Transport and Turbulence Five Year Plan

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Five Year Planning Workshop
PPPL, Princeton Univ.
12-13 Dec. 2002

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

- Establish key τ_E and transport scalings
  - e^- vs i^+ transport, dependence on ρ^*, β_T, ω_{ExB}
- Assess roles of low- and high-k turbulence in heating and transport
- Assess fast ion confinement
  - Influence on neoclassical, turbulent heating and transport
- Determine influence of E_r (ω_{ExB}) on turbulence, L-H

Use knowledge gained to control plasma transport

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

Transport Goals are Related to IPPA Goals

- Five year goal (IPPA 3.1.1)
  - Advance the scientific understanding of turbulent transport, forming the basis for a reliable predictive capability in externally controlled systems
- Ten year goal
  - Develop fully integrated capability for predicting the performance of externally controlled systems including turbulent transport, macroscopic stability, wave particle physics and multi-phase interfaces

Three-Pronged Approach to Achieving the Transport Goals in FY03-08

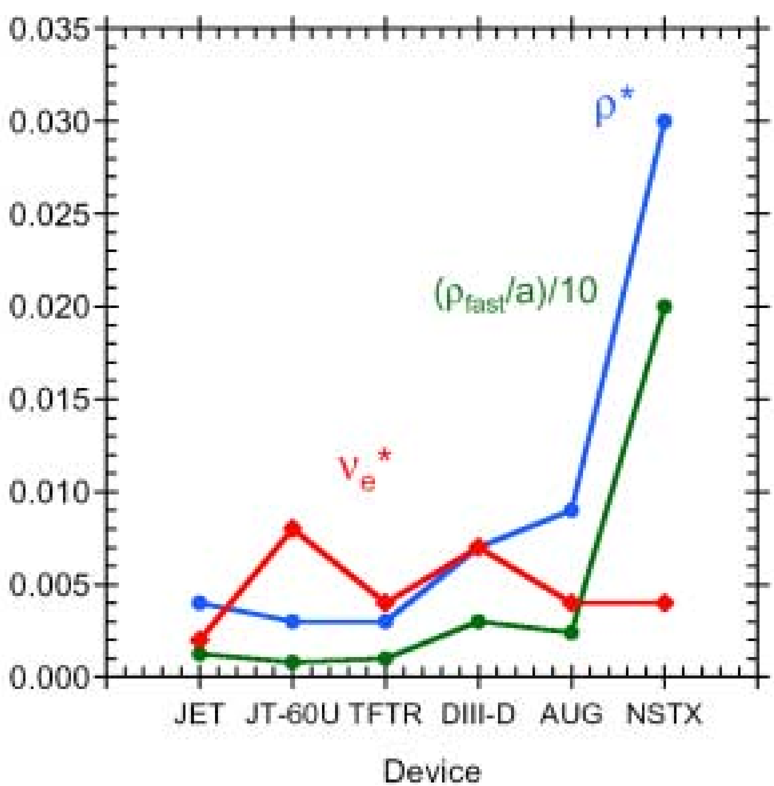
- FY03-08 experimental research plan
  - Detailed experiment/theory comparison
  - Develop and extend profile and turbulence diagnostics
    - Electrostatic, electromagnetic instabilities
    - Plasma response
- Continued development of theoretical and numerical tools
  - Understand fundamental transport physics
  - Develop predictive capability
- Contrast and compare ST with conventional R/a devices (e.g., ITPA)

