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Transport and Turbulence

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For the NSTX National Team

DOE Review of
NSTX Five-Year Research Program Proposal
June 30 – July 2, 2003

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Outline

- Experimental studies
  - Major accomplishments and observations
  - Core transport (global, ions, electrons, momentum, particle/impurity, fast ions)
  - Edge transport and fluctuations
- Theory and modeling
- Research plan elements
  - Facility and diagnostic upgrades

Major Transport Accomplishments and Observations

- Global confinement enhanced over values given by conventional R/a scalings

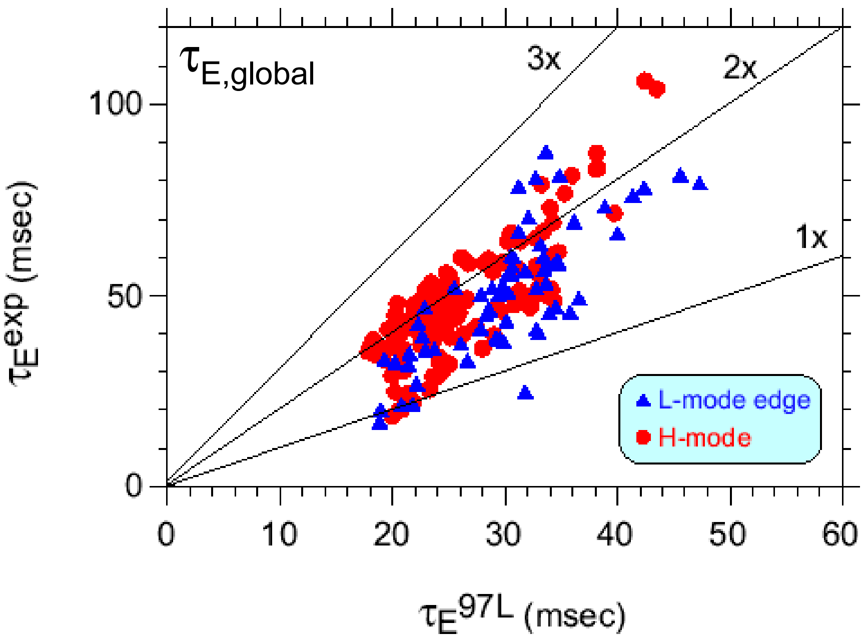
- Ion transport low
  - Near neoclassical
  - Consistent with impurity injection results
  - Gyrokinetic codes indicate ITG/TEM modes suppressed in NBI discharges

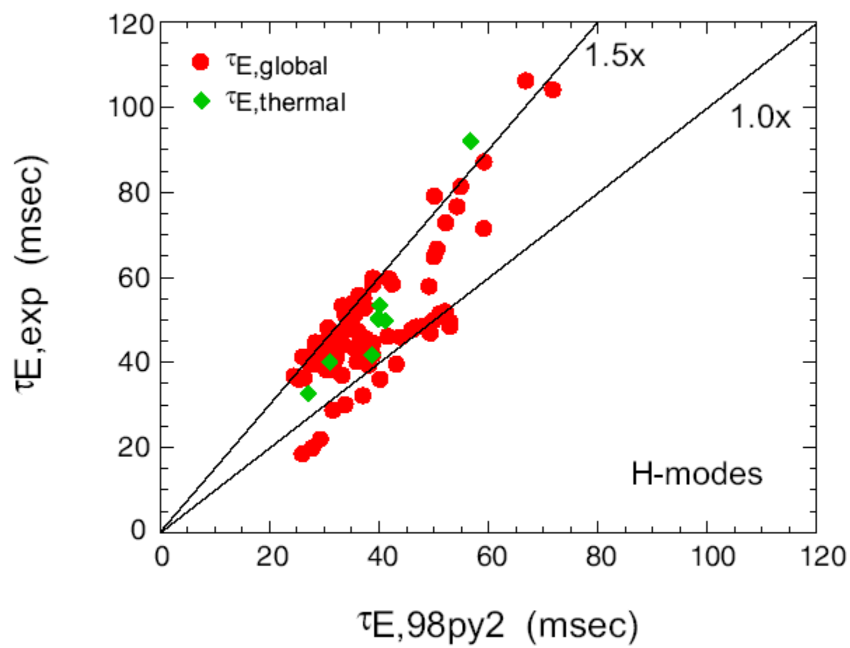
- Electron transport dominates
  - e^- confinement can be improved – ITBs
  - Unique opportunity to study short-λ modes and e^- transport without presence of long-λ modes

- Unique class of fast ion collective modes that may affect transport
  - Source for stochastic ion heating?

