ITPA-SSO
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Status of ITER AT simulations by TASK code

A. Fukuyama and M. Honda
Department of Nuclear Engineering, Kyoto University

Outline

- Present Status of TASK Code
- Improvement of CDBM Tansport Model
- Simulation of ITER Operation Scenario
- Summary

TASK Code

- **Transport Analysing System for TokamaK**
- **Features**
  - **A Core of Integrated Modeling Code in BPSI**
    - — Modular Structure
    - — Reference Data Interface
  - **Various Heating and Current Drive Scheme**
    - — EC, LH, IC, AW, (NB)
  - **High Portability**
    - — Most of Library Routines Included (except LAPACK and MPI)
    - — Own Graphic Libraries (gsaf, gsgl)
  - **Development using CVS** (Concurrent Version System)
    - — Open Source (V0.90 http://bpsi.nucleng.kyoto-u.ac.jp/task/)
  - **Parallel Processing using MPI Library**
  - **Extension to Toroidal Helical Plasmas**

Modules of TASK

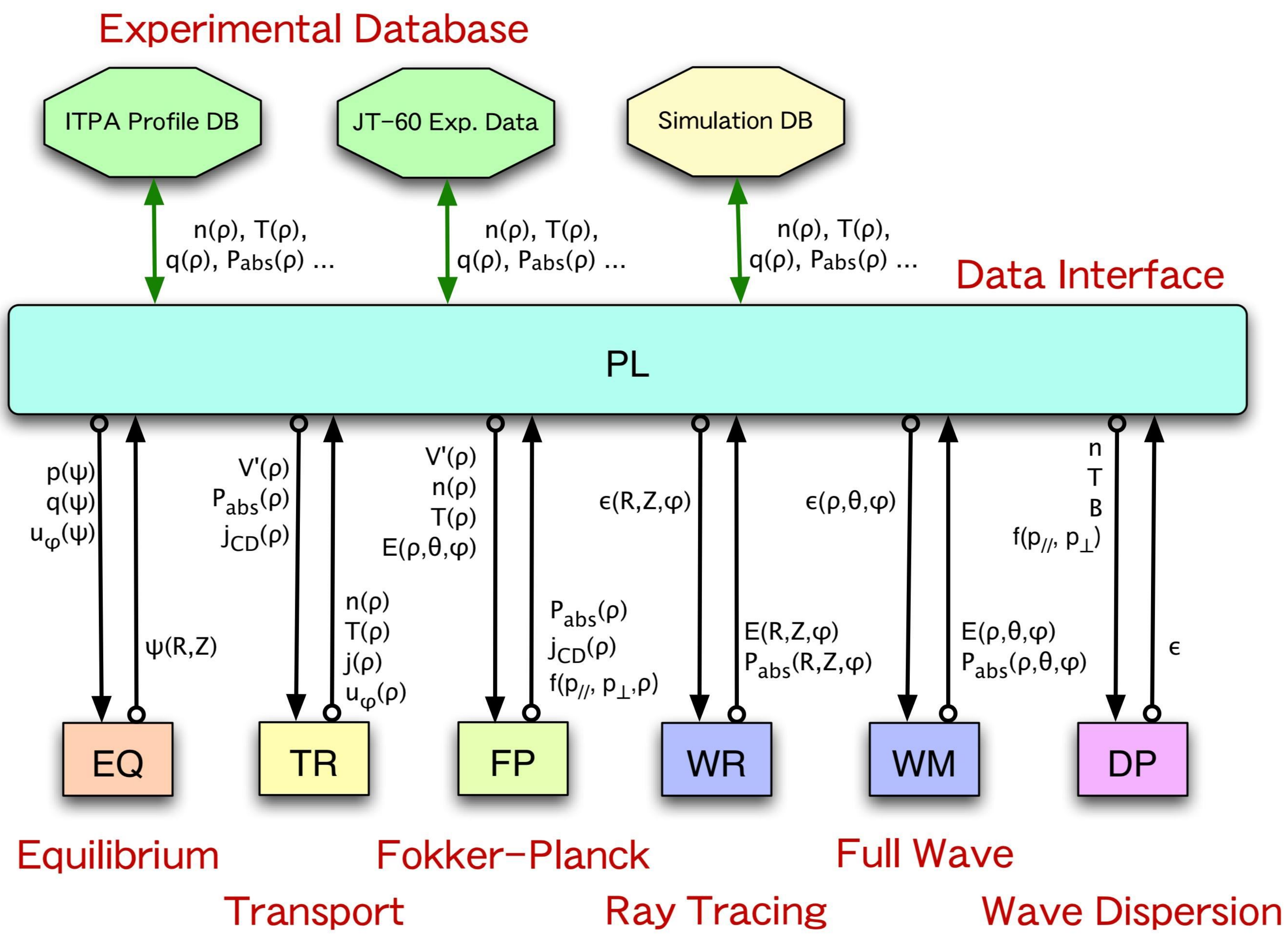
EQ	**2D Equilibrium**	Fixed boundary, Toroidal rotation
TR	**1D Transport**	Diffusive Transport, Transport models
WR	**3D Geometr. Optics**	EC, LH: Ray tracing, Beam tracing
WM	**3D Full Wave**	IC, AW: Antenna excitation, Eigen mode
FP	**3D Fokker-Planck**	Relativistic, Bounce-averaged
DP	**Wave Dispersion**	Local dielectric tensor, Arbitrary $f(\boldsymbol{v})$
PL	**Data Interface**	Data conversion, Profile database
LIB	**Libraries**	

Associated Libraries

GSAF	2D Graphic library for X Window and EPS
GSGL	3D Graphic library using OpenGL

All developed in Kyoto U

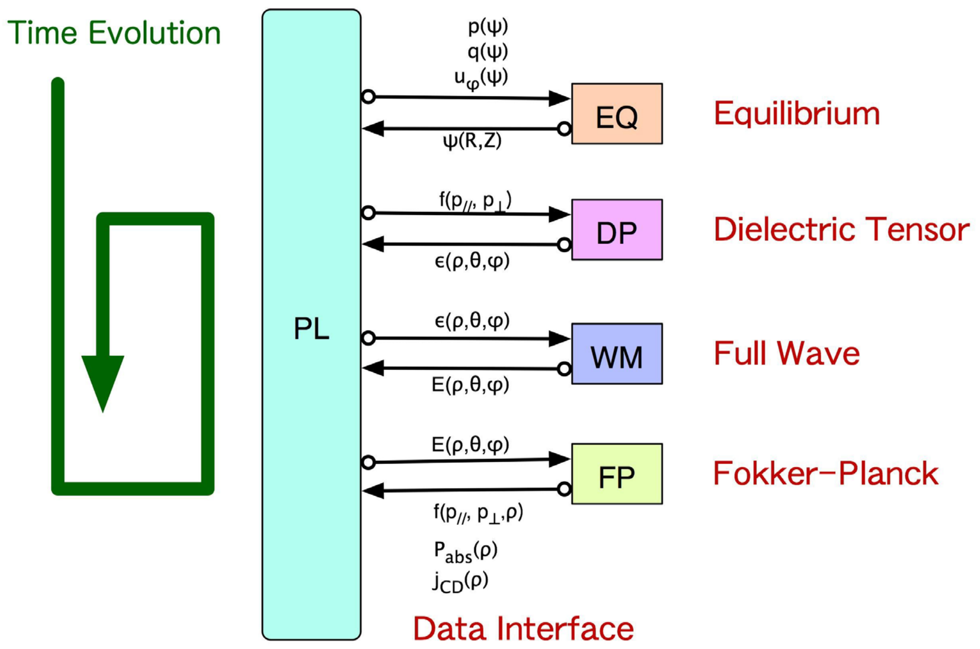
Modular Structure of TASK



Self-Consistent Wave Analysis with Modified $f(v)$

- **Modification of velocity distribution from Maxwellian**
  - Absorption of ICRF waves in the presence of energetic ions
  - Current drive efficiency of LHCD
  - NTM controllability of ECCD (absorption width)