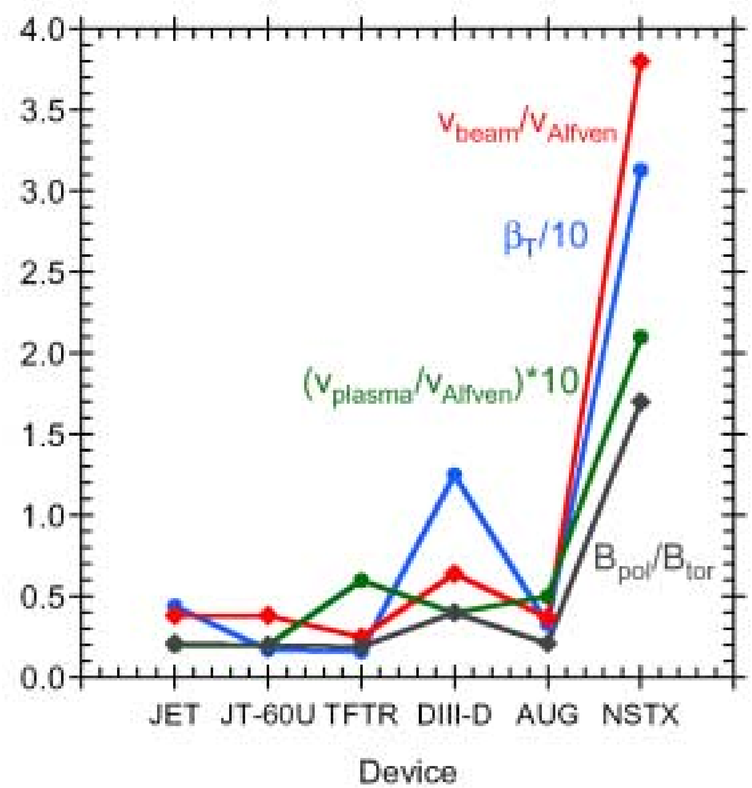
NSTX Offers Unique Opportunities

Low $B_T \rightarrow$ Large gyro-scale lengths, high β_T

Low R/a $\rightarrow$ Large field line pitch on LFS

Relatively high beam energy $\rightarrow$ High relative velocity





NSTX Parameters Challenge Existing Theory Framework

ST Features/Theory Issues

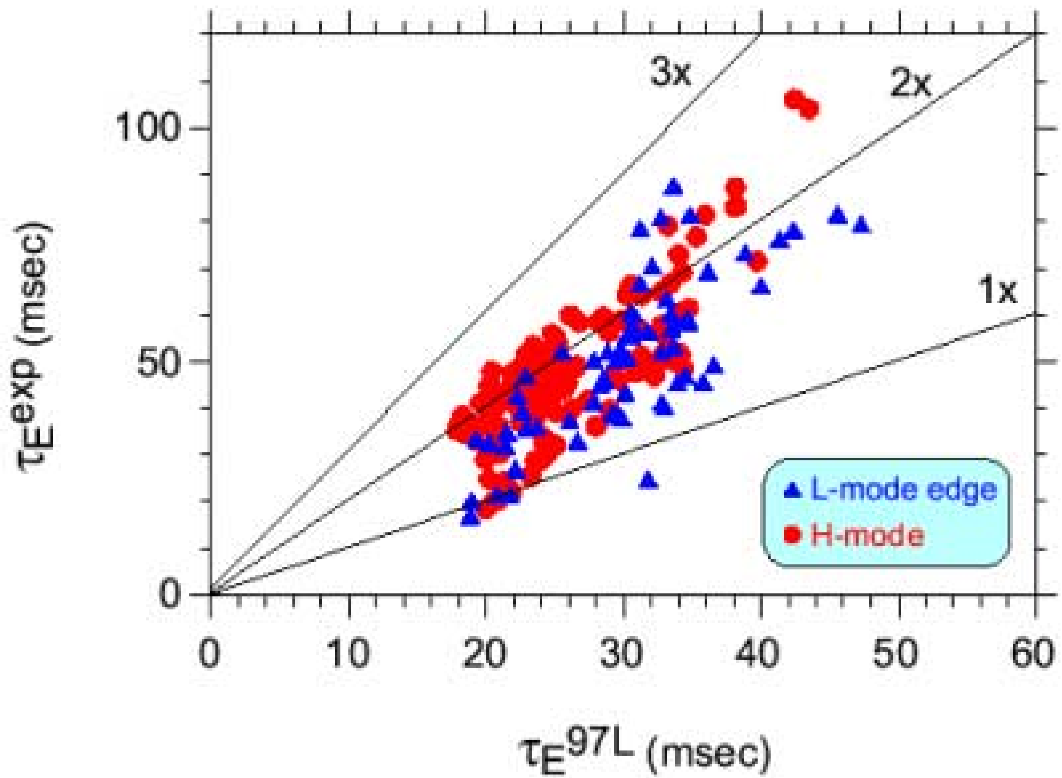
- Local $\beta_t \rightarrow 1$ (75% achieved experimentally in core)
  - Electromagnetic effects
- Trapped particle fraction → 1
  - Validity of fluid treatment of electrons
- $\rho_i/L\sim0.2$ (near edge); $\rho_i\sim1$ to 3 cm
  - Validity of spatial scale length ordering
- High ∇B, ExB flow (>200 km/sec) → flow shear (10^5 to 10^6/sec)
  - Effect on microstability and turbulence characteristics
  - Dominant (?) role of electron transport
- V_{fast}/v_{Alfven} ~3 to 4
  - Fast ion driven instabilities (TAE, CAE/GAE)
- $\rho_{fast}/a\sim1/5-1/3$
  - Fast ion confinement, non-adiabatic behavior

Validity of present gyrokinetic treatment

Outline

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

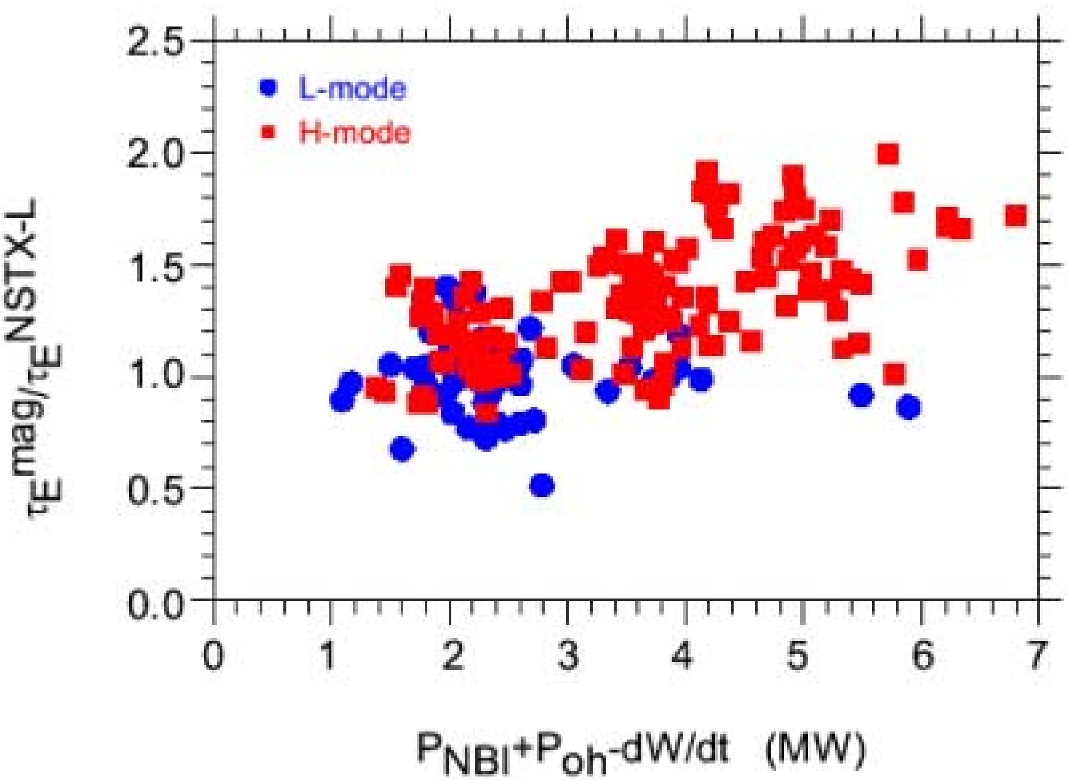
Global Confinement Exceeds Predictions from Conventional Aspect Ratio Scalings