- Convective transport at edge may be significant

Global Confinement Exceeds Predictions from Conventional Aspect Ratio Scalings

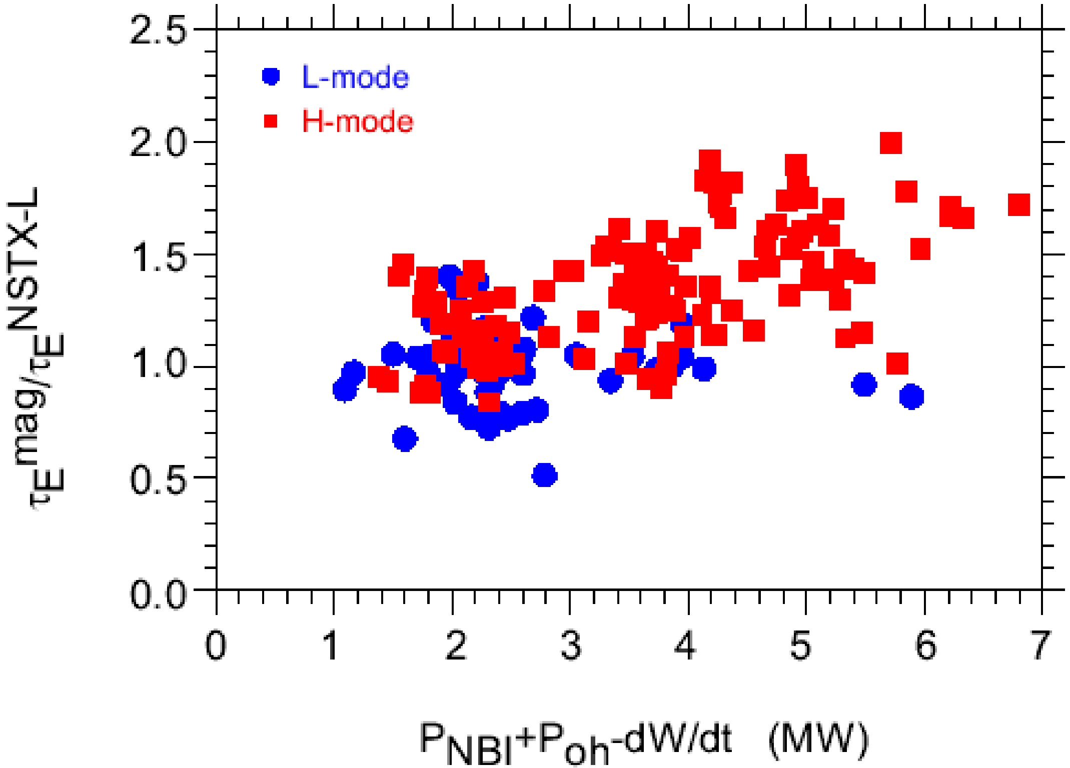




- Quasi-steady conditions
- $\tau_{E,global}$ from EFIT magnetics reconstruction
  - Includes fast ion component
- $\tau_{E,thermal}$ determined from TRANSP runs

NSTX NBI L-modes Exhibit Similar Parametric Scaling as Conventional Aspect Ratio Devices

$\tau_E^{NSTX\text{-}L} \sim I_p^{0.76}\, B_T^{0.27}\, P_L^{-0.76}$



More accurate determination of R/a dependence needed!

- ITPA topic of research

Less severe power degradation in H-mode $\tau_E \sim P^{-0.50}$

- Dedicated parametric scans needed

Global Scalings Are Manifestations of the Underlying Transport Physics

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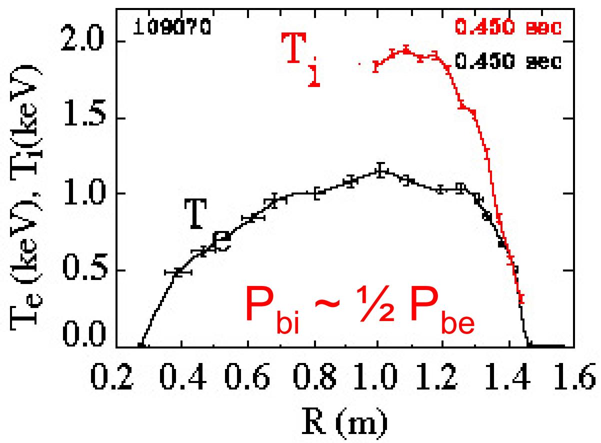
Plans