- **Self-consistent wave analysis including modification of $f(v)$**

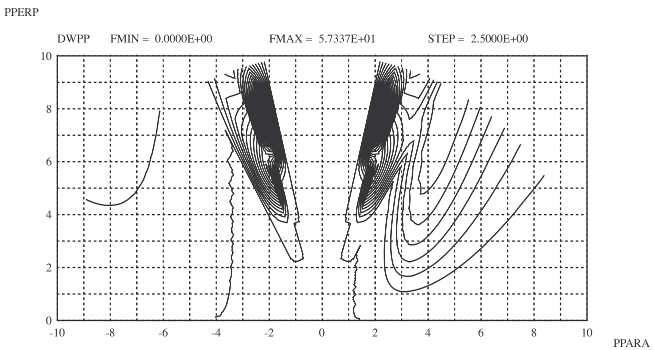


Development of Self-Consisten Wave Analysis

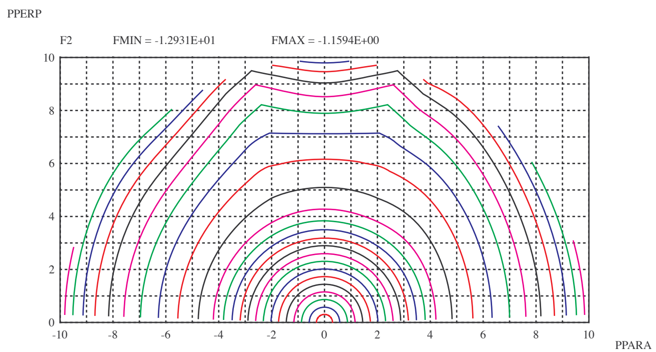
- **Code Development in TASK**
  - Ray tracing analysis with arbitrary $f(v)$: **Already done**
  - Full wave analysis with arbitrary $f(v)$: **Completed**
  - Fokker-Plank analysis of ray tracing results: **Already done**
  - Fokker-Plank analysis of full wave results: **Almost competed**
  - Self-consistent iterative analysis: **Soon**

- **Tail formation by ICRF minority heating**

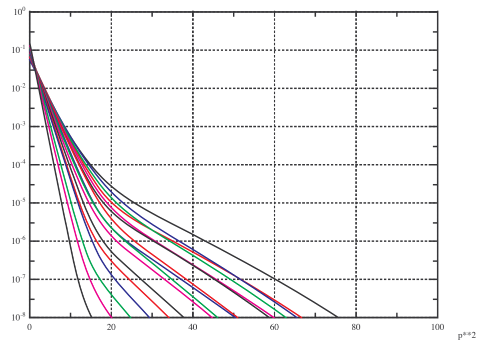
Quasi-linear Diffusion



Momentum Distribution



Tail Formation



The Way of Simulation

- **Neoclassical Transport Models**: **NCLASS**[6]
- **Turbulent Transport Models**: **CDBM, GLF23 v1.61 (retuned)**[6]**, Weiland**
  - CDBM: No $\boldsymbol{E} \times \boldsymbol{B}$ shearing ($\omega_{\rm E1}$) and magnetic curvature (κ_*) effects
  - GLF23: Using toroidal rotation velocity ($V_{\rm tor}$) from exp. data
  - Weiland: Assuming $k_\theta \rho_s = 0.316$
- **Solve thermal transport equations**
  - **Fixed density profiles**
  - Taken from experimental analysis data in **ITPA profile database**
    - 1D: R, a, I_p, B_t, κ, ϕ_a
    - 2D: $T_{\rm e,i}$, $n_{\rm e,bulk,imp}$, $Z_{\rm eff}$, j, $Q_{\rm heating}$, $S_{\rm NB,wall}$, $V_{\rm rot}$, Metrics
    - $T_{\rm e,i}$ data used only for initial profiles and boundary conditions
    - q data used only if j is not available.
  - **Boundary conditions** enforced at $\rho \leq 0.9$
  - **Particle flux calculated from $S_{\rm NB,wall}$ in thermal equations**
  - Diagonal turbulent transport coefficient set to zero if negative

[6]By courtesy of NTCC site (http://w3.pppl.gov/ntcc/)

Conditions for Comparison

- Comparison of resulting $T_{\mathrm{e,i}}$ profiles with experimental data in each discharge
  - At a fully relaxed time (typically 0.5 s)
  - Compared with fitted temperature profiles, not measured ones
- **55 discharges described** in **"ITER Physics Basis: Chapter 2[7]"**
  - 38 L-mode discharges
  - 14 H-mode discharges with small ELMs
  - 3 H-mode discharges with giant ELMs
- **Figures of merit**
  - **Relative RMS error, $\sigma_{\mathrm{T}}^{\mathrm{rel}}$, relative to the maximum experimental temperature for each temperature profile within the region of** $0.2 \le \rho \le 0.9$

$$\sigma_{\mathrm{T}}^{\mathrm{rel}} = \sqrt{\frac{1}{N}\sum_{j=1}^{N} \epsilon_j^2}, \quad \epsilon_j = \frac{T_j^{\mathrm{sim}} - T_j^{\mathrm{exp}}}{T_{\mathrm{max}}^{\mathrm{exp}}}$$

T_j: jth point of experimental data and simulation result for each temperature
N: the number of experimental data points in a profile