- τ_E^{exp} from EFIT magnetics reconstruction
  - Includes fast ion component
- Quasi-steady conditions

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!

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

- MHD vs confinement limit?

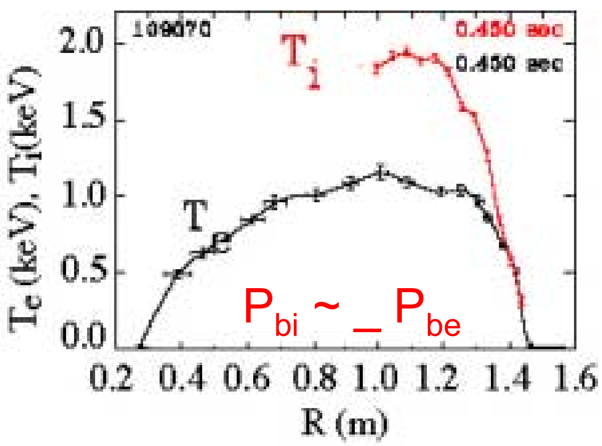
Different parametric dependences for more transient L-mode plasmas

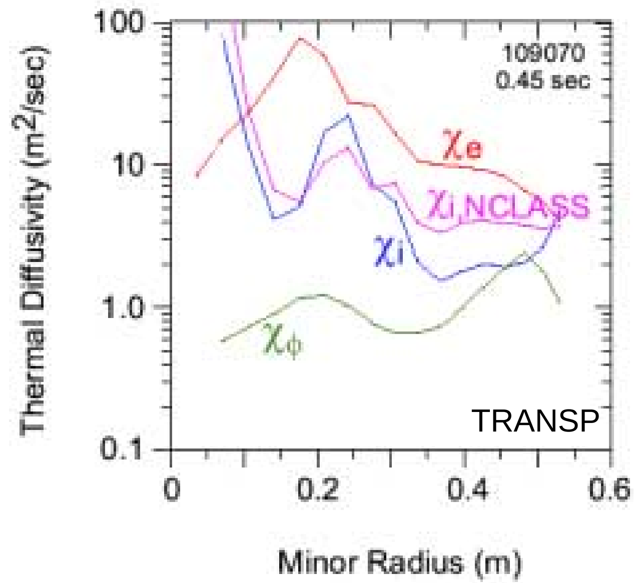
- Role of rotation?

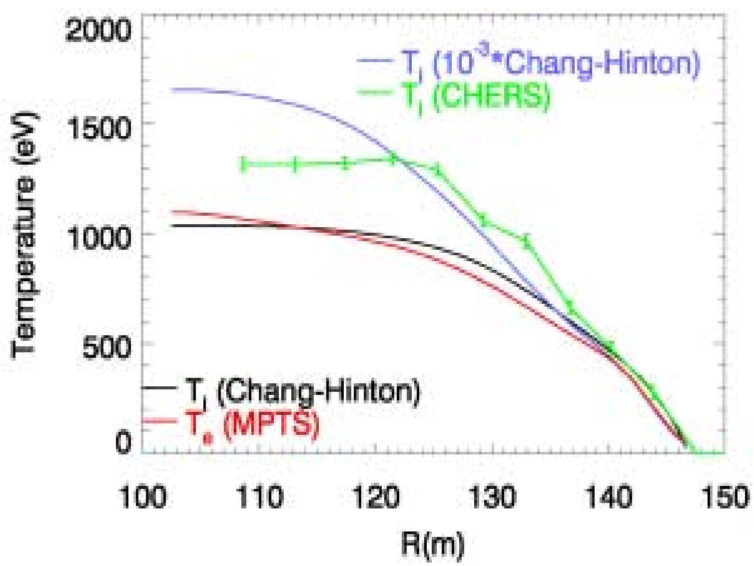
Global Confinement - Plans

- FY03: τ_E scalings in RF&NBI, L&H; τ_E^{th} to ITER DB; R/a dependence in ohmic; start of similarity exp'ts (DIII-D)
- FY04: R/a in NBI intra- and inter-device; transient vs steady-state/role of rotation; rotation control with error field correction coils; dimensionless scalings with β_t, ρ^*; relation of τ_E to q (MSE)
- FY05: Study of rotation dynamics on τ_E (poloidal CHERS)
- FY06: Relation of τ_E on q(r), E_r (LIF MSE)
- FY07: Profile control for optimized τ_E; causal relation between rotation, τ_E

$T_i > T_e$ during NBI Indicates Relatively Good Ion Confinement







ITG suppressed (GK calculations)

Ion confinement sometimes “too good”

Independent validation of T_i needed

Ion Energy Transport - Plans

- FY03: Establish χ_i baseline (if and when anomalous); start to test role of ITG (T_i/T_e, $n_e(r)$, ω_{ExB} dependence); compare to GK