- Establish parametric dependencies on engineering variables (FY04)
  - H-mode
  - RF vs NBI
  - Submit additional data to ITPA confinement database
- Perform dimensionless scalings [β_t, ρ^*, R/a] (FY05)
- Establish role of rotation, E_r, q(r) on τ_E (FY06)

Tools

- Collaborative studies
  - Similarity experiments with DIII-D, MAST
- Rotation control and diagnosis
  - Error field correction coils
  - Edge spectroscopy, CHERS, Poloidal CHERS
  - MSE

$T_i > T_e$ during NBI Indicates Good Ion Confinement

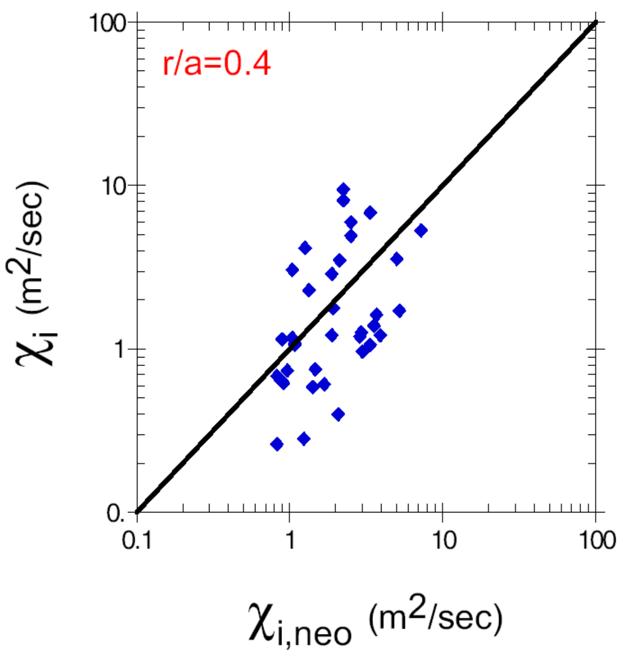


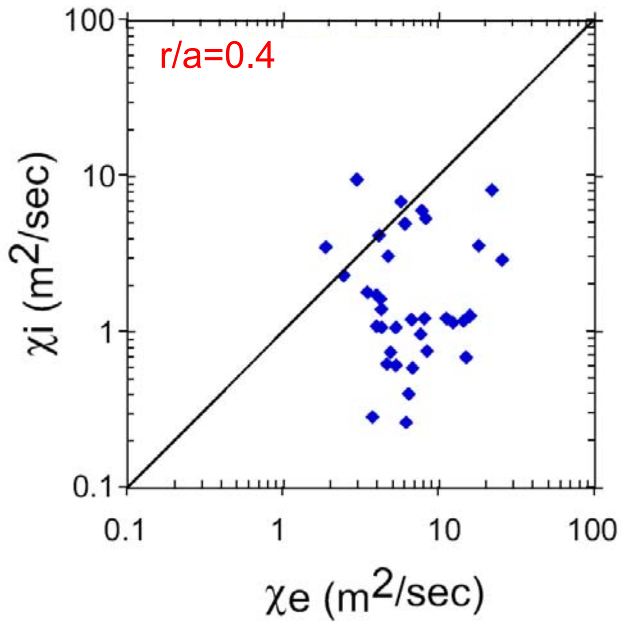
ITG suppressed (GK calculations)

- Electrons dominate transport loss

Regions of $\chi_i < 0$ now limited to edge

- Additional atomic physics in data reduction
- Other effects (e.g., high f_t leading to in-out asymmetry) being assessed