  - **Six figures of merit defined in ITER Physics Basis as described later**

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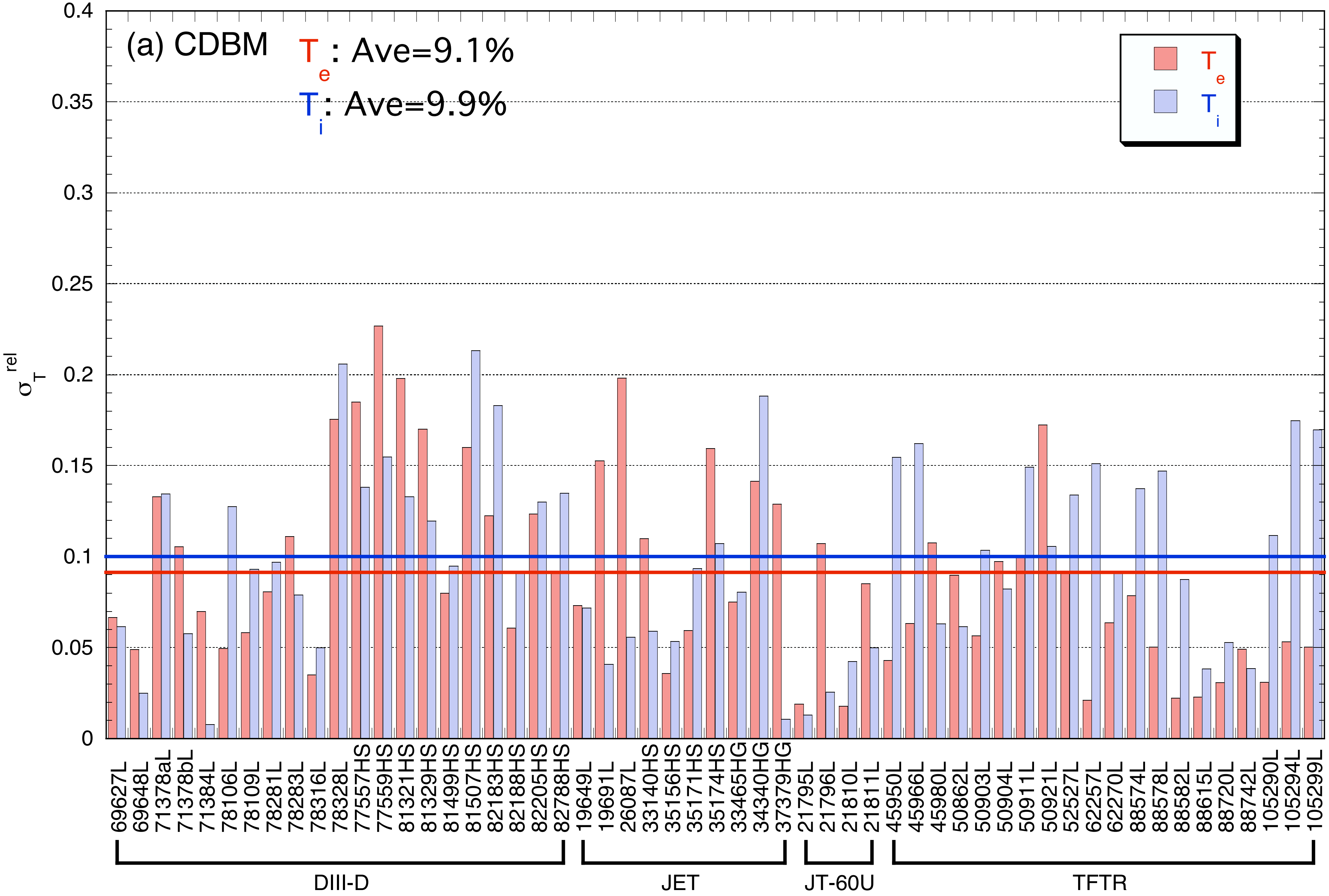
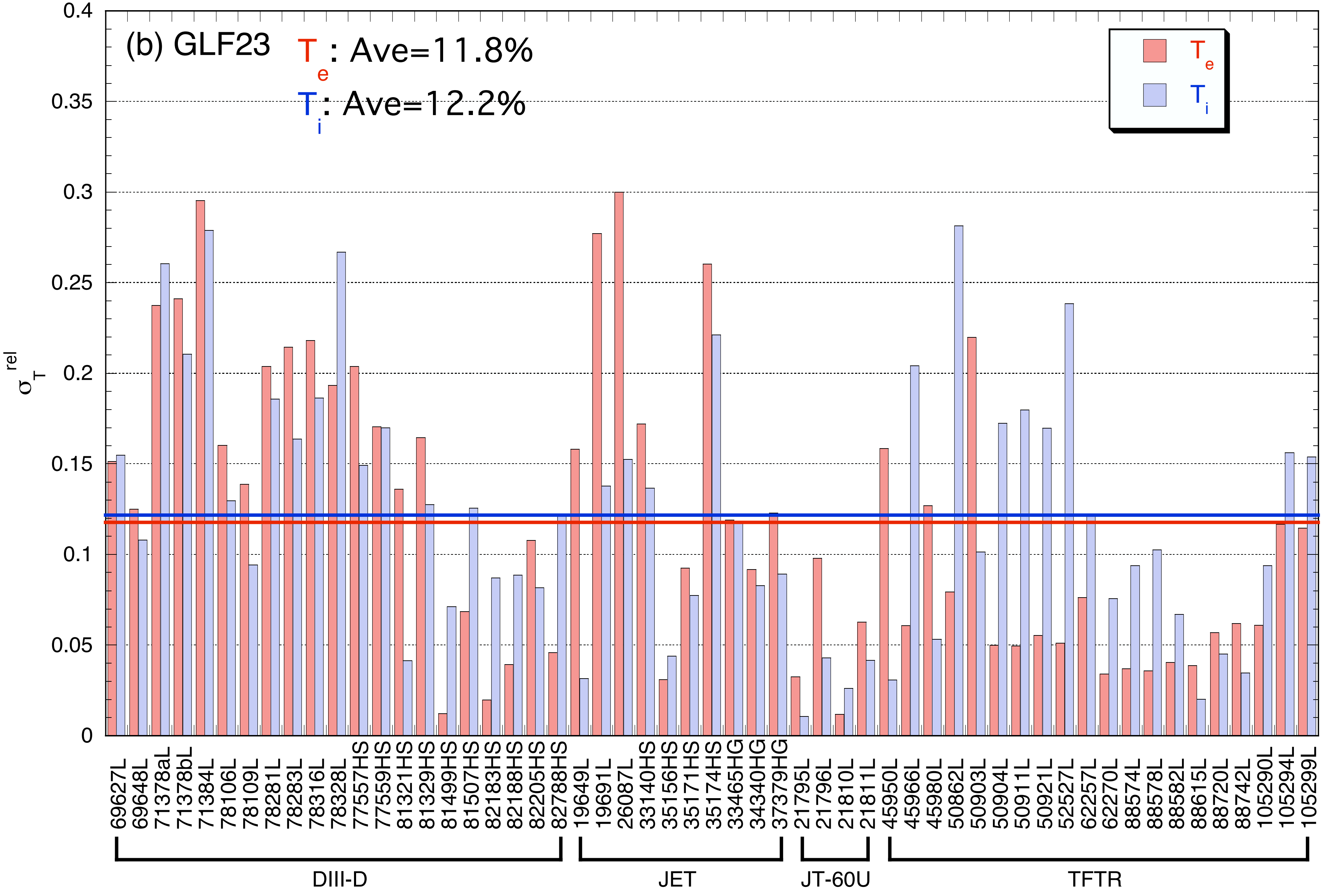
[7] ITER Physics Basis Expert Groups 1999 *Nucl. Fusion* **39** 2175-2249

Relative RMS Error for Temperature Profiles (CDBM)

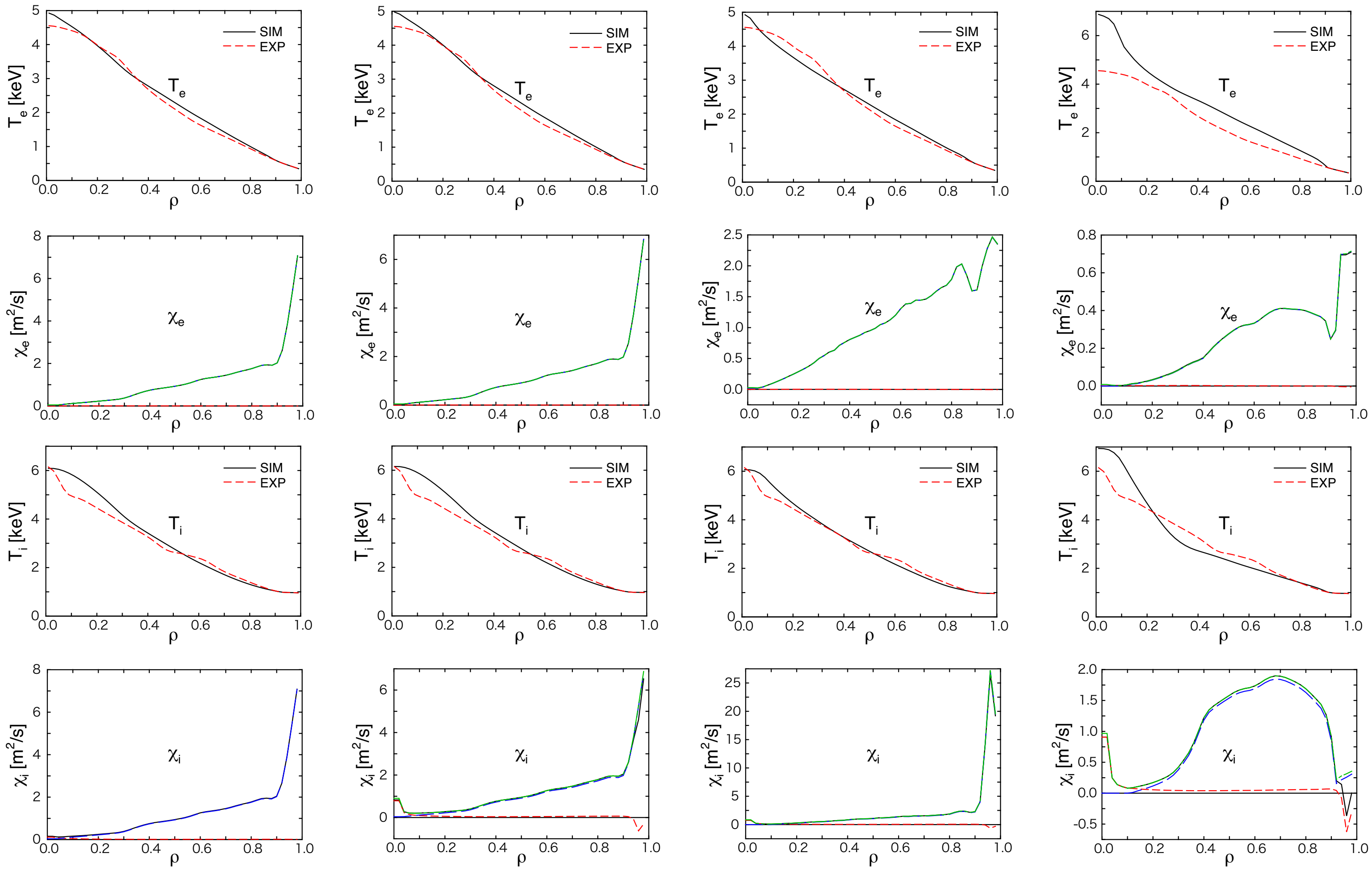


Relative RMS Error for Temperature Profiles (GLF23)

