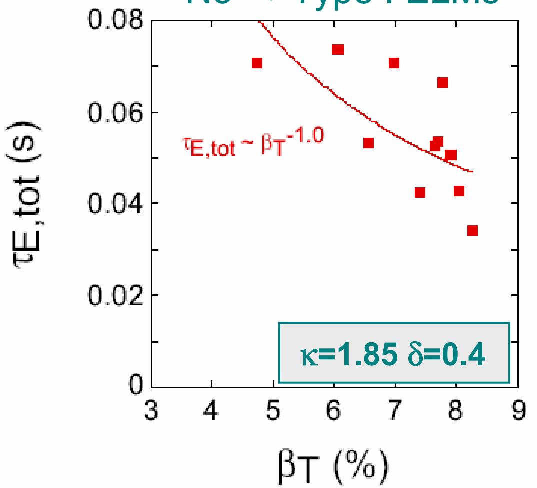
- L-H threshold power
  - Apparent I_p dependence, L-H easier with high-field-side fueling
  - Triangularity, X-point height, configuration important
- Global confinement dependences differ from those at higher aspect ratio
  - $\tau_E \sim B_T^{0.9} \leftrightarrow \tau_E^{98y,2} \sim B_T^{0.15}$; $\tau_E \sim I_p^{0.4} \leftrightarrow \tau_E^{98y,2} \sim I_p^{0.9}$
- Significant improvement in global confinement with Lithium evaporation

β-scaling high priority ITPA topic: Shape (ELMs) matter!

Small Type V ELMs



No → Type I ELMs



Global Scaling Studies are Important for Being Able to Scale to Future Devices

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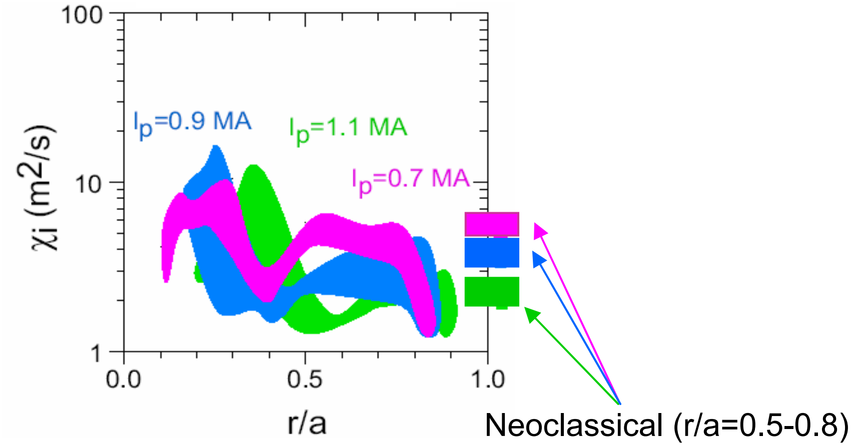
Most global confinement studies have given way to local transport studies, but some important research opportunities remain

- 2008-2010
  - Determine I_p, B_T, shape dependence of L-H threshold power
  - Identify source of variation in β-degradation of confinement
  - Establish effect of Lithium PFC on L-H threshold, global confinement
    - Key component of global **and** local studies
  - Dependence of τ_E on R/a for optimizing NHTX, ST-CTF designs
    - Within NSTX and through NSTX/DIII-D similarity experiment
- 2010-2013
  - Evaluate role of X-point in determining $P_{L\text{-}H}$
  - Verify scaling trends at high P_{heat} (≤ 12 MW) to support NHTX, ST-CTF physics designs
    - Varying beam deposition profile, torque input
  - Scaling in long-pulse discharges (≤ 2.5 s)