Assess Role of Long-λ Turbulence on Ion Transport

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Plans

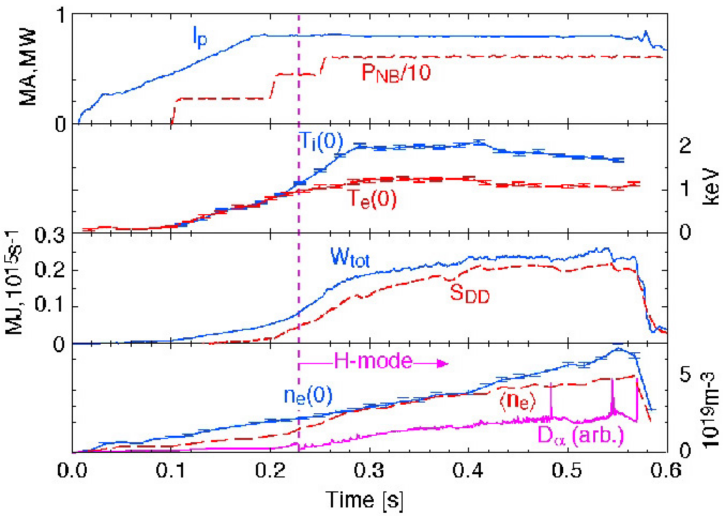
- Establish baseline of ion heat fluxes, χ_i
  - Test role of ITG by varying key parameters [T_i/T_e, $n_e(r)$, ω_{ExB}] (FY04)
  - Establish effect of rotational shear on transport (FY04-05)
  - Isolate neoclassical pinch terms (FY05)
  - Relate transport fluxes to changes in $q(r)$, E_r, η_i, β' (FY05-06)
- Relation of transport to long-λ fluctuations (FY06)
- Experiment/gyrokinetic theory comparisons (ongoing)
  - Develop predictive capability

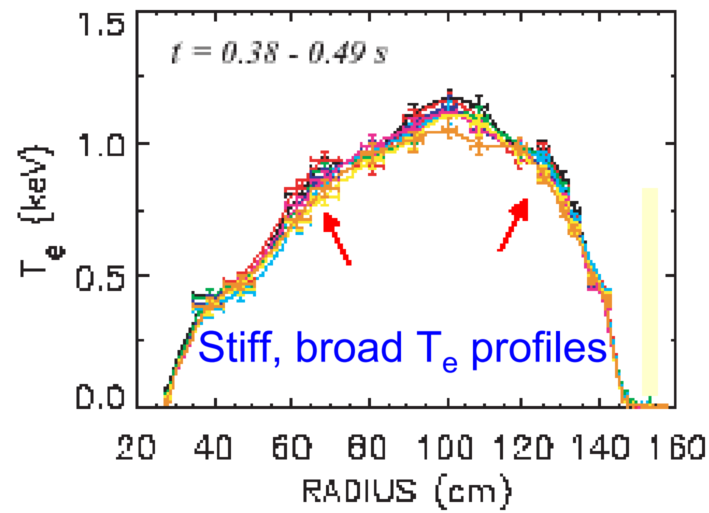
Tools

- Rotation control and diagnosis
  - Error field correction coil
  - Co- vs counter-injection
  - RF vs NBI
  - Edge spectroscopy, CHERS, poloidal CHERS, fast edge spectroscopy
- Profile control and diagnosis
  - RF vs NBI
  - Deuterium pellet injector
  - MSE
- Fluctuations
  - Microwave imaging reflectometry

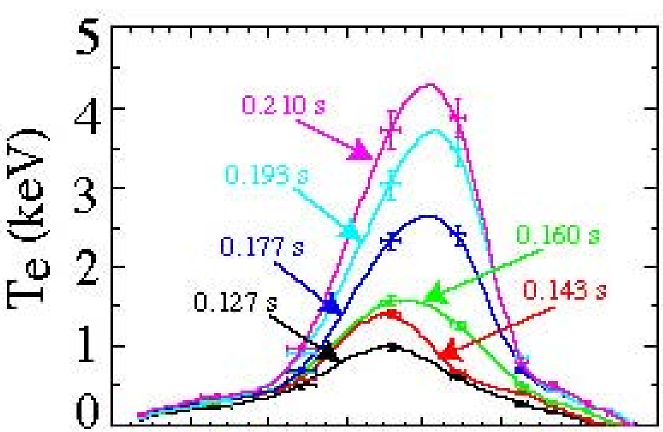
Electrons Are Primary Loss Channel In NBI Due To ITG/TEM Suppression

Relation of $T_e(r)$ to critical gradient physics?

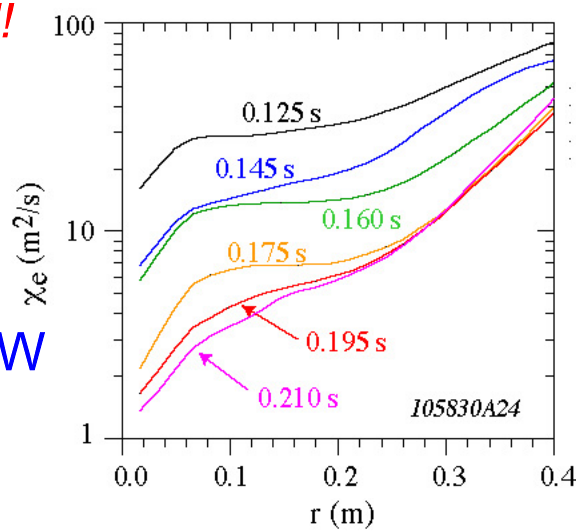




e⁻ confinement can be improved!