- FY04: Extend ITG study; relation to rotation (error field correction coil); calibrated reflectometry to assess modes for possible stochastic heating; initial assessment wrt to low-k fluctuations

- FY05: Co vs counter to study effect of flow shear, thermal friction pinches; η_i, β' variation by pellet for ITG study; extend study of ion transport/low-k fluctuations

- FY06: Detailed study of ion transport to full-k turbulence; relate transport fluxes to changes in q, E_r (LIF MSE)

- FY07-08: Extend studies of ion tranpsort and full k-spectrum of fluctuations; predictive capability based GK/exp't comparisons

"Stiff" T_e Profiles during Flattop Period with NBI

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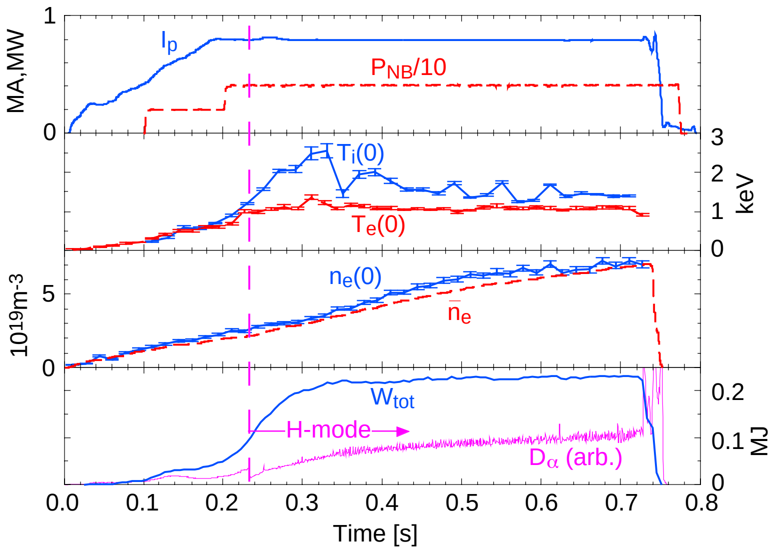
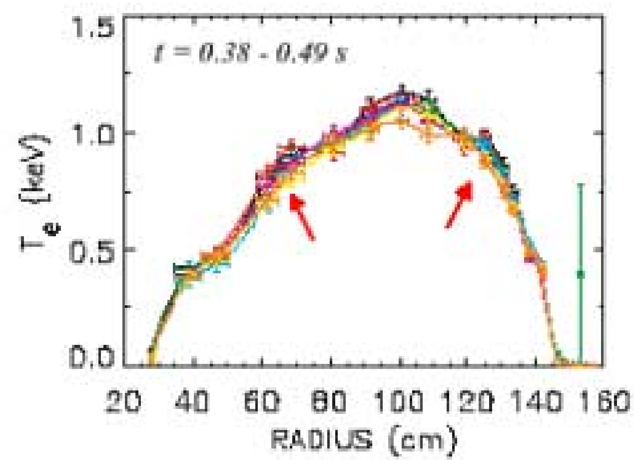
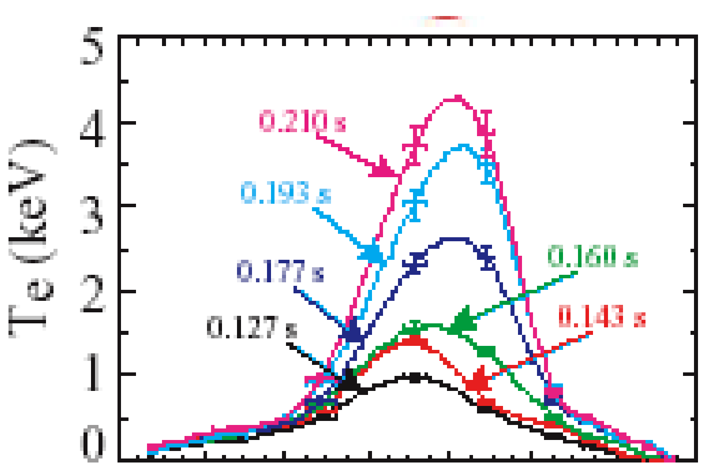
Electrons impervious to transport events

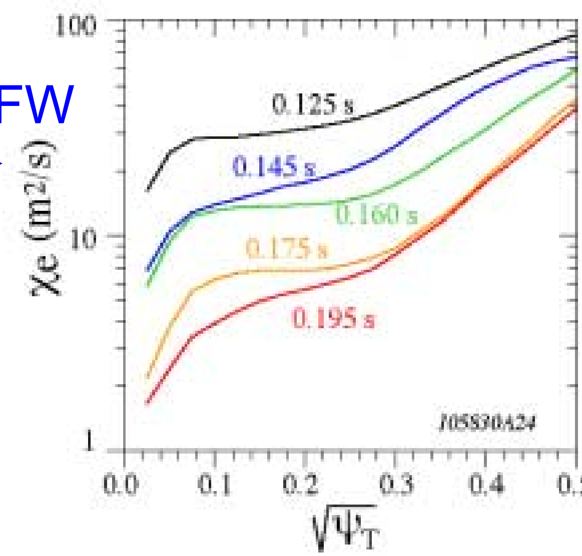


Critical marginality?





