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NSTX

Turbulence & Transport Plan for FY07-09

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Draft talk for PAC-21
PPPL, Jan 17-19, 2007

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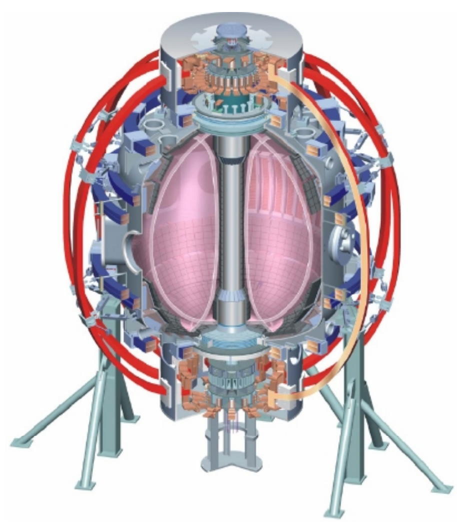

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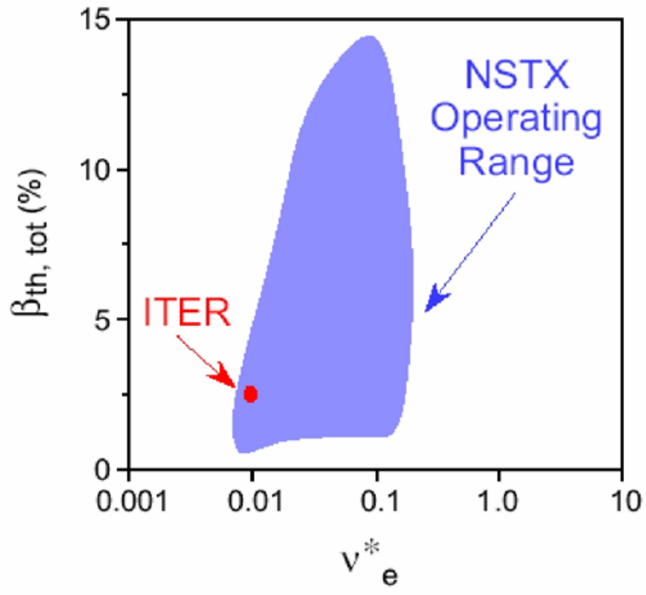
NSTX Provides Unique Opportunities to Investigate Critical Turbulence & Transport Issues

NSTX

- Operation spans turbulence regimes
  - electrostatic → electromagnetic at high-β_T
- NBI primarily heats electrons
  - analogous to α-heating, ITER relevant
- High rotation and rotational shear influences transport and turbulence stabilization, ITBs
- Excellent laboratory for electron physics studies
  - electrons anomalous
  - ions ~neoclassical



- Low B_T allows measurement of localized electron-scale turbulence
  - ρ_e ~ 0.1mm
- FY07 run will address broad range of T&T topics while focusing on measuring and understanding high-k fluctuations

Turbulence & Transport Goals for FY07 a Mixture of Focus and Breadth

Research Milestone (R07-1)

- Study variation of local high-k turbulence with plasma conditions

Other Research Goals

- Contribute to ITPA and inter-machine experiments
  - global scaling and profile databases (L, H, L→H)
- Probe local electron transport
  - high-k milestone, perturbative heat transport studies
- Momentum transport/confinement
  - prepare for JOULE Milestone FY08
- Investigate particle transport
  - relation of measured ion/impurity transport to neoclassical theory
- Extend ST scaling database
  - establish confidence for projection to future devices, e.g. CTF

