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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

Sept 17, 2007

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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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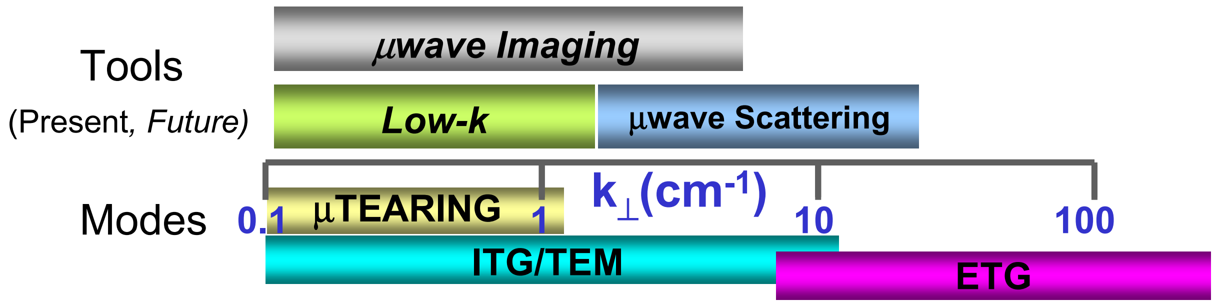
Facility and diagnostic <u>upgrades</u> will aid achieving T&T goals

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)

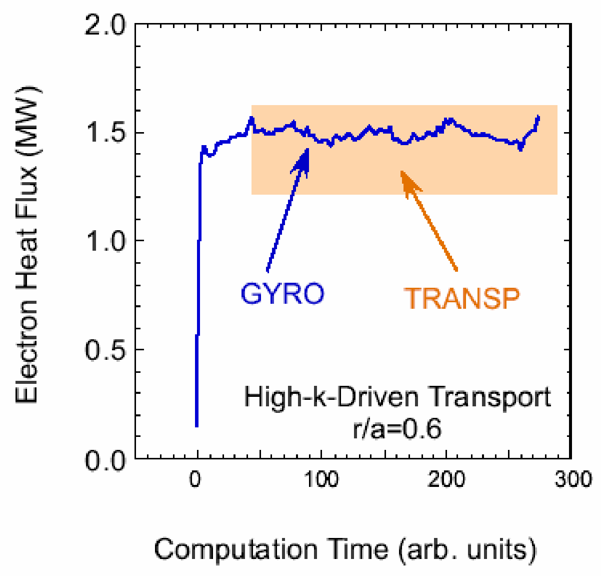
Full complement of turbulence measurements will cover a wide k-range