Ion Transport Often Found to Be Near Neoclassical In H-modes

Controls τ_E scaling with I_p

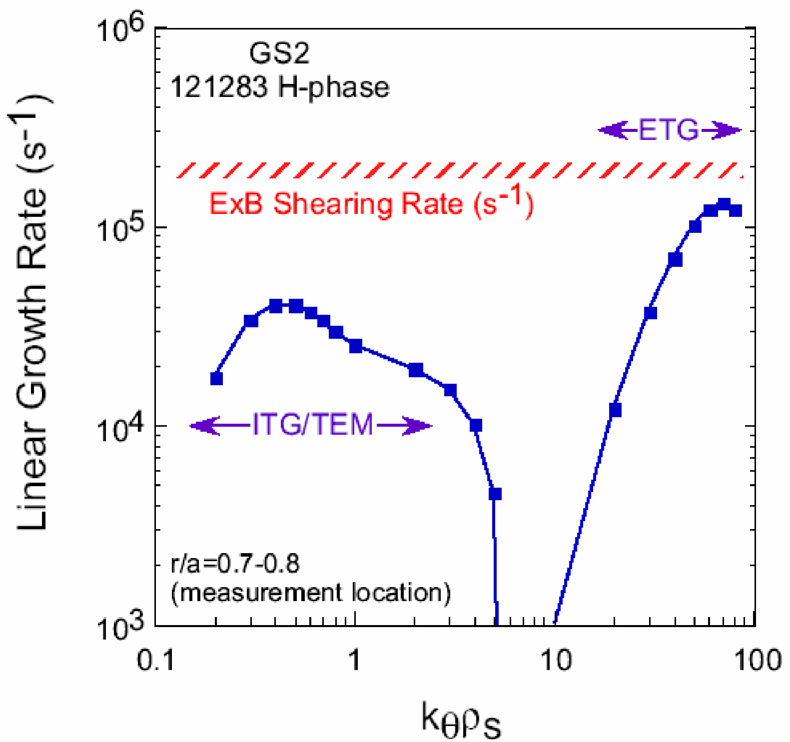


Neoclassical levels determined from GTC-Neo: includes finite banana width effects (non-local)

Orbit squeezing/shrinking may be responsible for setting ρ_i-scale extent of T_i gradient in some discharges

Linear GS2 calculations indicate possible suppression of low-k turbulence by ExB shear during H-phase

- Supported by non-linear GTC results



χ_i anomalous in some cases

Establish a Predictive Understanding of Transition Between Neoclassical and Turbulent Ion Transport Regimes

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- Predictive understanding crucial for design/operation of NHTX, ST-CTF
- NSTX tools allow for transitioning between turbulent and neoclassical transport

- 2008-2010
  - Actively change ITG/TEM driving/damping terms (T_e/T_i, ExB shear) using HHFW and magnetic braking
  - Relation of first low-k turbulence measurements to transport
  - Ion internal transport barrier studies: relation to current profile, integer q, ExB shear
  - Validation of orbit shrinking theory
- 2011-2013
  - More detailed comparison of inferred χ_i and low-k fluctuations to gyro-kinetic predictions:
    - Assessment of non-local transport due to large ρ^*
    - Zonal Flow dynamics in edge and core (test theoretical q-dependence)
    - *Comprehensive validation of neoclassical and ITG theories*
  - Assessment of ion transport and turbulence levels at high P_{heat} and for various input torques, q-profiles
  - Neoclassical theory development with full FLR
- 2013
  - Low-to-medium k turbulence levels using Microwave Imaging Reflectometer
  - Ion transport in RF plasmas with T_i/T_e<1 and low input torque using Imaging X-ray Crystal Spectrometer

NSTX Is In a Strong Position to Study and Understand Electron Transport

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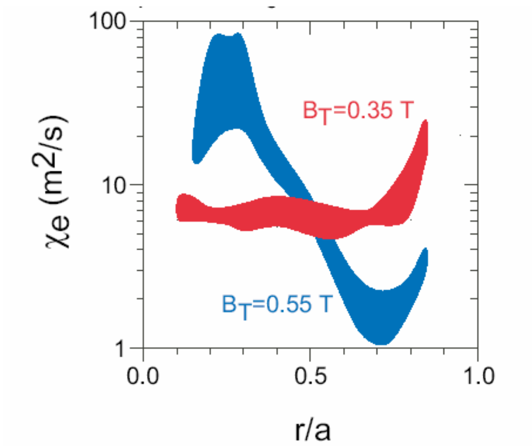
Electron transport anomalous: controls B_T scaling