New Diagnostic Tools Enhance Turbulence and Transport Studies

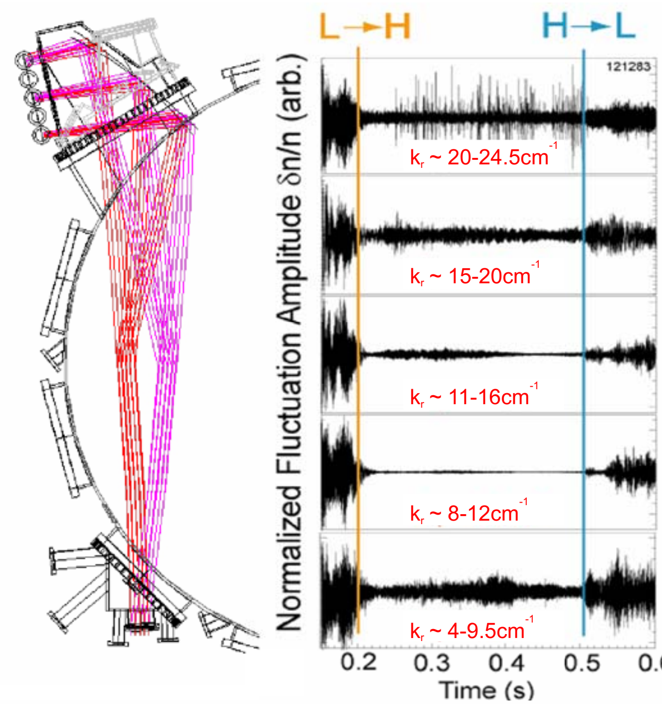
NSTX

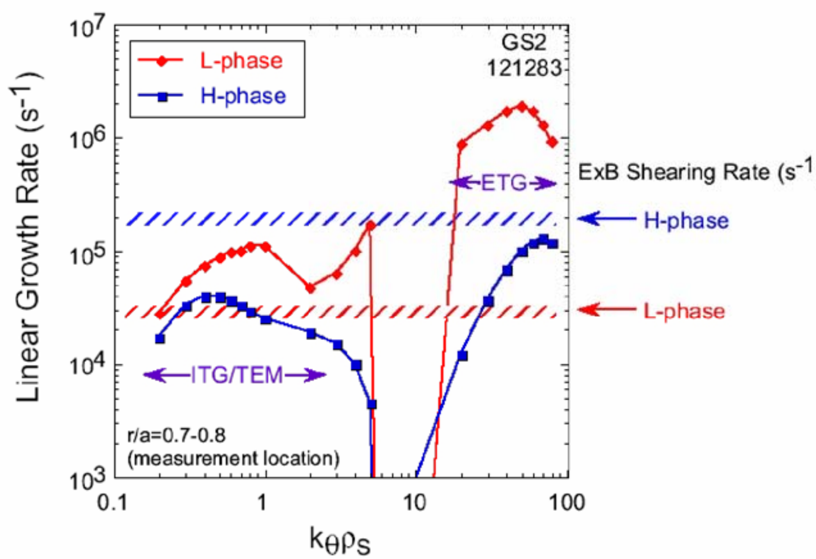
- 30 channel MPTS provides higher resolution T_e, n_e profiles
- MSE: 12 + 4 channels provides a stronger, more detailed j(r) constraint (NOVA Photonics)
- Multicolor tangential SXR system allows fast (<1ms) $T_e(r)$ reconstruction (JHU)
- Reflectometer upgrades for low-k radial/poloidal correlation measurements, backscattering for high-k measurements (UCLA)
- High-k collection mirror upgrade improves beam convergence, simplifies scanning of radial position, k_θ measurement under evaluation for FY08
- Poloidal CHERS now installed; expect analyzed data at end of run

High-k System Provided Initial Measurements of Short Wavelength Turbulence During FY06

NSTX

- Microwave scattering system measures reduced fluctuations (ñ/n) in upper ITG/TEM and ETG ranges during H-mode
- TRANSP calculations indicate reduced transport after L→H transition
  - electron transport remains anomalous
  - ions at neoclassical level
- GS2 calculations show lower linear growth rates during H-mode: ETG unstable?
- Non-linear GTC results indicate ITG modes stable during H-mode
  - consistent with χ_i ~ neoclassical





(S. Kaye, *submitted to Nucl. Fusion*)