ITB w/ HHFW



NSTX Provides Unique Opportunities to Study Electron Transport

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Plans

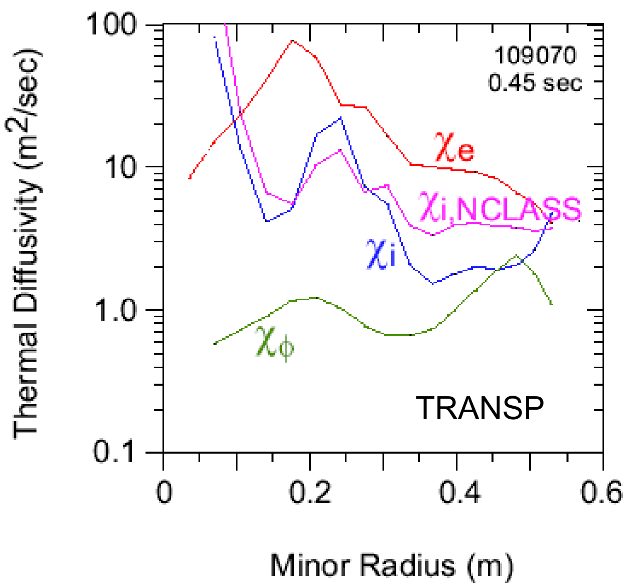
- Improve electron transport
  - Develop reliable methods to generate ITBs (FY04)
- Assess role of ETGs/Establish link to critical gradient physics
  - Vary T_i/T_e, η_e, β' (FY04-06)
  - Effect of flow shear (FY05-06)
- Relation of transport to short-λ fluctuations (FY05-06)
  - ETG modes are measurable
- Experiment/gyrokinetic theory comparisons (ongoing)

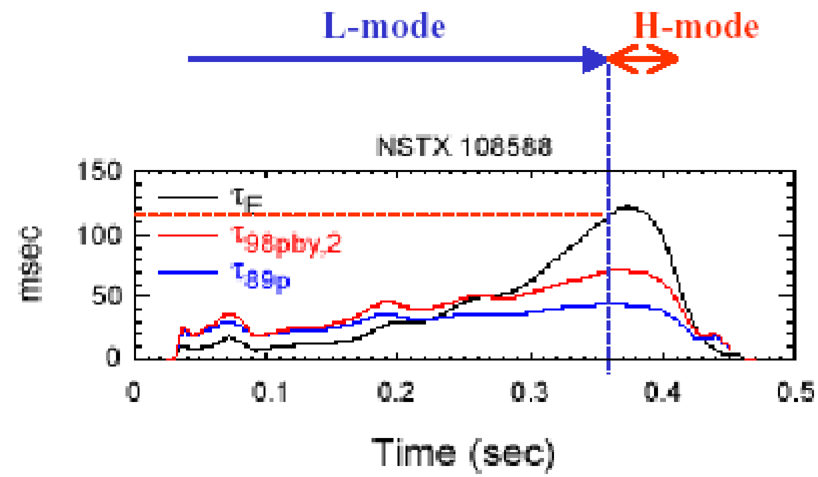
Tools

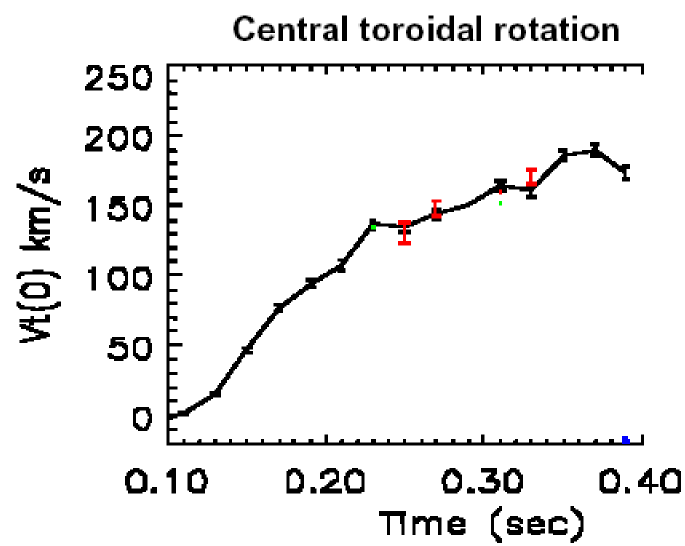
- Profile control and diagnosis
  - NBI vs RF (HHFW/EBW, CW/Modulated)
  - Deuterium pellet injector
  - MSE
  - MPTS upgrade
- Rotation control and diagnosis
  - Error field correction coil
  - RF vs NBI, Co- vs counter-injection
  - Edge spectroscopy, CHERS, poloidal CHERS, fast edge spectroscopy
- Fluctuations
  - High spatial resolution microwave scattering