ITB w/ HHFW

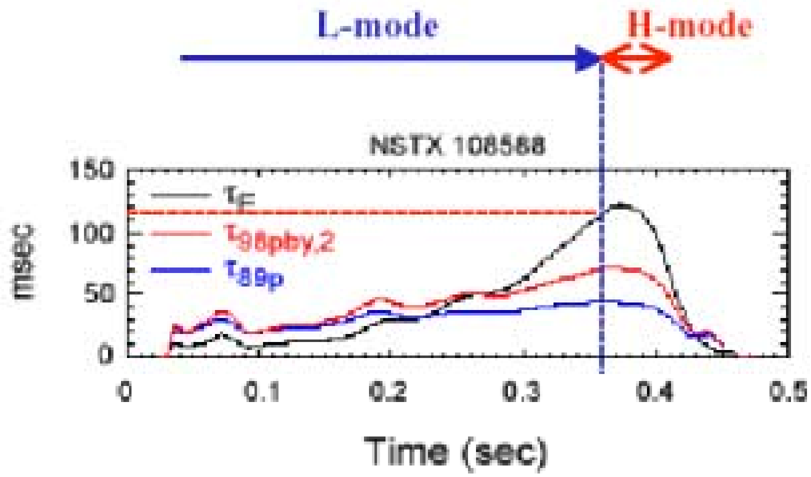


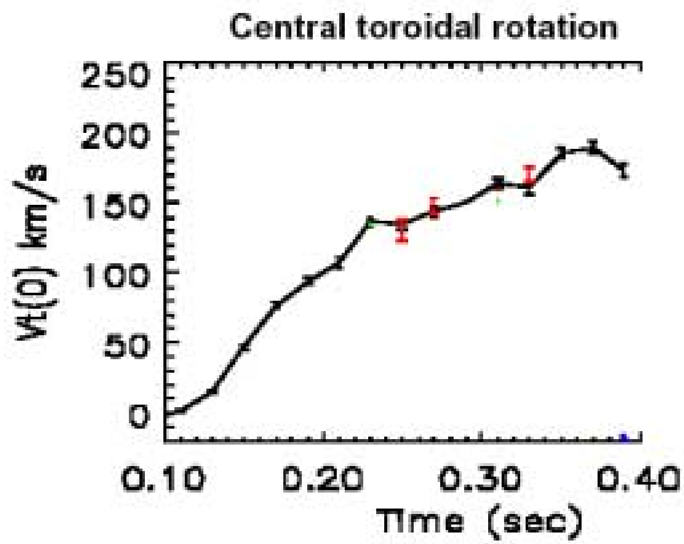
Electron Energy Transport - Plans

- FY03: Establish χ_e baseline
- FY04: Test T_e resiliency (modulated HHFW); Assess role of ETG (vary T_e/T_i, η_e, β' with RF); relate to q (MSE); compare to GK; initial high-k measurements
- FY05: Extend ETG study with pellets (η_e, β'); study effect of flow shear (co vs ctr) using poloidal CHERS; extend high-k comparisons
- FY06: Detailed study of electron transport to full-k turbulence; relate transport fluxes to changes in q, E_r (LIF MSE)
- FY07-08: Extend studies of electron transport and full k-spectrum of fluctuations; predictive capability based GK/exp’t comparisons

Momentum Transport Coupled to Plasma Transport

- Inferred momentum transport low ($\chi_\phi < \chi_i \leq \chi_{neo}$)
- Temporal increase of τ_E associated with temporal increase of rotation (causality?)





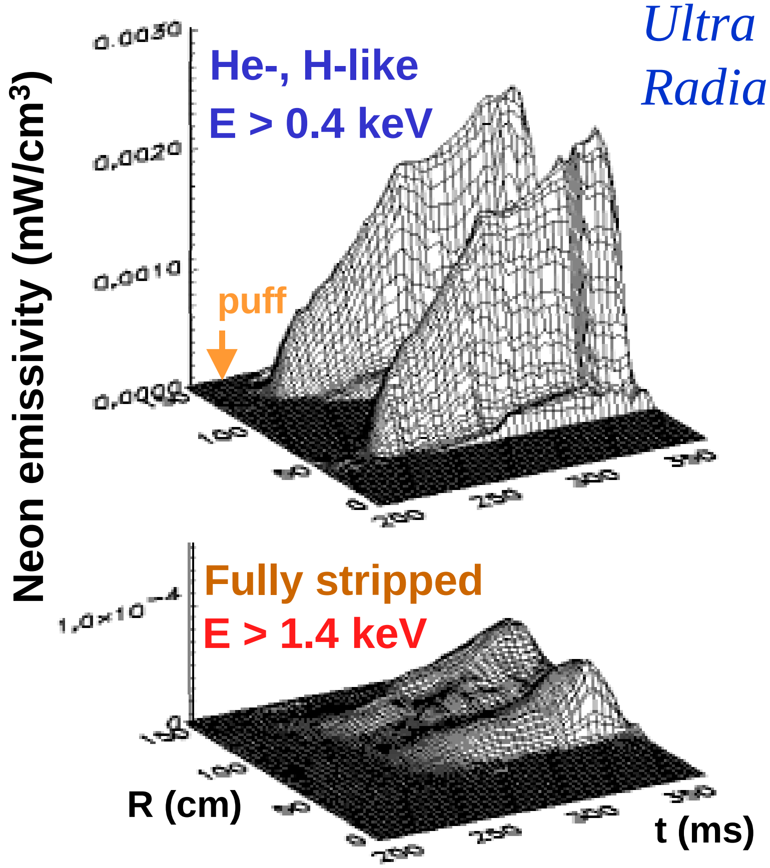
Momentum Transport - Plans

- FY03: Establish χ_ϕ baseline (edge $v_{\phi,\theta}$ + CHERS); initial RF vs NBI comparison
- FY04: Extend RF vs NBI comparison; study effect of error fields on v_ϕ; study relation of v_ϕ and q(r) for ITB generation; compare χ_ϕ to GK estimates
- FY05: Co vs ctr/poloidal CHERS for assessment of non-ambipolar losses and flow shear generation
- FY06-08: Relate E_r (LIF MSE) to flows (CHERS); study relation of E_r, v_ϕ and q(r) for ITB generation; determine rotation/confinement dynamics causality, study zonal flows (1 msec CHERS)