RF-heated Plasmas Provide a Good Testbed for Electron Turbulence Theory

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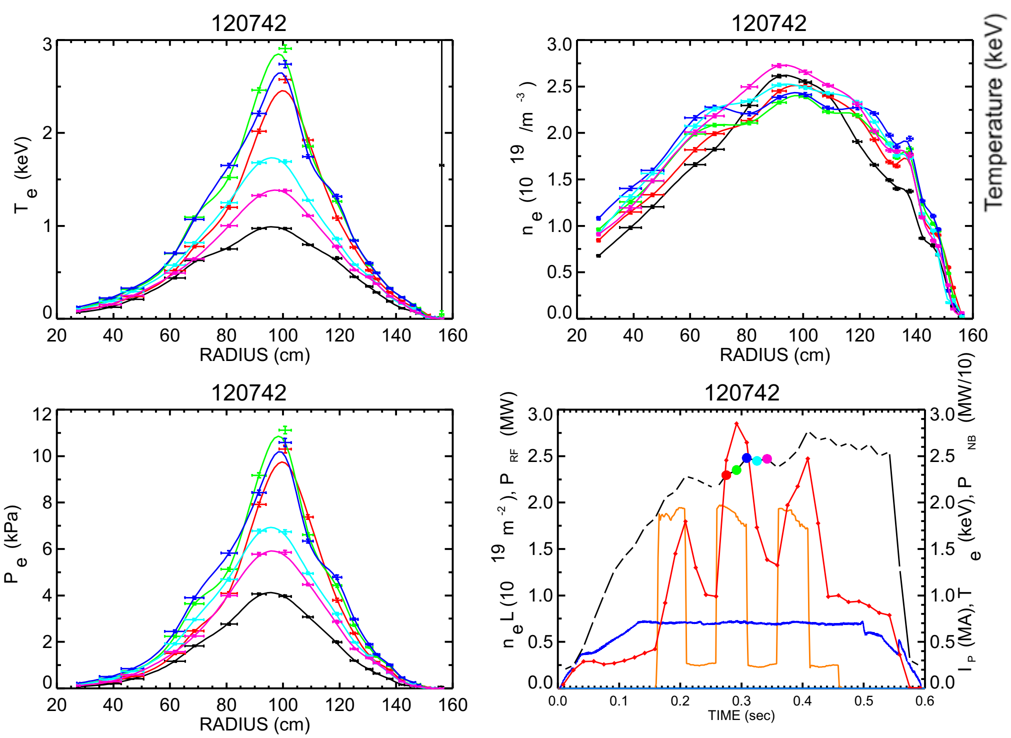
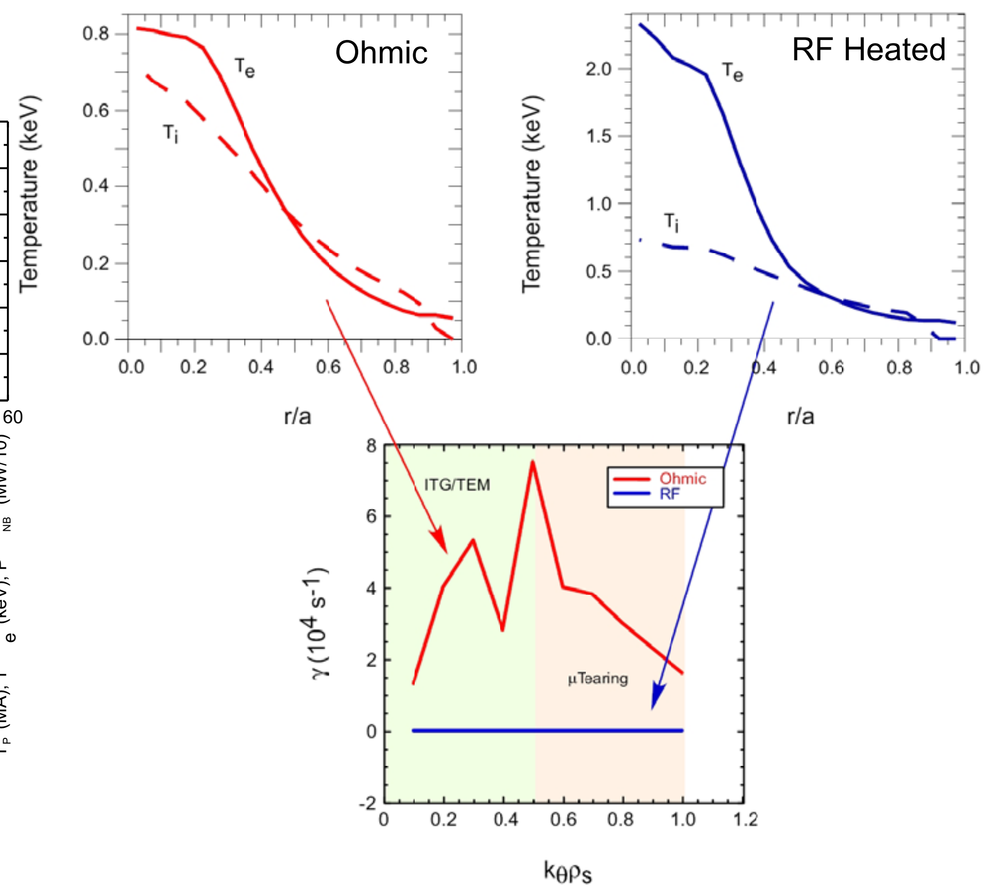
- Linear GS2 results indicate difference in high-k stability between ohmic and RF heated plasmas

- High-k measurements will study variation in turbulence fluctuation levels as function of T_e/T_i ratio (FY07 milestone)





What Causes Improved Confinement in Reversed Magnetic Shear Plasmas?