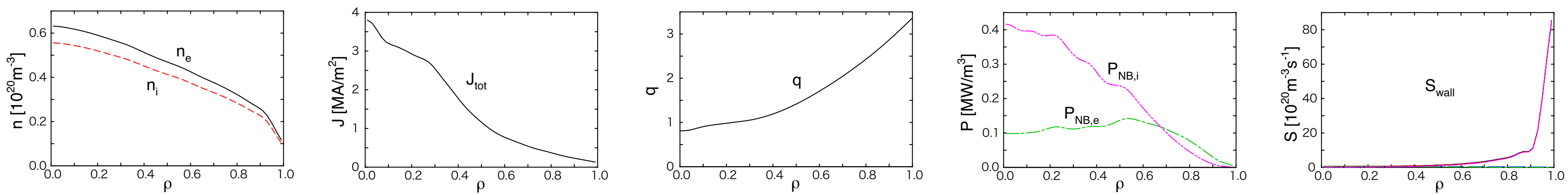


TFTR #88615 (L-mode, NBI heating)

CDBM CDBM05 GLF23 Weiland

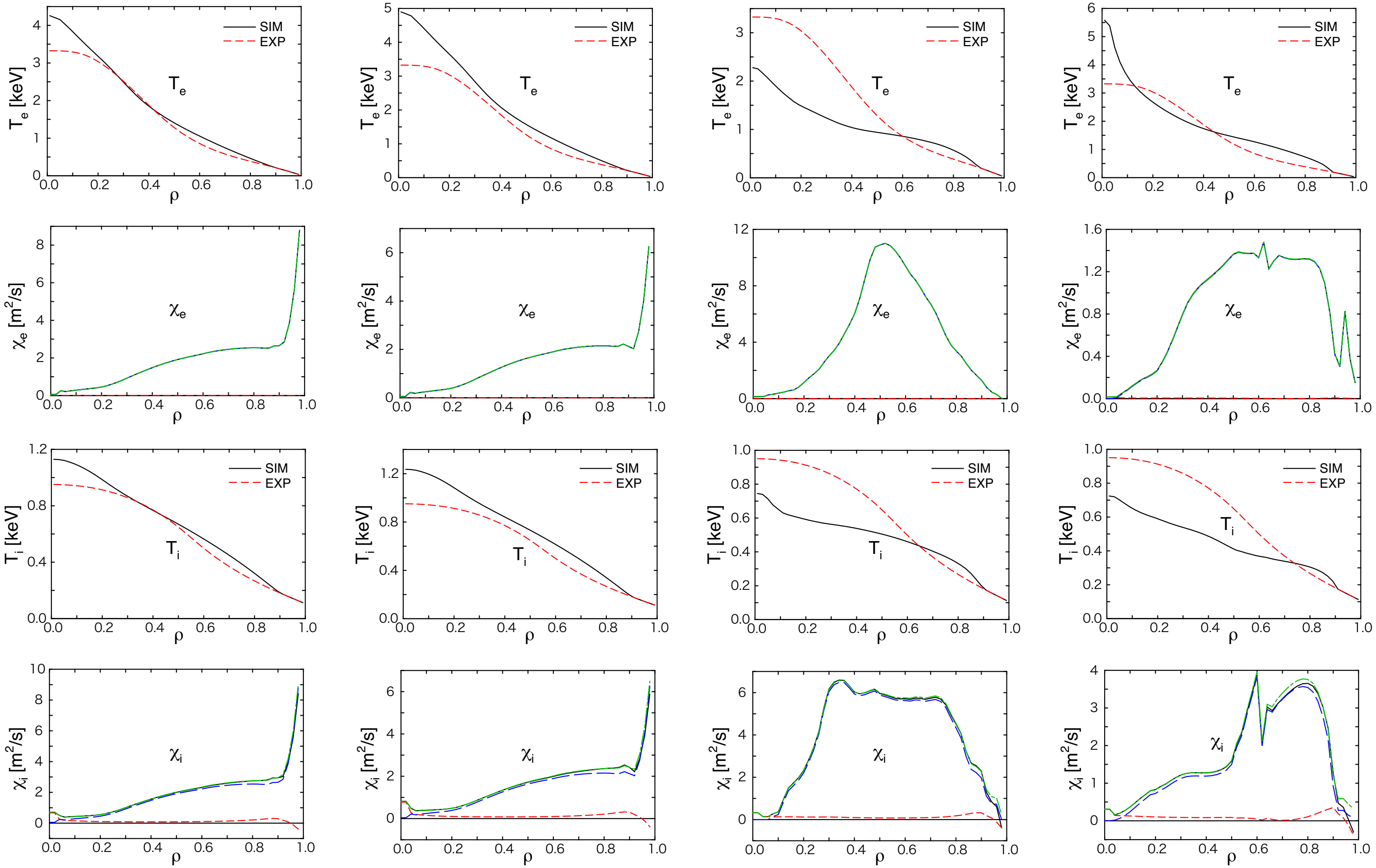


Common Profiles

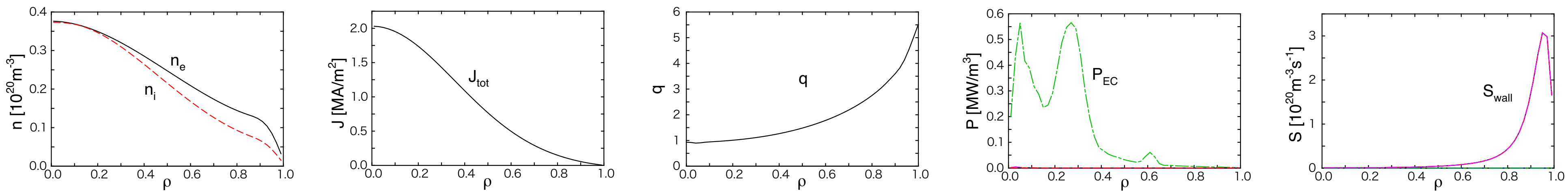


DIII-D #78316 (L-mode, ECH and ICH heatings)

