Latest Current Profile Simulation for ITER with TASK

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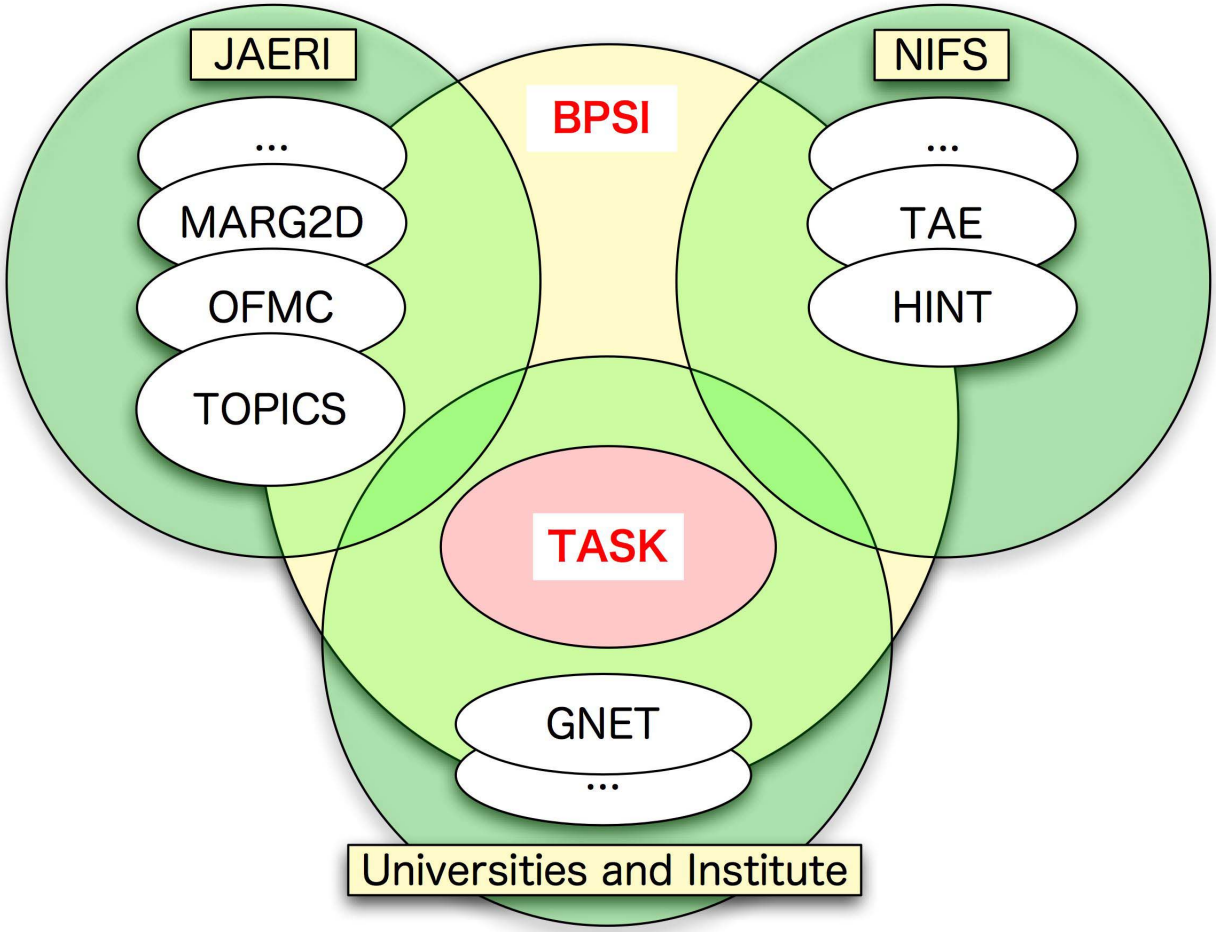
Contents

- TASK: Core Code for Integrated Modeling
- ITER Current Profile Simulation (present status)
- Summary

BPSI and TASK

TASK: Core code of BPSI for ITER, JT-60, LHD, and small machines



TASK Code

- **Transport Analysing System for TokamaK**
- **Features**
  - **A Core of Integrated Modelling 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)
    - — Own Graphic Libraries (gsaf, gsgl)
  - **Development using CVS** (Concurrent Version System)
    - — Open Source (by the end of 2004)
  - **Parallel Processing using MPI Library**
  - **Extension to Toroidal Helical Plasmas**