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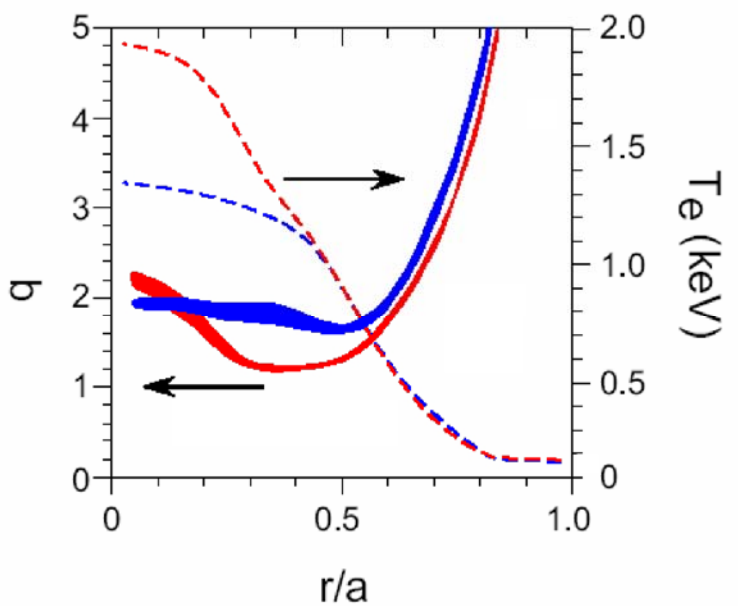
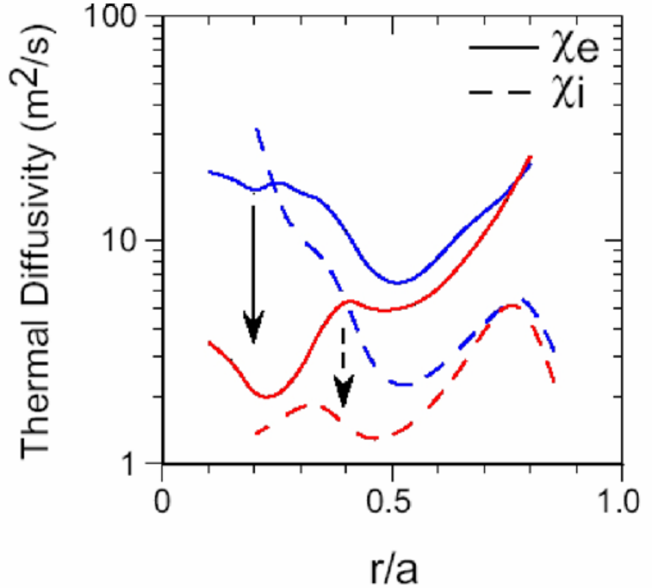
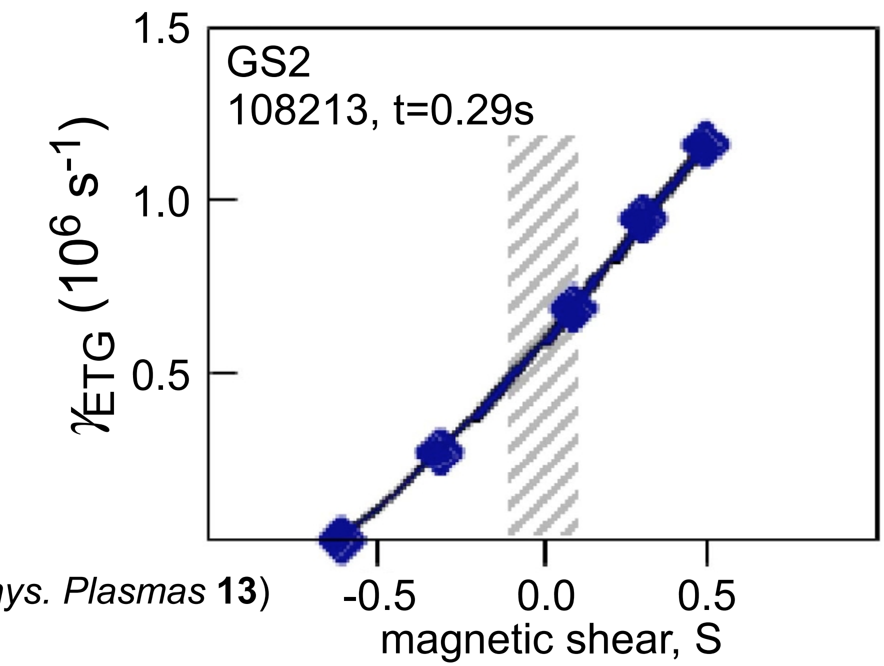




- Strong reverse shear L-mode achieves higher ∇T_e and lower χ_e, χ_i
- Linear GS2 calculations indicate both high & low-k modes need to be considered
  - ETG stabilization for S < -0.5
  - μTearing (low-k) may be important
  - non-linear gyro calculations underway
- PAC 19-3: scan magnetic shear, high-k will measure TEM/ETG, low-k detects μTearing



(D. Stutman, *Phys. Plasmas* **13**)

NSTX Addresses High-Priority ITPA Tasks and Joint Machine Experiments

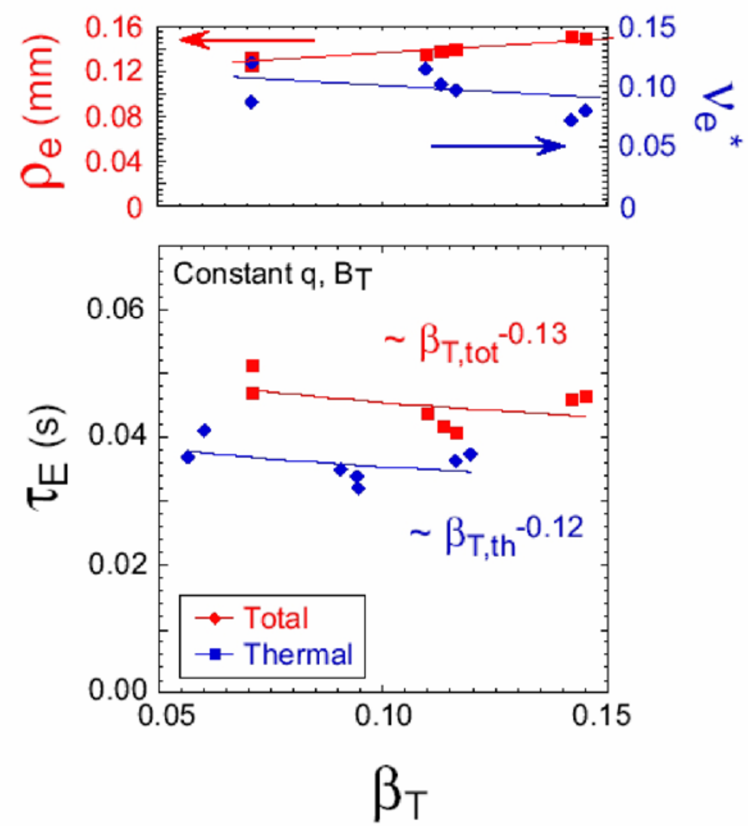
(S. Kaye, *submitted to Nucl. Fusion*)

- β scaling important to ITER (advanced) scenarios: $B\tau_{98y2} \sim \beta^{-0.9}$