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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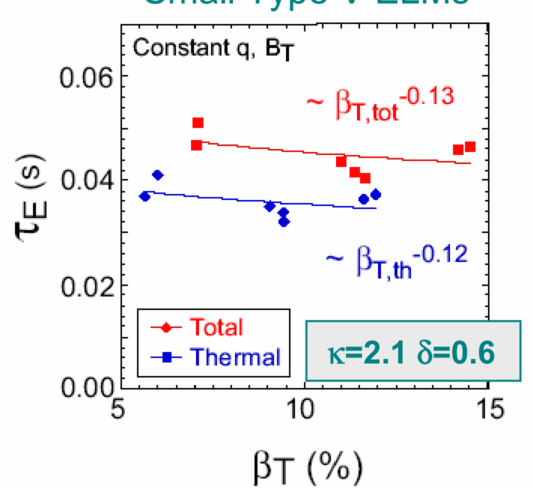
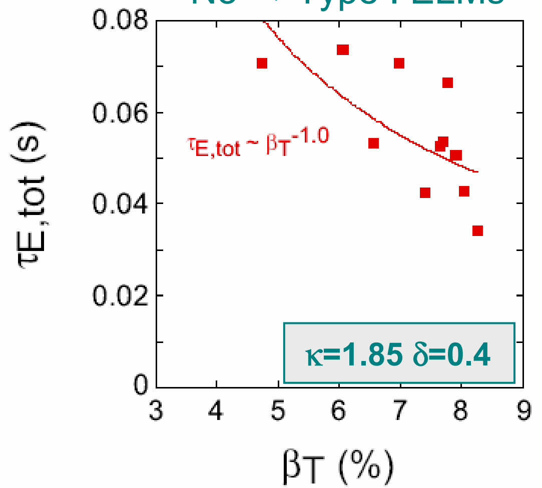
- L-H threshold power
  - Apparent I_p dependence, L-H easier with high-field-side fueling
  - Triangularity, X-point height, configuration important
- Global confinement dependences differ from those at higher aspect ratio
  - $\tau_E \sim B_T^{0.9} \leftrightarrow \tau_E^{98y,2} \sim B_T^{0.15}$; $\tau_E \sim I_p^{0.4} \leftrightarrow \tau_E^{98y,2} \sim I_p^{0.9}$
- 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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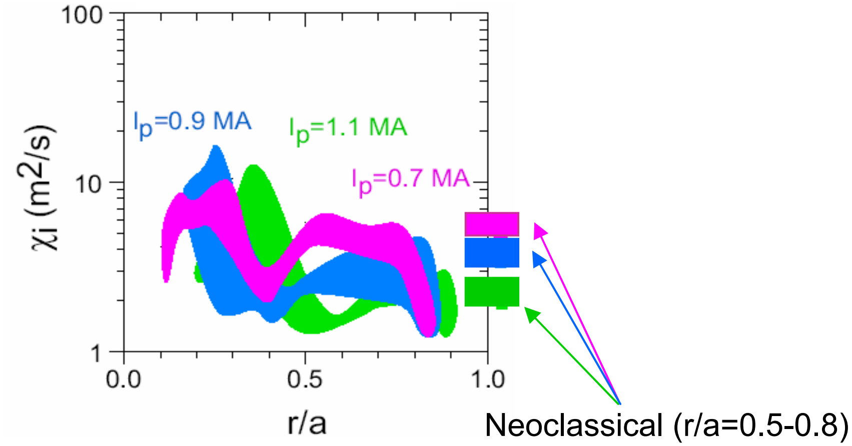
Most global confinement studies have given way to local transport studies, but some important research opportunities remain

- 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

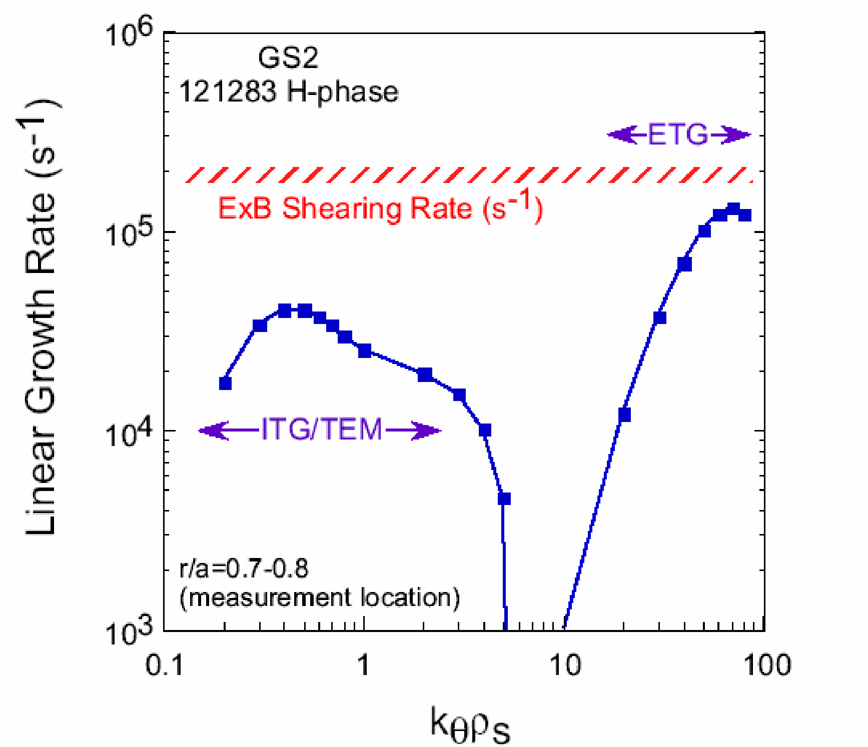


Neoclassical levels determined from GTC-Neo: includes finite banana width effects (non-local)