Momentum Fluxes Reflect Underlying Transport Physics

- Inferred momentum transport low ($\chi_\phi < \chi_i \leq \chi_{neo}$) – consistent with ITG/TEM suppression







- Temporal increase of τ_E associated with temporal increase of rotation (causality?)

Study Momentum Transport to Understand Processes Controlling Heat Transport

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Plans

- Establish momentum flux dependencies and controlling physics
  - Vary input torques (FY04)
  - Extensive experiment/gyrokinetic, neoclassical theory comparisons (ongoing)
- Use flow/flow shear to control transport
  - ITBs (FY04-05)
  - L-H transitions (FY04-05)
  - Understand rotation/confinement causality (FY06-08)
- Study zonal flows (FY07-08)

Tools

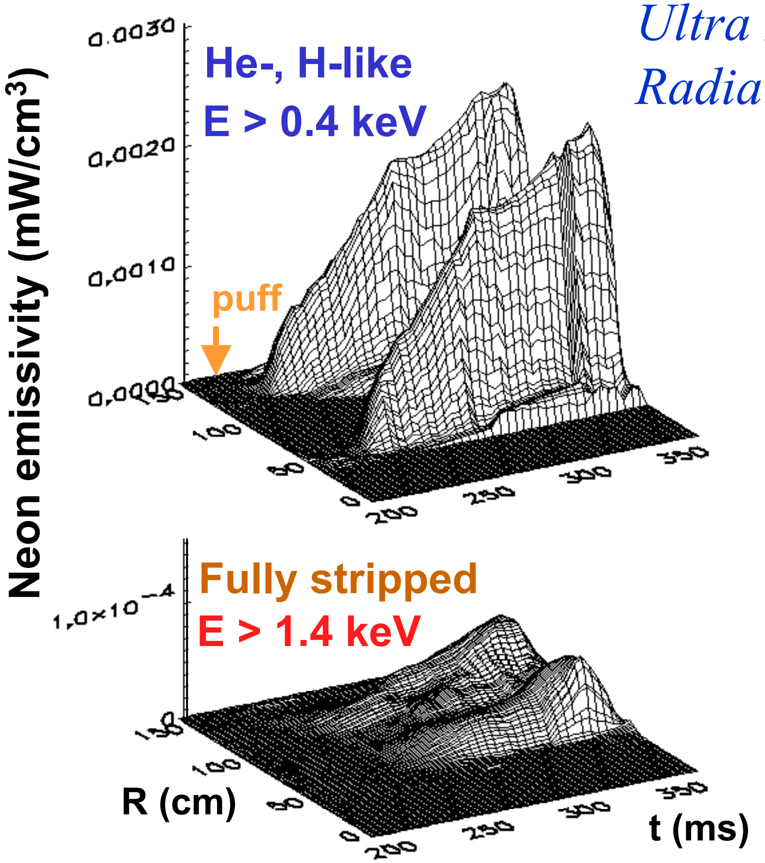
- Rotation control and diagnosis
  - Error field correction coil
  - RF vs NBI
  - Co- vs counter-injection
  - MSE
  - Edge spectroscopy, CHERS, poloidal CHERS, fast edge spectroscopy