- Confinement shows weak β_T scaling in strongly shaped NSTX plasmas
  - $\tau_e \sim \beta^{-0.1}$, $\kappa = 2.1$, $\delta = 0.6$

- Result consistent with DIII-D and JET

- ASDEX-U and JT60-U show strong confinement degradation with β_T (plasmas with weaker shaping)

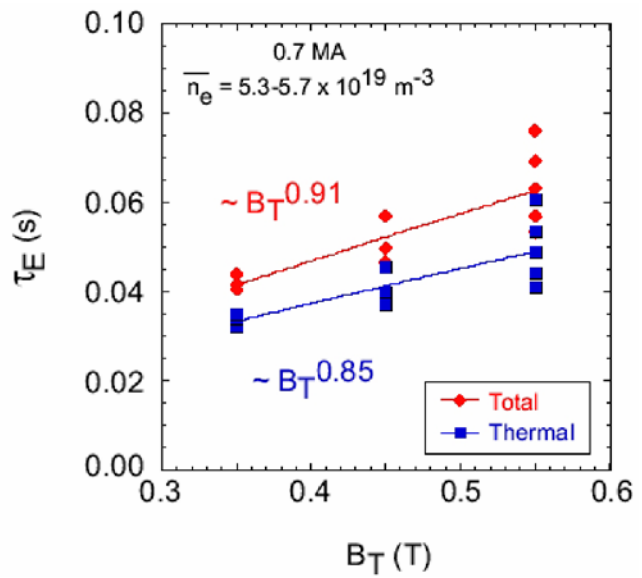


- NSTX will assess β_T scaling in <u>weakly</u> shaped plasmas (ITPA CDB-2)

- Will participate in joint machine experiments with DIII-D/MAST to determine aspect ratio dependence of confinement (ITPA CDB-6)

Strong B_T Scaling Driven by Variation of Electron Thermal Transport

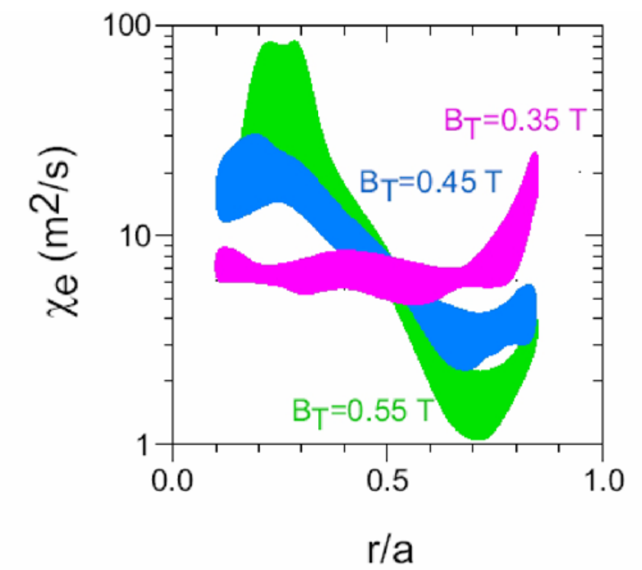
NSTX

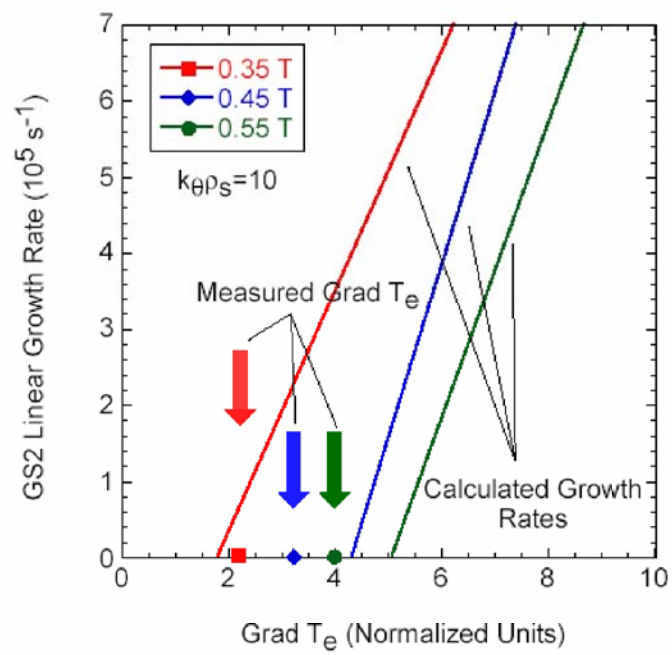


- T_e profile broadens, χ_e reduced for r/a > 0.5 with increasing B_T
  - ions remain ~neoclassical

- GS2 linear calculations indicate ETG unstable at 0.35 T, stable at 0.45, 0.55 T
  - BT=0.35T: R/L_{Te} 20% above critical gradient
  - BT=0.45, 0.55T: R/L_{Te} 20-30% below critical gradient

(S. Kaye, *submitted to Nucl. Fusion*)