Modules of TASK

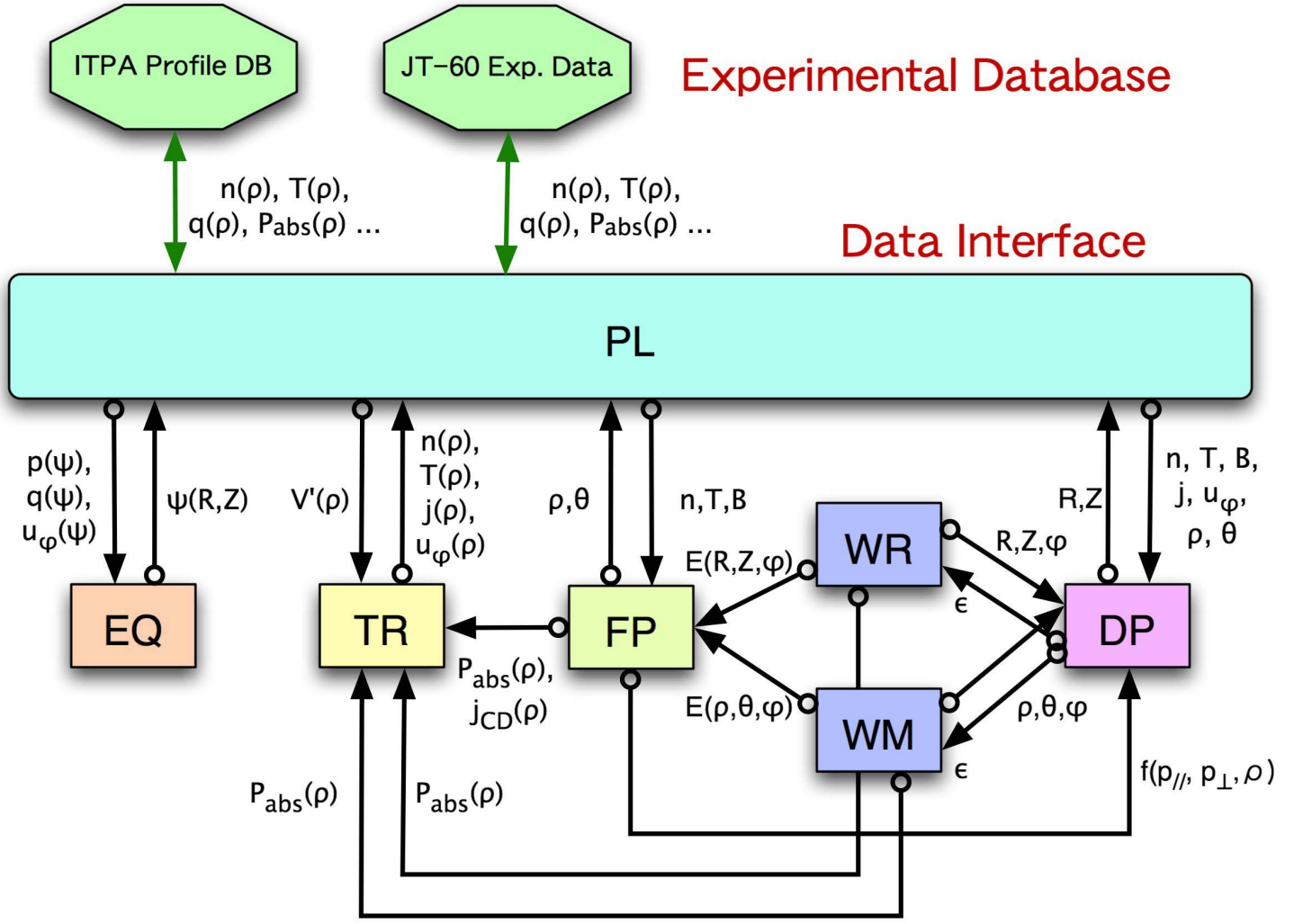
EQ	**2D Equilibrium**	Fixed boundary, Toroidal rotation
TR	**1D Transport**	Diffusive Transport, Transport models
WR	**3D Geometr. Optics**	EC, LH: Ray tracing, Beam tracing
WM	**3D Full Wave**	IC, AW: Antenna excitation, Eigen mode
FP	**3D Fokker-Planck**	Relativistic, Bounce-averaged
DP	**Wave Dispersion**	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