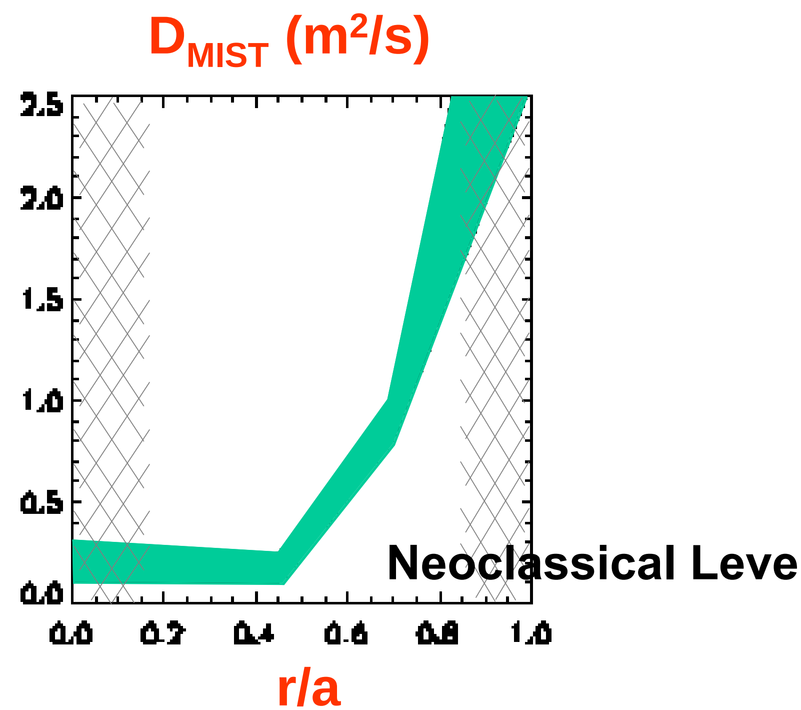
Particle/Impurity Transport Transport Properties Inferred from Perturbative Experiments

NSTX

Neon injection: Impurity transport near neoclassical in core



Ultra Soft X-ray Radiation



Impurity/Particle Transport - Plans

- FY03: Impurity gas injection at higher β_T
- FY04: Supersonic gas injection for impurity transport, make use of USXR, TGS, GEM detectors
- FY05: Deuterium pellet injection for perturbative particle transport
- FY06-08: Extend perturbative experiments with impurity injector

Fast Ion Confinement Studies Just Starting

Results

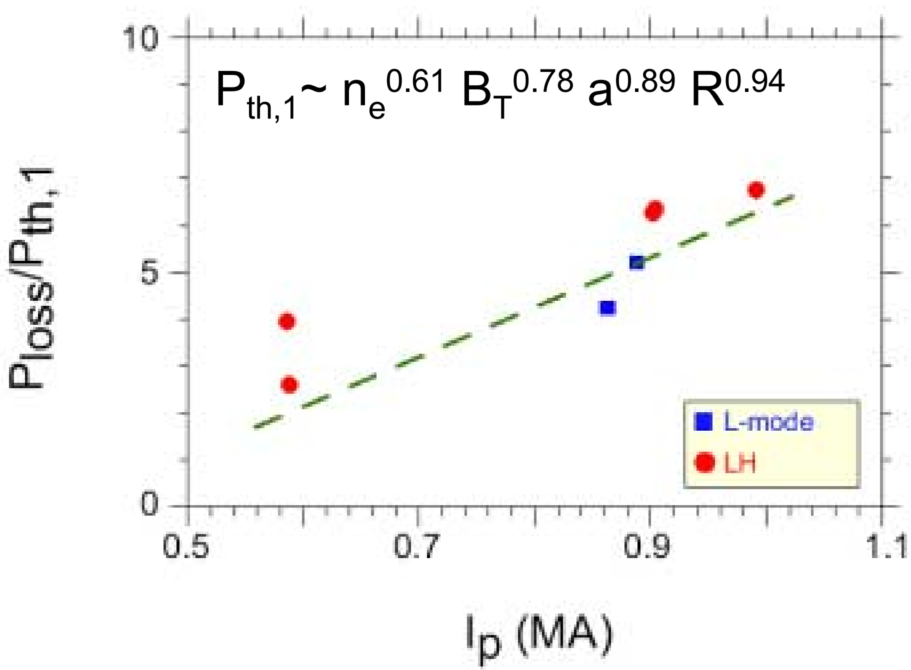
- Decay of neutrons consistent with classical slowing down
- Loss rate measurements disagree with modeling
- Variations in neutron rate for nominally similar discharges

Plans

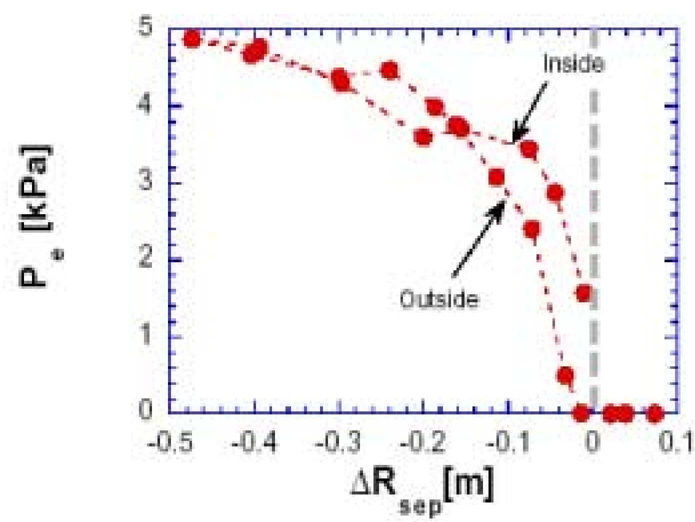
- FY03: Overall confinement trends with parameter, L vs H (sFLIP)
- FY04: Control loss fraction (vary gap)
- FY05: Non-ambipolar losses (co vs ctr); power deposition profile with neutron collimators
- FY06-08: Extend studies using an array of solid state detectors