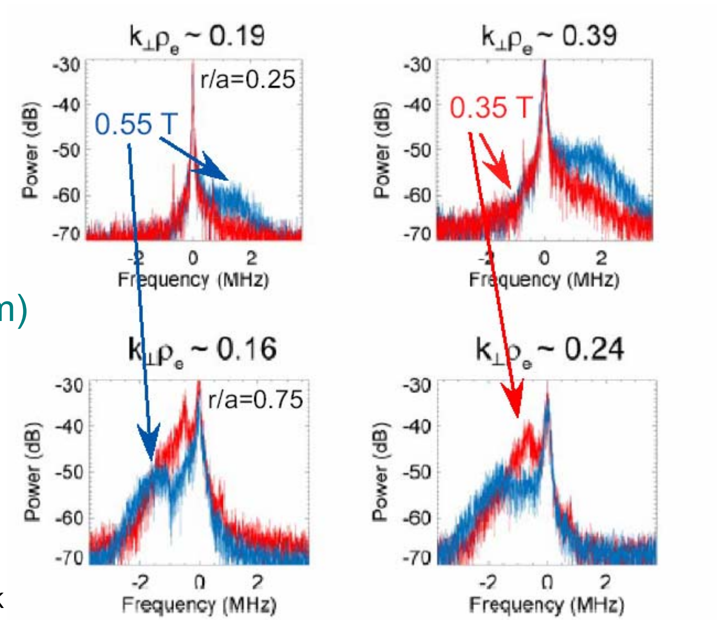


Low-k microtearing important in “Hybrid” and weak RS discharges

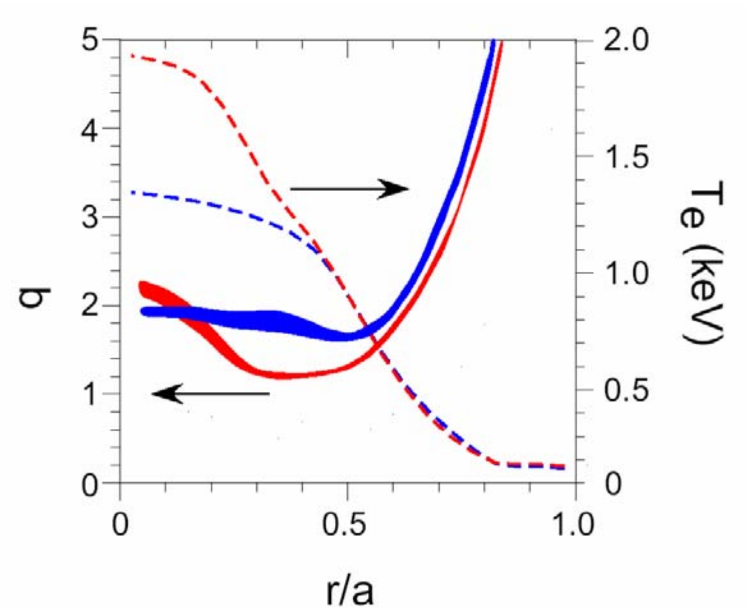
Inferred χ_ε agrees with predictions from non-linear theory

Consistent with high-k fluctuations in ETG range

(Δr=±3 cm)



Electron temperature profile & transport controlled by q-profile



Electron Transport is One of the Top Research Priorities

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- Anomalous electron transport can be "isolated" (i.e., ion transport neoclassical)

- 2008-2010
  - Investigate TEM/ETG using present high-k_r system
    - Role of collisionality, establish critical gradient using HHFW to change R/L_{Te}
    - Turbulence spreading
    - *High-k turbulence/control a collaborative opportunity for NSTX/C-MOD/DIII-D*
  - Role of reversed magnetic shear, low order rational q for eITB formation
  - Microtearing mode investigation using internal δB measurements with MSE
    - Change driving/damping(?) terms: β, ν^*, ExB shear
  - Perturbative electron transport using ELMs and pellets
    - Relation to high-k turbulence

Compare measurements to results of gyrokinetic calculations with built in synthetic diagnostics for Verification and Validation of physics models