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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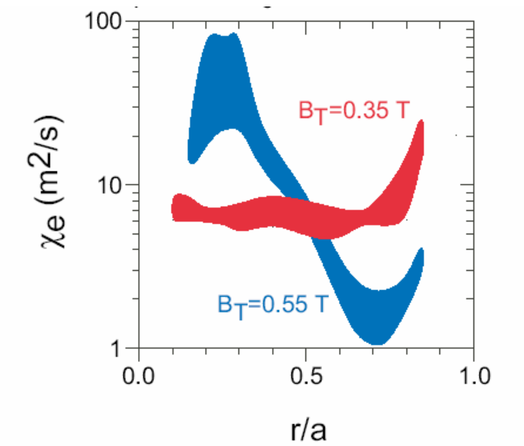
Electron transport anomalous: controls B_T scaling

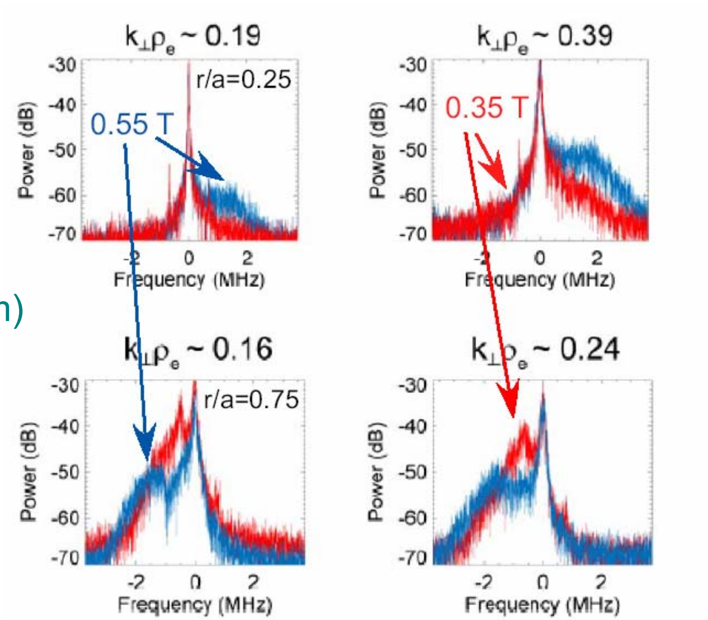


Low-k microtearing important in “Hybrid” and weak RS discharges

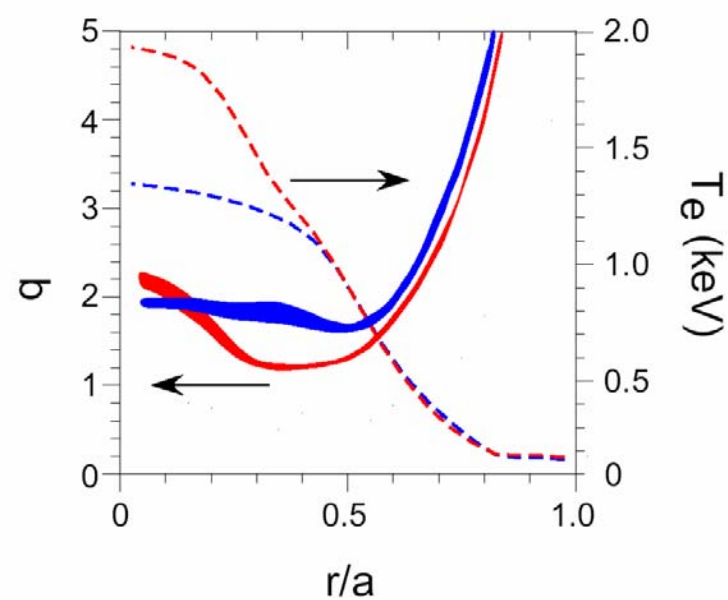
Inferred χ_ε agrees with predictions from non-linear theory