Edge Characterization and Transport Studies (Including L-H) Have Just Begun

L-H transition: $P_{thresh} > P_{scal}$; I_p dependence

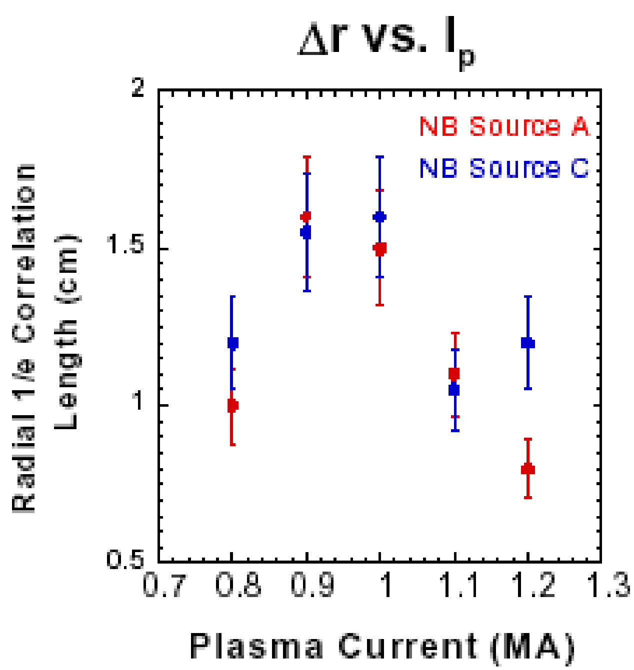


Edge power balance indicates inconsistency between EFIT separatrix location and MPTS

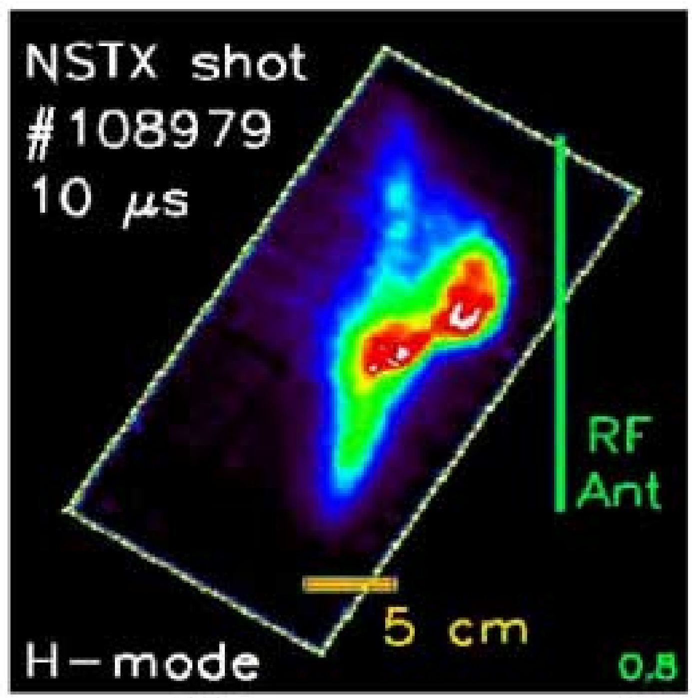


Fluctuation Characteristics Related to Plasma Transport

Radial correlation lengths of fluctuations related to τ_E



Convective-cell (“blob”) transport potentially significant



ñ/n goes down from L to H

Edge Transport and Fluctuations - Plans

- FY03: Submit L-H data to ITER db; study role of E_r on transitions with gap, I_p variations, RF; extend radial correlation length, blob studies, edge pedestal characterization
- FY04: Identify dimensionless variables controlling L-H (similarity expts); preliminary assessment of low and high-k turbulence, compare to theory
- FY05: Co vs ctr/poloidal CHERS for assessment of E_r on L-H; extend studies of low- and high-k turbulence, comparison with non-linear GK results; extend edge characterization (He beam spectroscopy)
- FY06-08: Role of E_r (LIF MSE) extended; full k-spectrum turbulence measurements; edge transport barriers with CT injection; liquid Li/cryopump for density control; extend edge characterization with fast CHERS

Theory and Modeling - Tools

- Core Transport
  - NCLASS neoclassical
  - Gyrokinetic codes (GS2, GYRO, GTC)
  - Predictive TRANSP (GLF23, M-M, NCLASS)
- Edge Transport (diffusive and non-diffusive transport)
  - BAL
  - BOUT
  - UEDGE