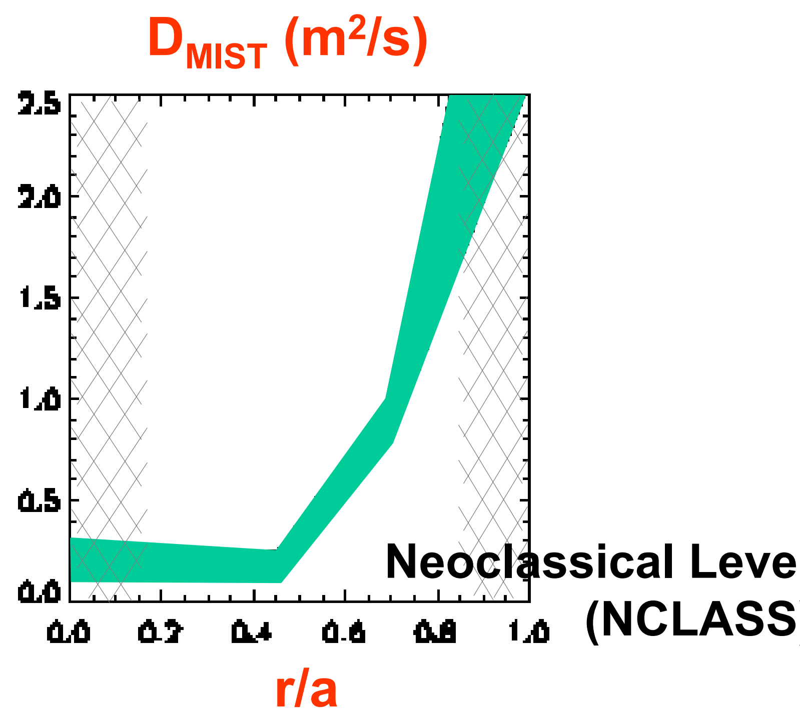
Impurity Transport Near Neoclassical in Core

Neon injection experiments

Impurity transport modeling

Ultra Soft X-ray Radiation





Establish Relation Between Impurity/Particle Transport and Heat Transport

<u>Plans</u>

- Perturbative and non-perturbative impurity transport exp'ts (FY04)
- Perturbative particle transport studies (FY05-06)

<u>Tools</u>

- Regular and supersonic gas injectors
- Li/B pellet injector
- Deuterium pellet injector
- USXR, Transmission grating spectrometer, PIXCS X-ray camera

Fast Ion Confinement and Collective Effects are Fundamental Issues for Next Step Devices (including ITER)

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Results

- Decay of neutrons consistent with classical slowing down
- Loss rate measurements disagree with modeling (trend and magnitude)
  - Developing a more detailed, diagnostic-localized model

Plans

- Establish overall confinement trends (FY04)
- Study transient effect of non-ambipolar losses on transport barrier formation (FY04-05)
- Use beam-target neutrons as probes for power deposition profile (FY05-06)

Tools

- Co vs counter-injection
- Fast particle diagnostics
  - FLIP
  - Neutron collimators
  - Solid-state particle detectors
- MSE
- Full orbit and guiding center codes

Understand Edge Transport and Relation to Core

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Results

- L-H threshold conditions differ from those at conventional R/a
- Convective-cell ("blob") transport significant
- Fluctuation radial correlation lengths related to τ_E

Plans

- Study role of E_r on L-H transitions (FY04-05)
- Assess low and high-k turbulence (FY04-06)
  - Radial correlation lengths
  - Convective-cells
- Active modification of edge transport to change core transport (FY04-08)

Tools

- Edge characterization
  - GPI, reflectometry, scattering
  - MPTS upgrade
  - MSE
  - Fast edge spectroscopy, He beam spectroscopy
- Edge control techniques
  - Co vs counter-injection
  - SOL biasing via CHI
  - CT injection
  - Li coating
  - Cryopump

NSTX Operating Space Challenges Theory Frameworks

ST Features

- Near unity β in core
- Large f_t, ρ_i/L, ρ_{fast}/a
- Large ω_{ExB}, $v_{fast}/v_{Alfvén}$

Tools

- Core transport
  - NCLASS, GTC-NEO neoclassical
  - Gyrokinetic codes (GS2, GYRO, GTC) and FULL
  - TRANSP in predictive mode (GLF23, Multi-mode, NCLASS)
- Edge transport (diffusive and non-diffusive models)
  - BAL
  - BOUT
  - UEDGE
  - DEGAS2