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

NSTX

- 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

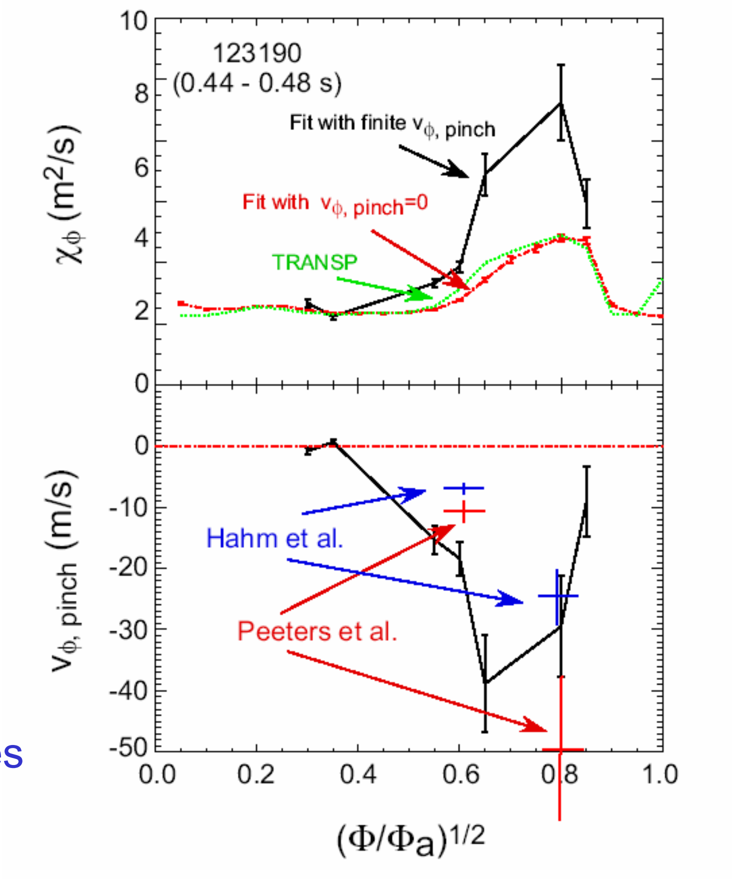
$\chi_\phi << \chi_i$, is common in NSTX, unlike at higher R/a

- Role of ITG, neoclassical transport?

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 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

Perturbative momentum transport studies using magnetic braking indicate significant inward pinch



Particle Transport Studies Will Focus on Developing a Predictive Capability

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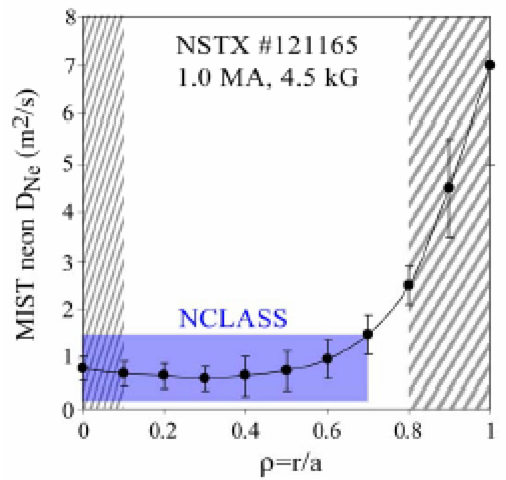
Impurity injection experiments/theoretical modeling indicate neoclassical level transport for injected Neon in H-mode