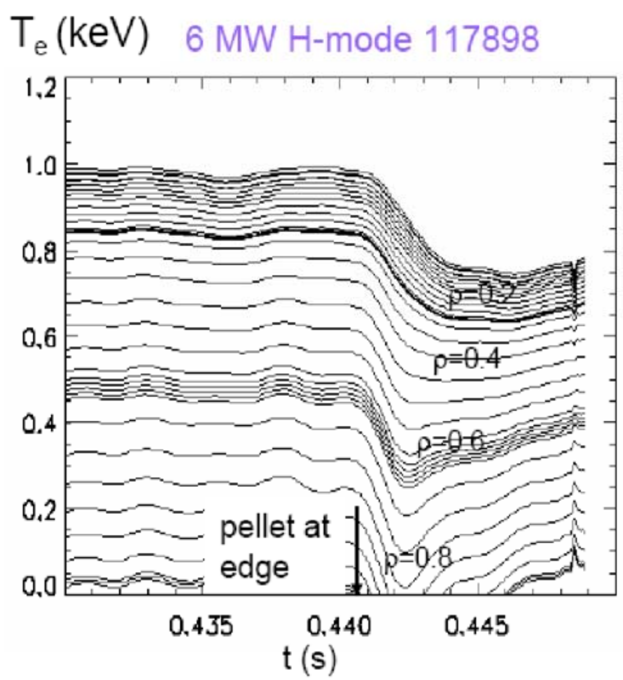


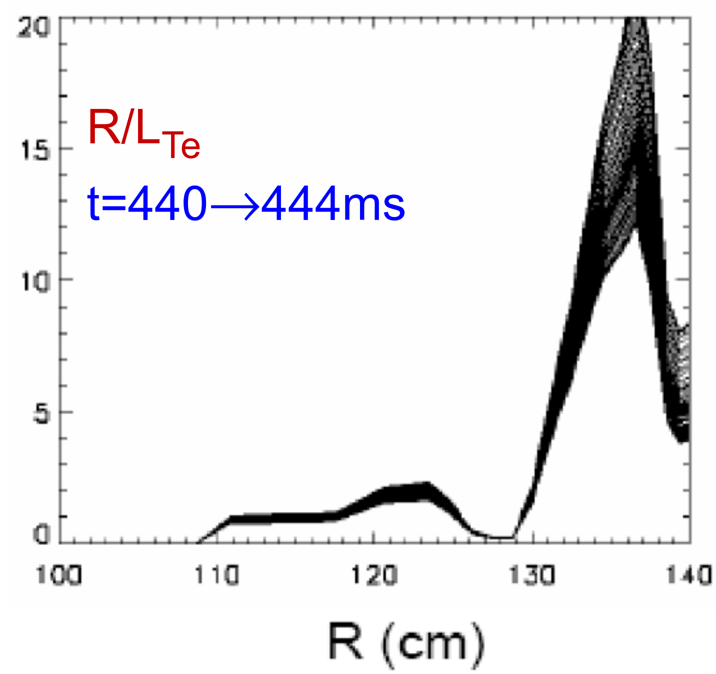
Perturbative Transport Experiments using Pellet Injection Support R/L_{Te} Near Critical Gradient

NSTX

- Soft X-ray system resolves fast T_e perturbation

- Pellets injected into high power H-mode, B_T = 0.45T
  - exhibits stiff profile behavior
  - suggests T_e profile close to marginal stability
  - injection into reversed shear L-mode show profiles not stiff





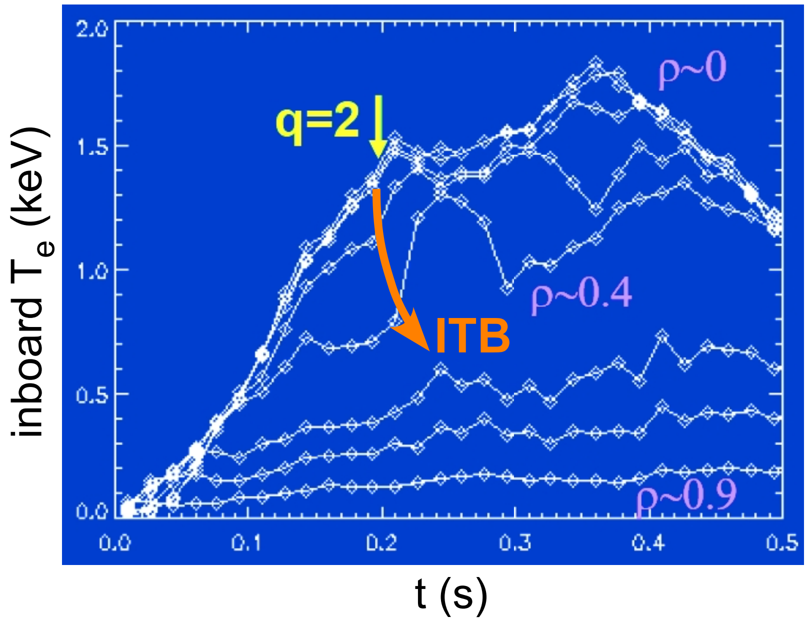
- PAC 19-3: Role of reverse shear on profile stiffness, comparisons to R/L_{TE}

Heat Flux Transport Studies Indicate Potential Role of Rational Surfaces on Electron Confinement