CDBM | CDBM05 | GLF23 | Weiland



Common Profiles



Elongation Effect for CDBM model

- From the figures of "Dependence on Devices", it is found that **the predictions by the CDBM model are generally overestimated for TFTR and underestimated for others; this behavior would be attributed to the elongation effect.**
- The original CDBM model was developed on the assumption of a circular cross section plasma.
- Develop **CDBM05 model including the dependence on the elongation effect in the formula of** F along with the reference[8] as follows:

$$F \propto \left(\frac{2\kappa^{1/2}}{\kappa^2+1}\right)^{3/2}.$$

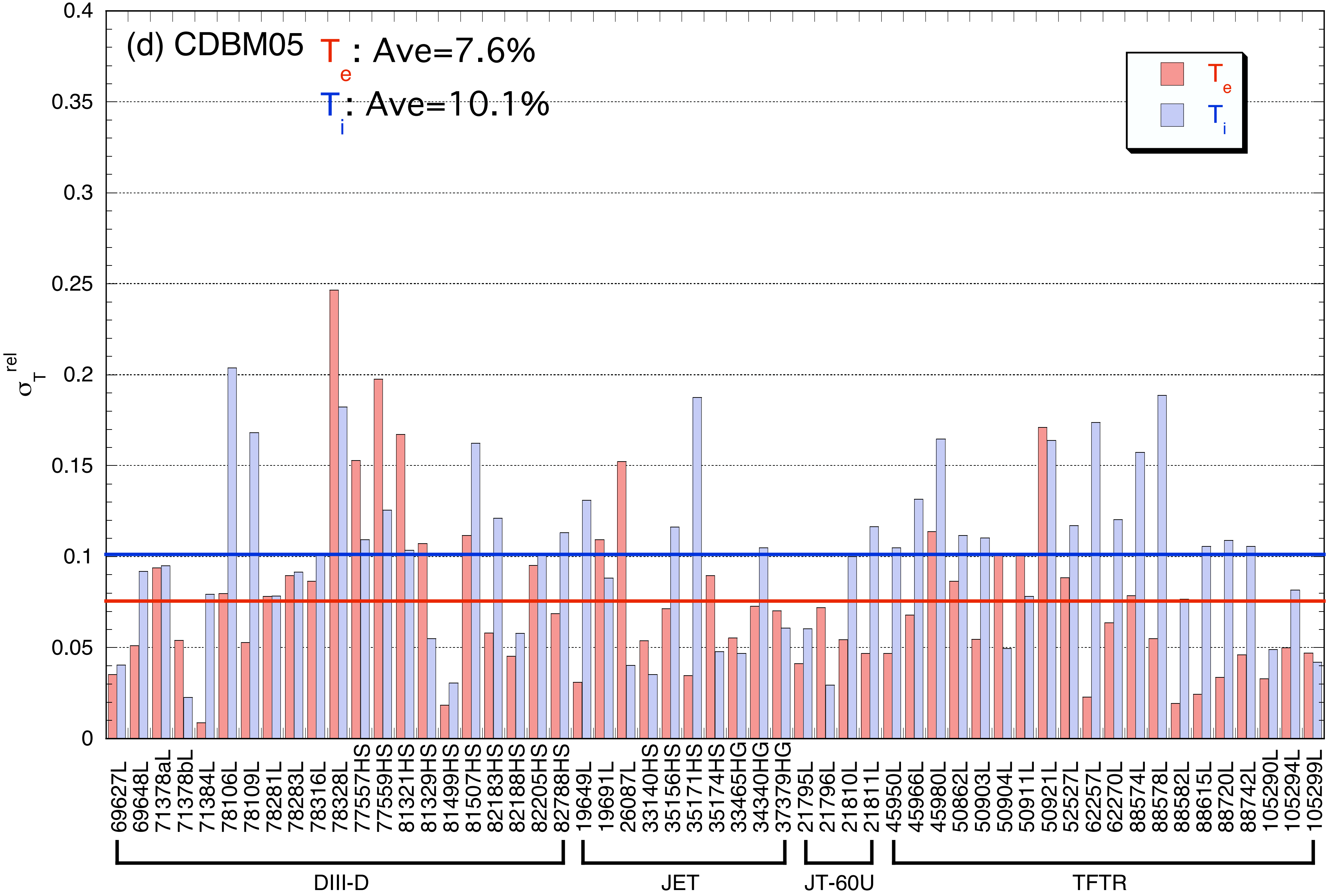
- This dependence clearly tends to decrease F and thus suppress the transport when the elongation κ is above unity (typically 0.65 when $\kappa = 1.5$).

Results

- **Large negative deviations for DIII-D H-mode shots are to some extent improved, but the predictions for some discharges (i.e. DIII-D L-mode and JET HSELM) are overestimated more than needs.**
- **On the whole, σ_W is improved from 23.5% to 20.8%.**

[8] Yagi M *et al* 1997 *J. Phys. Soc. Japan* **66** 379

Relative RMS Error for Temperature Profiles (CDBM05)



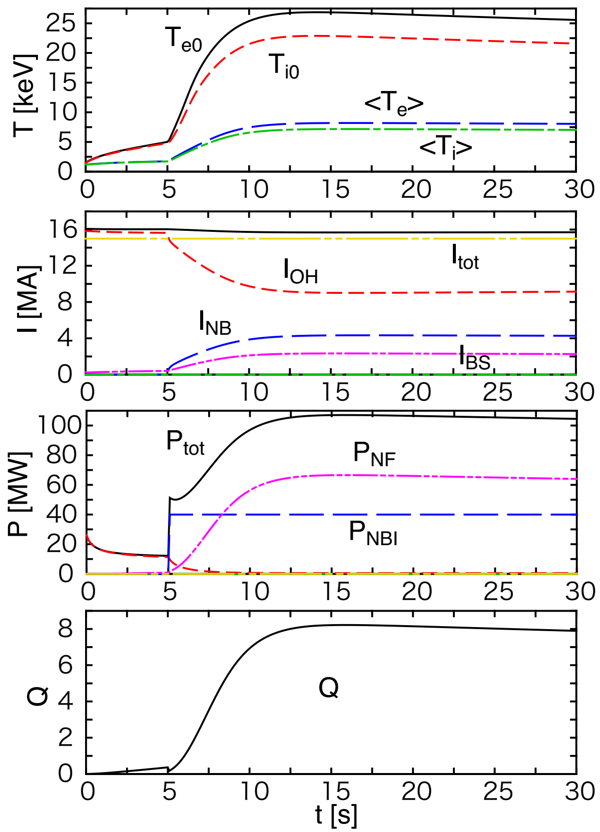
High Q Operational Scenario

- Large plasma current: $I_p = 15$ MA,   On-axis heating: $P_{NB} = 40$ MW
- Positive shear profile,   Relatively large f_{OH}