Develop a Predictive Understanding for Optimizing Performance of Future Devices

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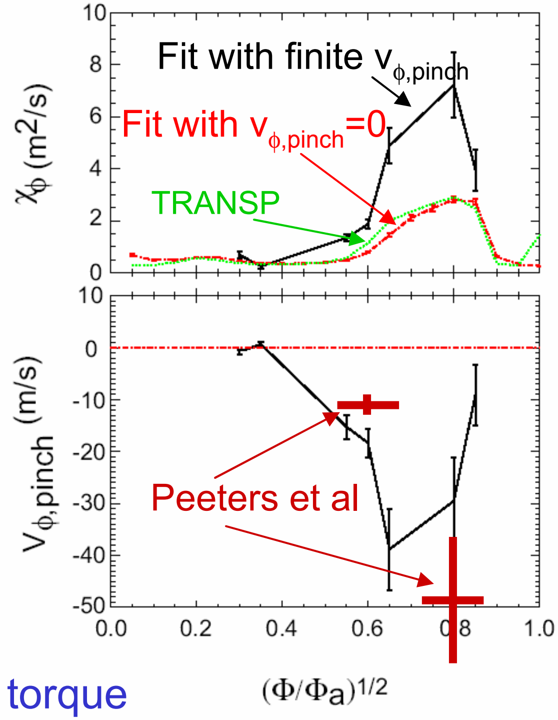
- 2010 - 2011
  - Local modification of electron transport and turbulence
    - Low power EBW (350 kW) and second NBI to modify q-profile
    - Assess turbulence spreading with low and high-k fluctuation measurements
  - Modulated EBW to probe local critical gradient physics
  - Microtearing mode investigations continue using internal δB, low-k for mode structure
  - Verify transport trends at high P_{heat}, varying input torque
- 2012 – 2013
  - Measure full range of medium-to-high k_r, k_θ turbulence
    - Mode structures, full frequency spectra, dispersion characteristics
    - Radial streamer identification
  - Localized heating with up to 1 MW EBW to probe critical gradient physics, turbulence spreading

Momentum Transport Studies Will Study High-Rotation, Relation to Energy Transport and Scaling to Future Devices

$\chi_\phi << \chi_i$, is common in NSTX, unlike at higher R/a

- Role of ITG, neoclassical transport?

Perturbative momentum transport studies using magnetic braking indicate significant inward pinch



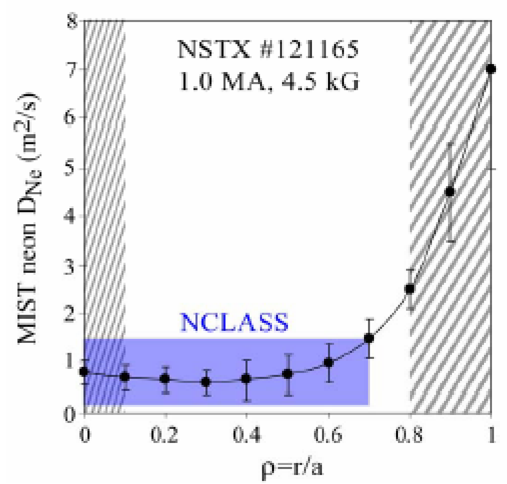
NSTX can explore momentum transport by varying input torque using both magnetic braking and NBI at various R_{tan}, energy

- 2008 – 2010
  - Validation of neoclassical theory using v_θ measurements
  - Determine v_{pinch}, χ_ϕ with varying input torque
    - Tests of inward pinch, NTV theories
    - Comparison with initial low-k
- 2011-2013
  - Relation of v_{pinch}, χ_ϕ to low-k in both L and H at various input torque
  - Zonal flows/GAMs and relation to other microinstabilities
  - Further v_{pinch}, χ_ϕ assessment with internal NCC
- 2013
  - Intrinsic rotation studies

Particle Transport Studies Will Focus on Developing a Predictive Capability

Impurity injection experiments/theoretical modeling indicate neoclassical level transport for injected Neon in H-mode

- Consistent with neoclassical ion energy transport



Understanding particle transport and achievable density profiles relates directly to the Integration goal of a non-inductively sustained, stable plasma

- 2008 - 2011
  - D & particle transport in NBI-fueling dominated core (steady-state and perturbative)
    - Relation to thermal χ, transport, core turbulence (initial low-k)
    - Density peaking
  - D & particle transport in outer region: requires extended modeling for determining S(r)
  - Impurity transport using gas puffing, TESPEL
  - Helium transport studies using He puffing or He discharges
  - Effect of Lithium plasma facing components

- 2011 – 2013
  - Determine role of low-k turbulence in controlling particle transport
  - Perturbative particle transport studies continue with second beamline

Proposed Five-Year Research Plan (2009-2013)

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