NSTX

- H-mode plasmas with different q profiles show large difference in χ_e for r/a < 0.7
  - verified with pellet injection perturbation measurements
- Plasma parameters roughly comparable
  - low-χ_e plasma has q=2 at large r/a, location of reduced transport
- Effect observed on T_e profile in L-mode upon entry of q=2 rational surface
  - ITB formation, radial propagation
- Similar to ITBs seen in DIII-D L-mode
  - reduced low, mid-k fluctuations
- Plan to validate effect in H-mode
  - smaller NSTX ρ*, (ITPA TP-8.2)
  - measure zonal flows with Doppler reflectometry

2 MW L-mode (112989)



n=3 Braking Coils Allow Momentum Transport and Confinement Experiments

NSTX

- NBI driven momentum transport
  - NSTX/DIII-D joint experiment, (ITPA TP-6.3)

- Plasma rotation can be controlled through n=3 magnetic braking
  - measure profile recovery from perturbation
  - assess effect of rotation on momentum and energy confinement

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- Poloidal CHERS diagnostic operational for FY07 run
  - FY08 milestone: measure poloidal rotation at low-A and comparison to theory

- FY07 diagnostics and momentum experiments provide groundwork for FY08 JOULE milestone: rotation and momentum transport physics

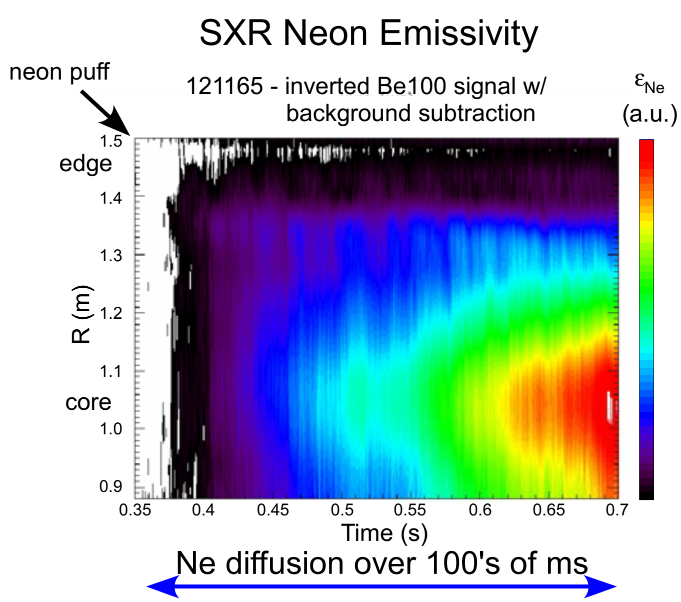
Particle Transport Experiments will Investigate Ion/Impurity Confinement

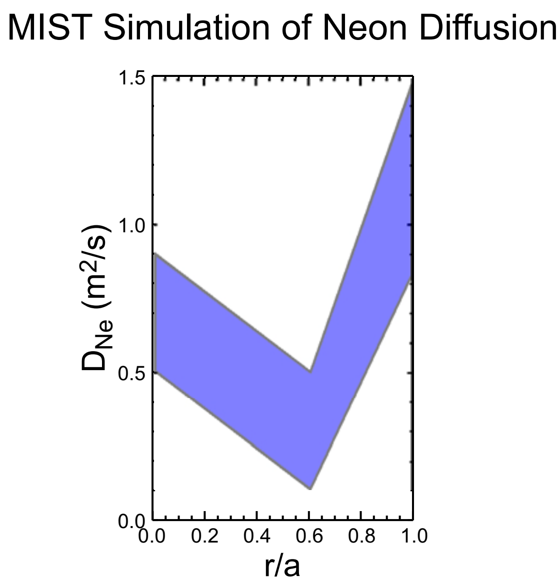
NSTX

- H-mode impurity seeding with neon gas puffing
  - MIST calculations indicate ~neoclassical transport
  - consistent with previous L-mode work

- Argon, CD4 puffing will verify Z-scaling

- n=3 magnetic braking will investigate rotational effects on particle transport





- PAC 19-5: Advance understanding of particle transport and control

Maturing Analysis Tools used to Guide Experimental Planning and Analysis

NSTX

- TRANSP analysis mature
  - free boundary, predictive TRANSP under development
    - incorporate TEQ (LLNL) for equilibrium calculations
    - incorporate TGLF (GA), when ready, for transport calculations