CDBM

$\beta_N = 1.49$

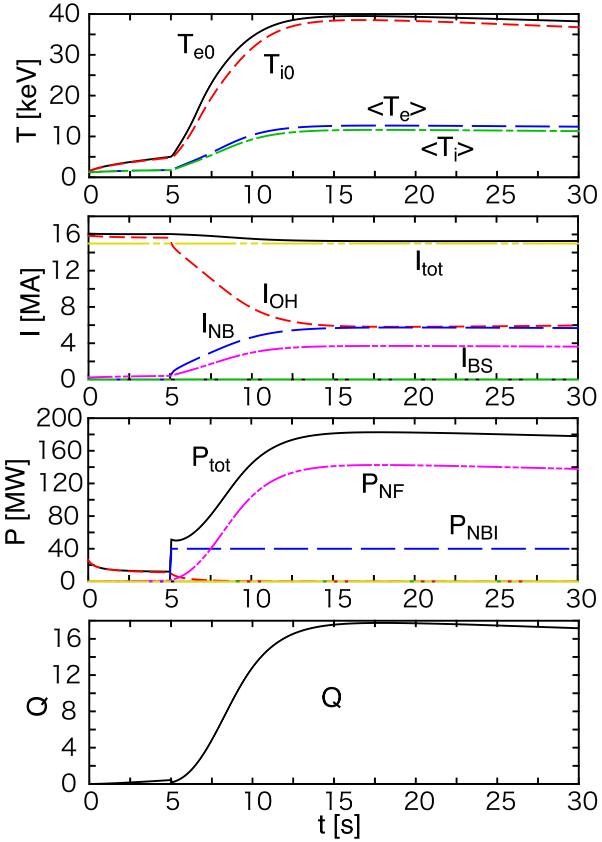
$\tau_E = 3.0$ s

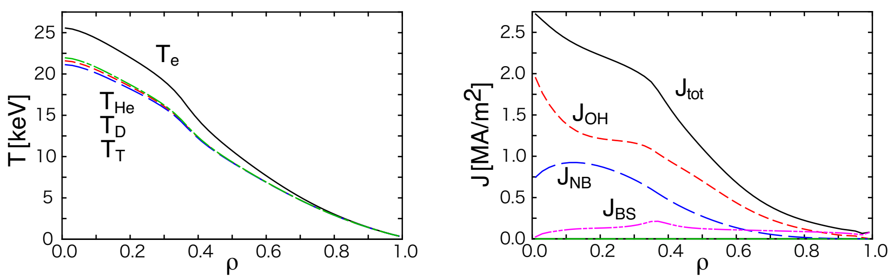


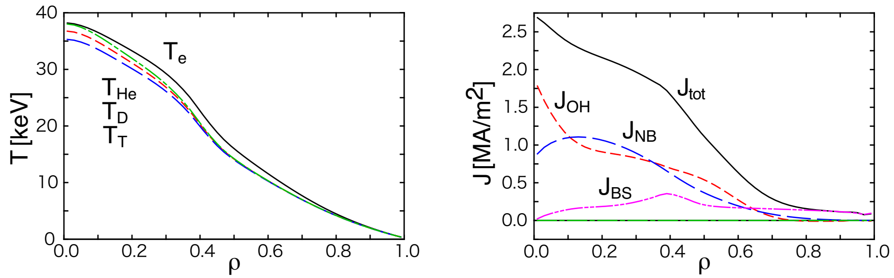
CDBM05

$\beta_N = 2.63$

$\tau_E = 3.1$ s

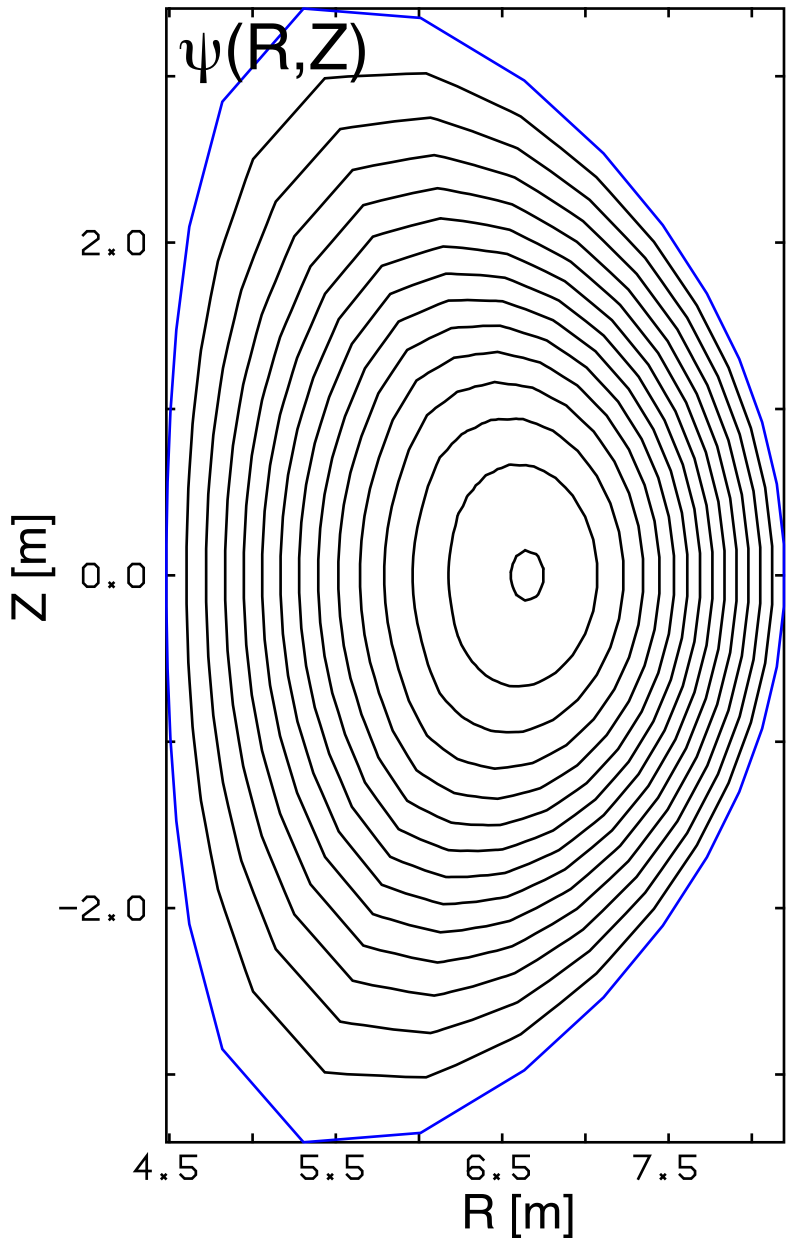






Configuration for Hybrid Operational Scenario

- R = 6.34 m
- a = 1.859 m
- κ = 1.857
- δ = 0.434
- B_ϕ = 5.3 T
- I_p = 12 MA
- $n_\mathrm{e,D,T,He}$ = 0.82, 0.369, 0.369, 0.041 m^{-3} on-axis
- NBI
  - Position of deposition: r = 0 m
  - Width of deposition profile: r_W = 1.0 m
  - Energy of NB particles: E = 1.0 MeV
  - Tangential radius: r_T = 6.2 m
  - Current drive efficiency: 1.0
  - Total power: P_NB = 33 MW



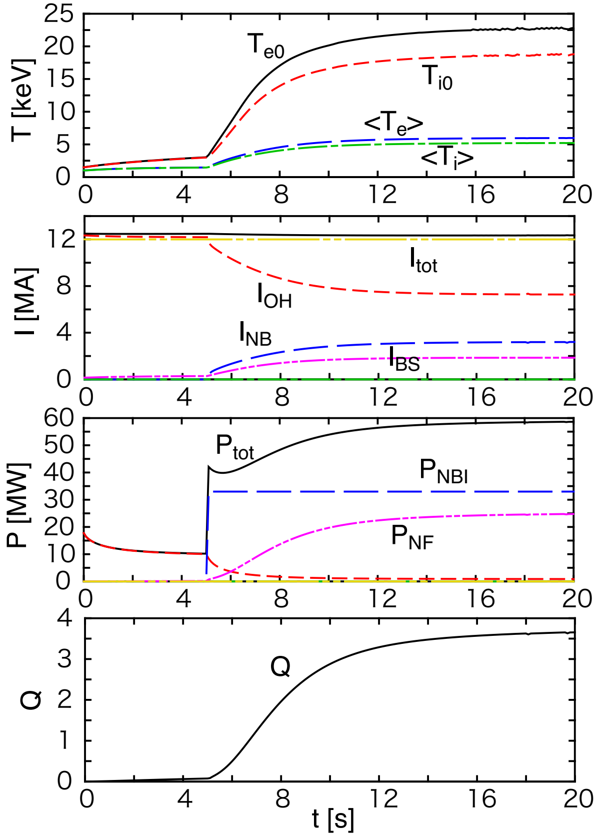
Hybrid Operational Scenario

- Moderate plasma current: $I_{\mathrm{p}} = 12\ \mathrm{MA}$, On-axis heating: $P_{\mathrm{NB}} = 33\ \mathrm{MW}$
- Flat q profile with small ITB inside $\rho = 0.4$