Extensive Benchmarking with Experiment Will Lead to Further Theory Development

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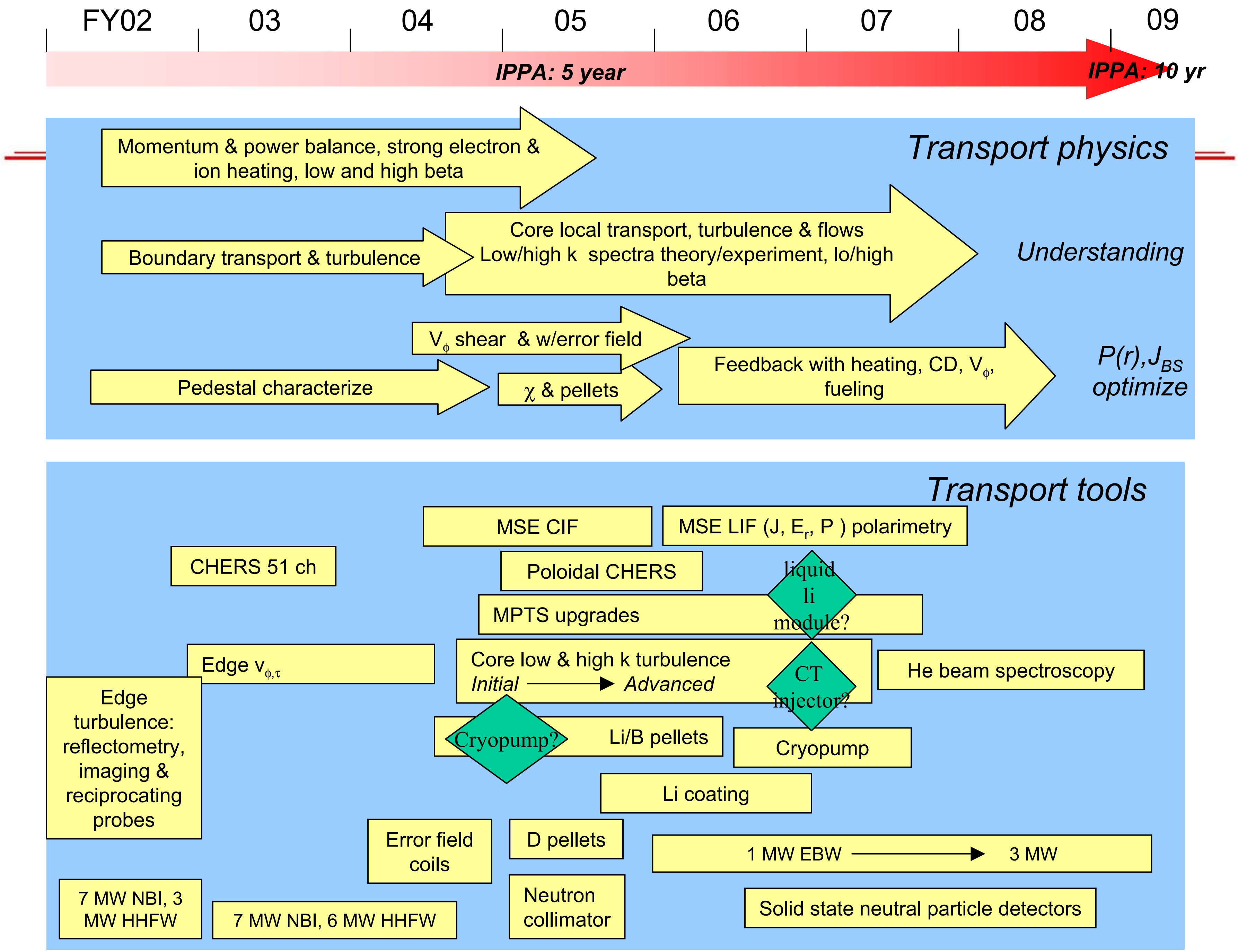
Plans

- Adapt neoclassical theory to ST parameter regime
  - Beam-thermal ion friction particle and heat pinches (FY03-04)
  - Large ρ/L: ST + ITB at conventional R/a (FY03-04)
  - Exp'tl tests of neoclassical theory if ITG/TEM suppressed (FY05)

- Extension of gyrokinetic turbulence-induced transport theory
  - Large ρ^*, β_T, f_t, shaping effects, e^- dynamics (FY04-05)
  - Non-linear calculations (FY04-05)
  - Incorporate non-local effects (FY05-06)
  - Comparison of measured/predicted turbulence levels (FY04-08)

- Develop stochastic heating models (FY05-07)

- Develop high-confidence predictive capability
  - χ's from empirical models (FY04)
  - χ's from gyrokinetic turbulence, neoclassical models (FY04)
  - Full heating scenarios (FY06-07)
  - Combine with MHD stability (FY7-08)



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NSTX Transport Goals Geared Towards Determining the Attractiveness of the ST and Contributing to Toroidal Transport Physics

- Establish key τ_E and transport dependencies
  - e^- vs i^+ transport, dependence on ρ^*, β_T, ω_{ExB}
- Assess roles of low- and high-k turbulence in transport and heating
- Assess fast ion confinement
  - Influence on neoclassical, turbulent transport and heating
- Determine influence of E_r (ω_{ExB}) on turbulence, L-H
- Establish theoretical basis for transport/heating in ST
  - Extensive theory/experiment benchmarking

Use knowledge gained to control plasma transport

Produce p(r), j(r), for optimal high τ_E, β_T, non-inductive current