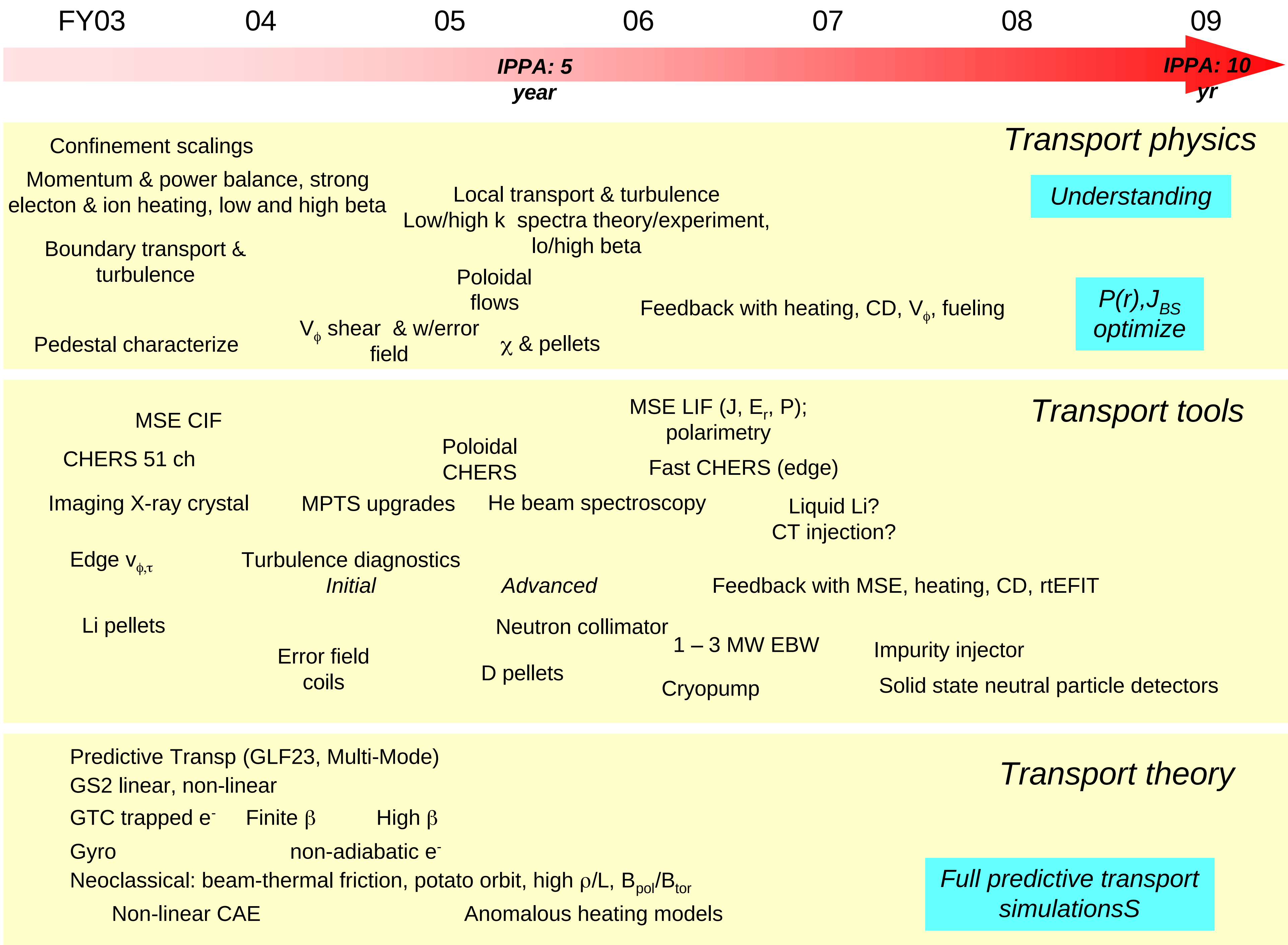
Theory and Modeling - Plans

- FY03: Predictive TRANSP using analytic estimates of χ's; validate GK codes in low R/a regime (benchmark); update neoclassical (beam-thermal friction, large ρ/L); non-adiabatic fast ions; edge transport modeling

- FY04: Predictive TRANSP analysis with χ's from non-linear GK runs; incorporate large ρ^*, β_T, f_T, shaping effects into GK codes; non-linear calcs of CAE mode amplitudes; start to compare turbulence measurements to theory

- FY05: Incorporate ExB, non-local effects in GK; extend theory/exp't comparison of turbulence; start developing anomalous heating models

- FY06-08: Start to develop high-confidence predictive capability; combine with MHD stability to form self-consistent package for integrated scenario development


FY03
04
05
06
07
08
09
IPPA: 5 year
IPPA: 10 yr
Transport physics
Confinement scalings
Momentum & power balance, strong electon & ion heating, low and high beta
Local transport & turbulence
Low/high k spectra theory/experiment, lo/high beta
Understanding
Boundary transport & turbulence
Poloidal flows
Feedback with heating, CD, V_ϕ, fueling
$P(r), J_{BS}$ optimize
Pedestal characterize
V_ϕ shear & w/error field
χ & pellets
Transport tools
MSE CIF
MSE LIF (J, E_r, P); polarimetry
CHERS 51 ch
Poloidal CHERS
Fast CHERS (edge)
Imaging X-ray crystal
MPTS upgrades
He beam spectroscopy
Liquid Li?
CT injection?
Edge $v_{\phi,\tau}$
Turbulence diagnostics
Initial
Advanced
Feedback with MSE, heating, CD, rtEFIT
Li pellets
Neutron collimator
1 – 3 MW EBW
Impurity injector
Error field coils
D pellets
Cryopump
Solid state neutral particle detectors
Transport theory
Predictive Transp (GLF23, Multi-Mode)
GS2 linear, non-linear
GTC trapped e^-
Finite β
High β
Gyro
non-adiabatic e^-
Neoclassical: beam-thermal friction, potato orbit, high ρ/L, B_{pol}/B_{tor}
Non-linear CAE
Anomalous heating models
Full predictive transport simulationsS