CDBM

$\beta_{\mathrm{N}} = 1.17$

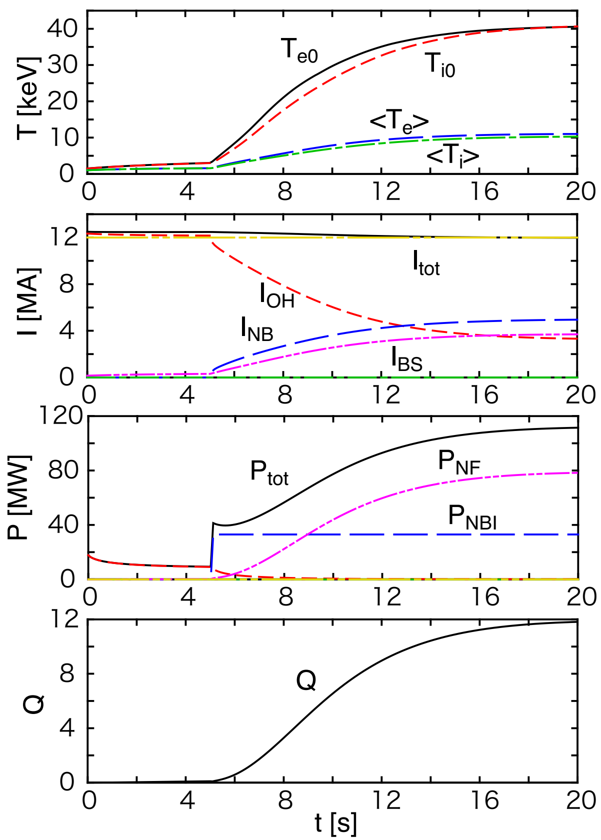
$\tau_{\mathrm{E}} = 3.1\ \mathrm{s}$

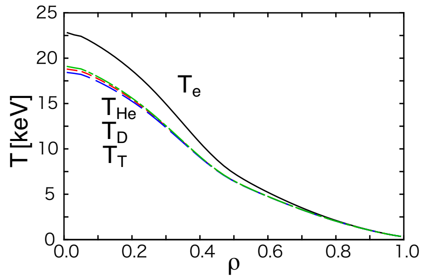


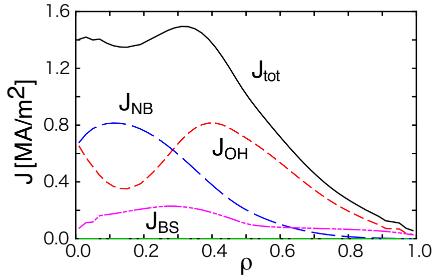
CDBM05

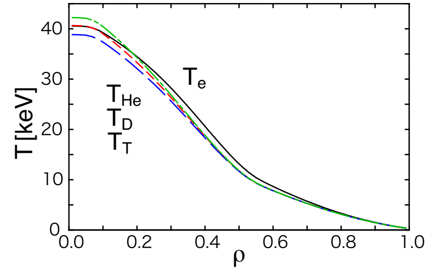
$\beta_{\mathrm{N}} = 2.58$

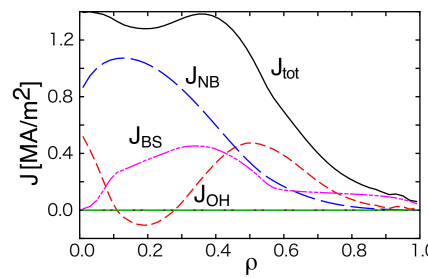
$\tau_{\mathrm{E}} = 3.6\ \mathrm{s}$





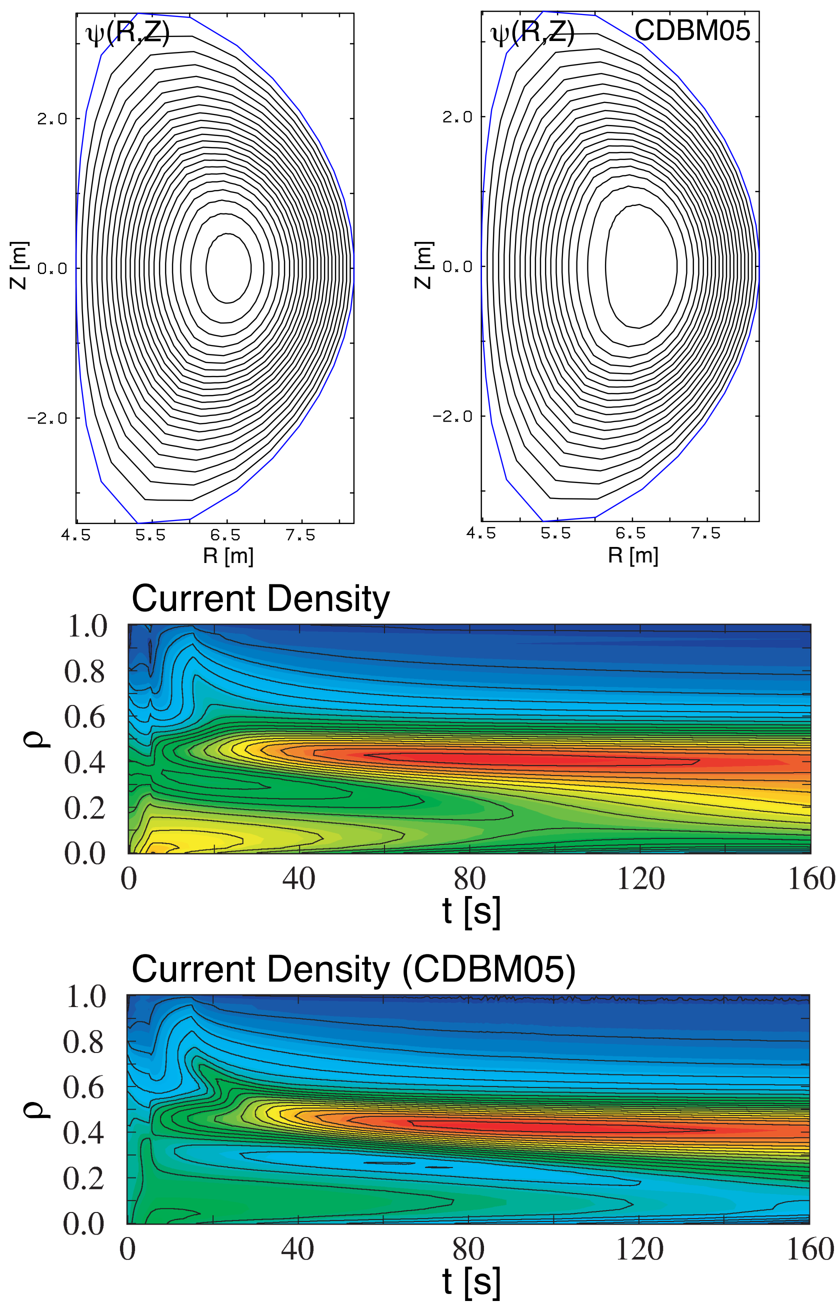






Configuration for Quasi-Steady State Operational Scenario

- $R = 6.34$ m
- $a = 1.859$ m
- $\kappa = 1.857$
- $\delta = 0.434$
- $B_\phi = 5.3$ T
- $I_p = 6$ MA
- $n_{e,D,T,He} = 0.54, 0.243, 0.243, 0.027\ m^{-3}$ on-axis
- NBI: same condition except $P_{NB} = 33$ or 17 MW
- LHRF
  - Position of deposition: $r = 0.837$ m
  - Width of deposition profile: $r_W = 0.8$ m
  - Tangential radius: $r_T = 6.2$ m
  - Parallel refractive index: $N_{||} = 2.0$
  - Total power: $P_{LH} = 25$MW