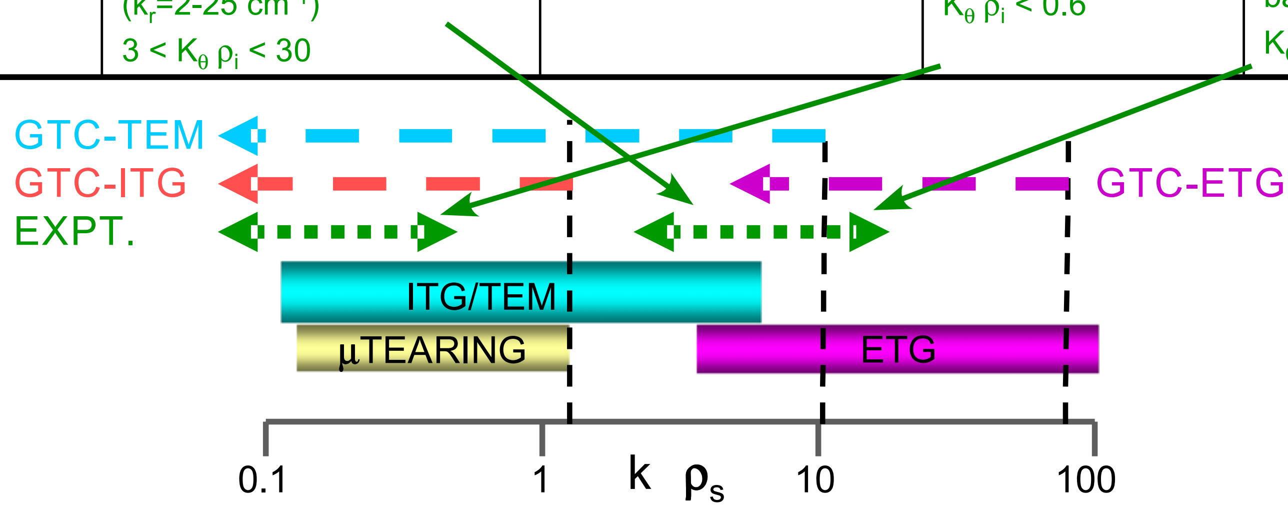
- Gyrokinetic codes used for analysis
  - GS2 (flux tube, linear and non-linear)
  - GTC (global, non-linear)
  - GEM (global, non-linear, collaboration with U. Colorado)
  - GYRO (global, linear and non-linear, collaboration with G.A.)
    - presently assessing low→high-k in reverse shear plasmas

- Other collaborations
  - IFS, U. Texas (Horton, Kim)
  - Max Planck-Garching (Jenko)
  - U. Saskatchewan (Joiner)

Plan to Compare Experimental Observations and Theory Predictions of Turbulence Fluctuations

NSTX

		Jan	Feb	March	April
GTC	ITG $K_\perp \rho_i < 1.5$	K_r-spectrum diagnostic in code (1/20)	Application		Sherwood
	ETG $K_\perp \rho_i < 80$	Particle decomposition and transition to XT-3	Application(2/20)		Sherwood
	ITG/TEM	Code development	Benchmarking and convergence studies	Application(3/1)	Sherwood
GEM	ITG/TEM Tearing/KBM	Convergence tests with numerical profiles	Include ion flow	Applications	Sherwood
	ETG	Improve ion response	Implement TRANSP interface(2/20)	Applications(3/20)	
EXPT.		Microwave Scattering (k_r=2-25 cm^{-1}) $3 < K_\theta \rho_i < 30$		Low-k reflectometry $K_\theta \rho_i < 0.6$	High-k backscattering $K_\theta \rho_i < 30$



FY07 T&T Experimental Program Addresses Milestone and Broad Physics Issues

NSTX

- R07-1 Study variation of local high-k turbulence with plasma conditions
  - RF-heated/reverse shear plasmas good testbeds for theory
  - additional high-k measurements in H-mode plasmas

- ITPA/Joint machine experiments leverage low-A NSTX contributions
  - address high-priority ITPA tasks
  - extend to low-A to test theory
  - establish basis for scaling to CTF

- Local transport experiments explore thermal and particle transport
  - correlate local electron transport with high-k measurements
  - test relation of neoclassical theory to measured ion/impurity transport

- Rotation and momentum confinement/transport studies
  - poloidal CHERS will acquire data, ready for FY08 milestone
  - momentum transport experiments, preparation for JOULE milestone

- Analysis codes continue to improve, benchmark with diagnostics

Experiments for FY07 Address Milestone and Turbulence and Transport Goals

NSTX

Priority 1

	Milestone	ITER/ ITPA	ST Physics
• Study of high-k turbulence in RF heated plasmas	✓		
• Effects of reverse shear on electron confinement	✓		✓
• Joint machine momentum transport using braking		✓	✓
• Confinement vs. A study for future ST optimization			✓
• Confinement vs. beta in weakly shaped plasmas		✓	✓
• Role of rational q surfaces in electron transport		✓	✓

Priority 2

	Milestone	ITER/ ITPA	ST Physics
• Relationship between ELMs and electron transport			✓
• NBI driven momentum transport/ion power balance		✓	✓
• DIII-D/NSTX study on energy/momentum confinement		✓	
• Investigation of magnetic electron transport on NSTX			✓
• Z-scaling of impurity transport			✓
• B_T scaling of core high-k fluctuations	✓		
• Spontaneous rotation with no external torque		✓	

Projected Turbulence and Transport Plans and Goals for FY08-FY09

NSTX

- Confinement and transport dependencies
  - develop understanding of role of q(r) and μ–instability driving terms
  - complete aspect ratio dependence and toroidicity scaling similarity experiments with DIII-D/MAST

- Role of rotation, E_r
  - establish momentum flux dependencies and controlling physics
  - understand/exploit relation between E_r shear and reduced transport
  - study zonal flows

- Role of low- and high-k turbulence
  - relate changes in turbulence to changes in transport over range of operating conditions
  - integrate measurements from turbulence diagnostics for comprehensive picture across full wavenumber spectrum

- Theoretical basis for transport and heating
  - test role of ITG, ETG, ... by varying drive and stabilization terms
  - continue comparisons to gyrokinetic theory over range of transport regimes: linear and non-linear calculations
  - develop predictive capabilities