- Consistent with neoclassical ion energy transport



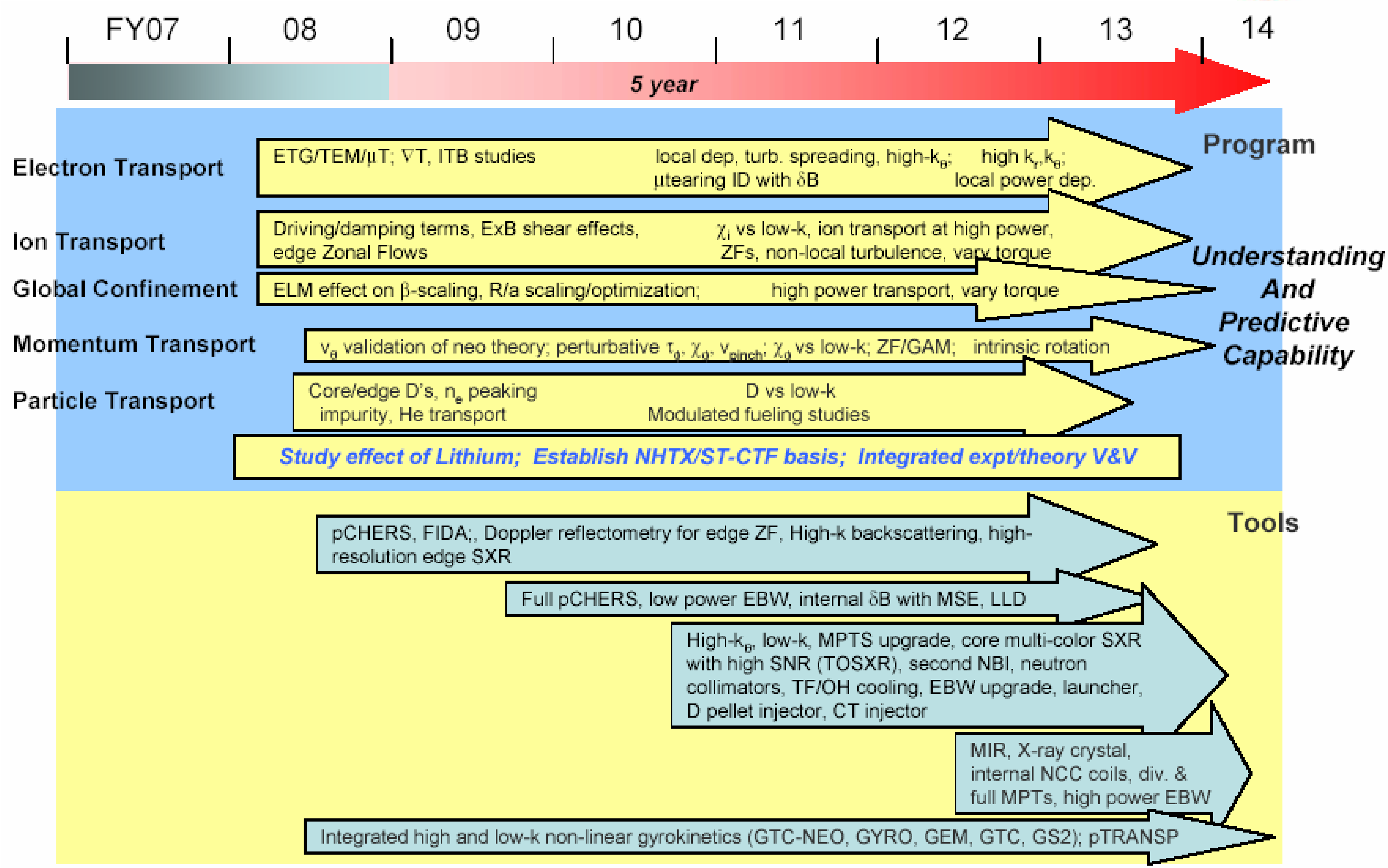
Understanding particle transport and achievable density profiles relates directly to the Integration goal of a non-inductively sustained, stable plasma

- 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)

NSTX



Backup Vugraphs

Theory Tool Development

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- 2D/3D state-of-art neutrals package for transport studies (TRANSP)
- Full FLR effects for complete non-local neoclassical transport
- Gyro-kinetic codes
  - GS2 (flux tube)
  - GYRO
  - GTC (kinetic electrons, finite-β, multi-ion species)
  - GEM (low-k microtearing, kinetic electrons for ETG)
  - Synthetic diagnostics for V & V
  - High + Low k non-linear calculations numerically expensive: is scale-separation possible when ITG suppressed, or is turbulence spreading important?
- Predictive tools
  - pTRANSP for scenario development
  - Low R/a relevant transport model (TGLF?)