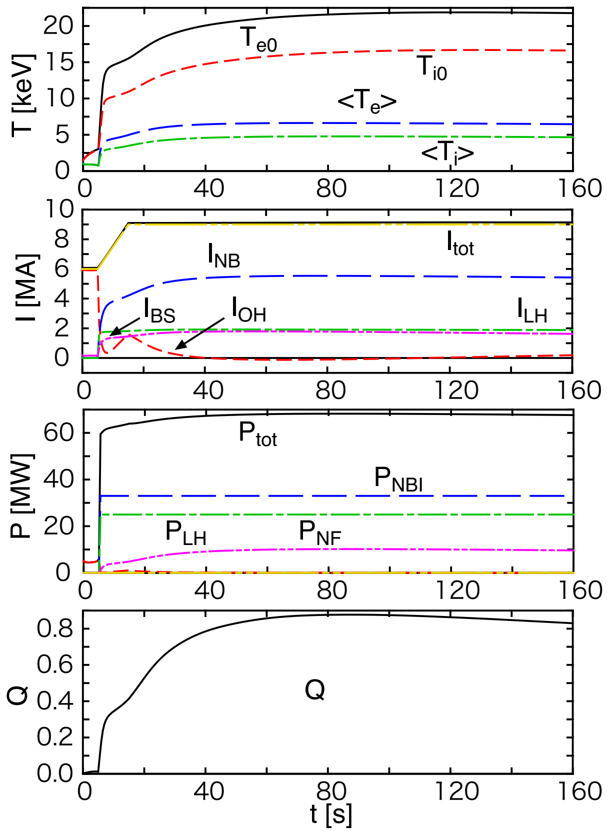
Quasi-Steady State Operational Scenario

- I_p = 6 → 9 MA for 10 s, Negative shear profile, $I_{OH} \sim 0$

CDBM

$\beta_N = 1.2$

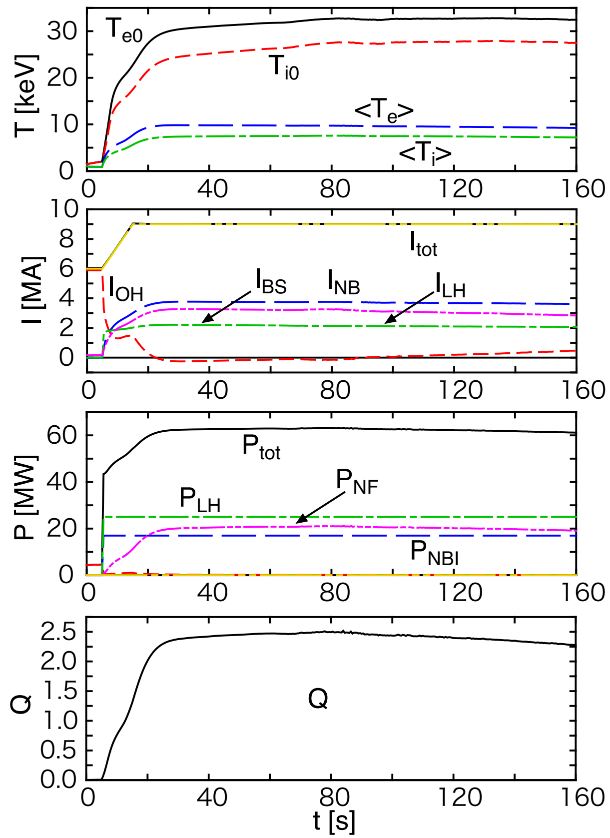
$\tau_E = 3.0$ s

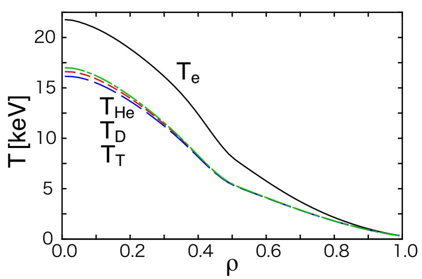


CDBM05

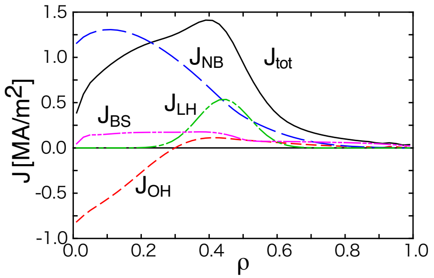
$\beta_N = 1.55$

$\tau_E = 3.2$ s

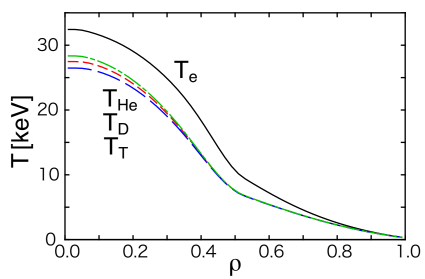




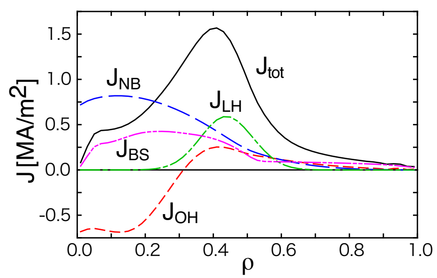
P_{NB} = 35 MW



P_{LH} = 30 MW



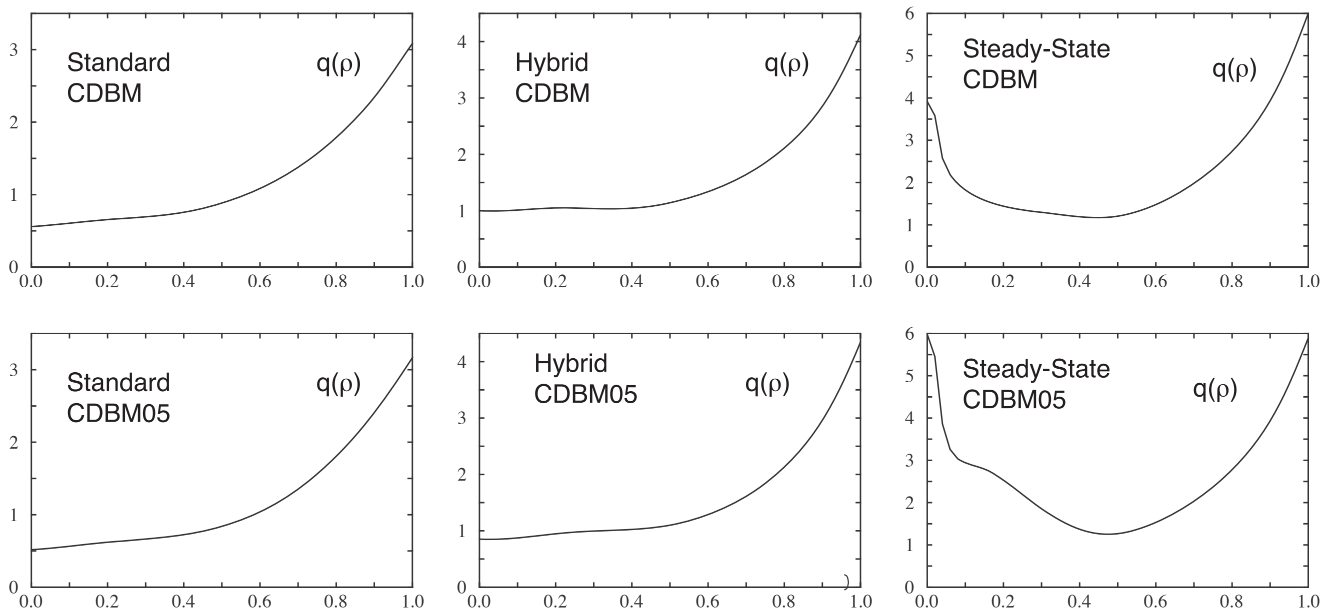
P_{NB} = 17 MW



P_{LH} = 25 MW

q Profiles of Previous Shots

Standard **Hybrid** **Steady State**



- Control of current profile in the hybrid operation requires more improvement to keep $q(0) > 1$.
- Performance of the quasi steady-state operation will be improved if the H-mode plasma edge (edge transport barrier) are included. .

Summary

- The CDBM05 transport model including the effect of elongation has shown better agreement with the L and H mode data in the ITPA profile database than the previous CDBM model and other models.

- Time-dependent 1-1/2D thermal transport simulations of ITER plasmas with the CDBM05 model predict desired performance of standard, hybrid, and steady state operations. H-mode edge transport barrier will further improve the performance.

- **Work in progress**
  - Simulation of ITB formation using the ITB profile database
  - More consistent simulation of ITER plasma
    - — Particle transport coupled with plasma rotation
    - — Wave heating and current drive including $f(\boldsymbol{v})$ modification
    - — FLR effects in full wave analysis