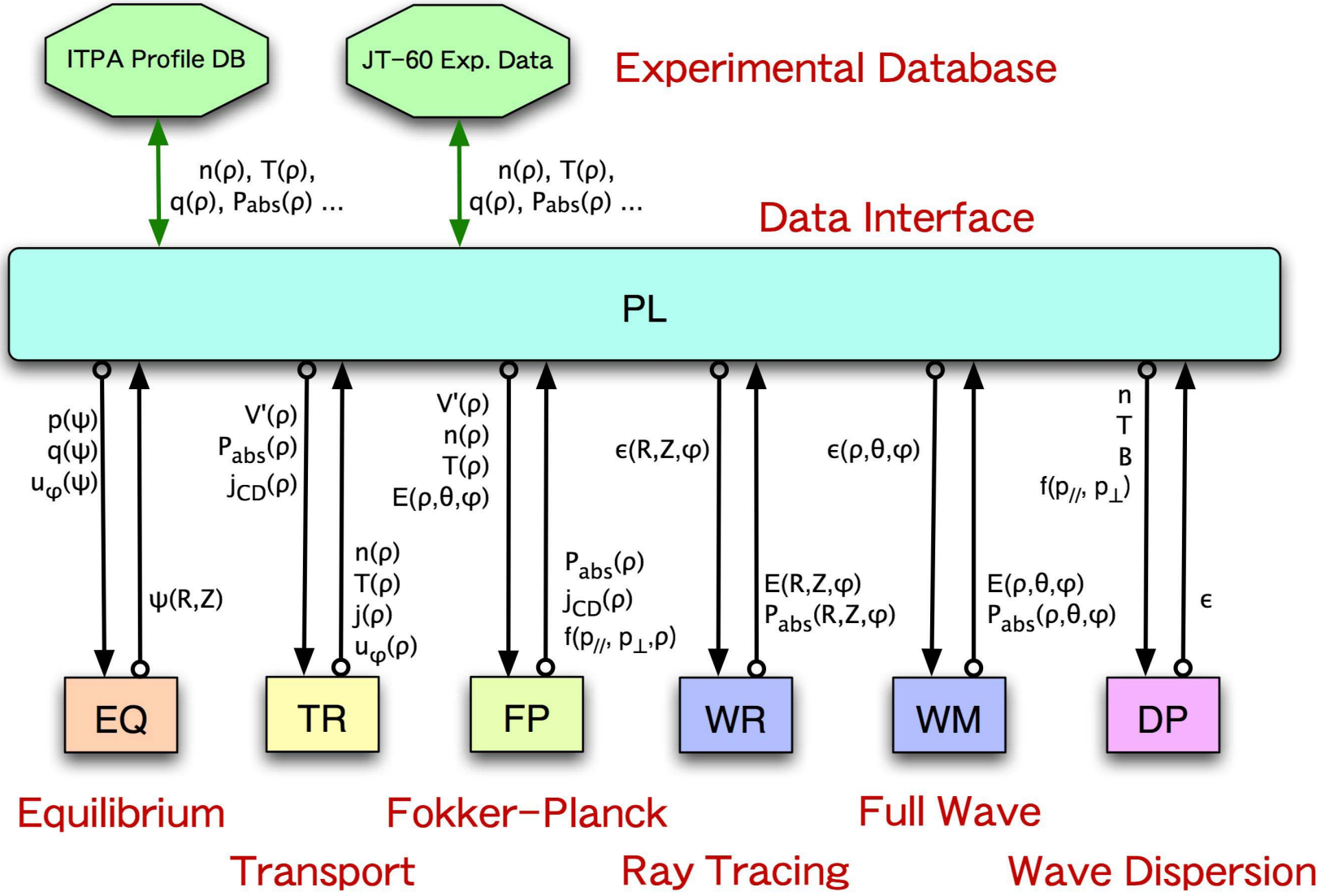
Present Structure of TASK



Under Development

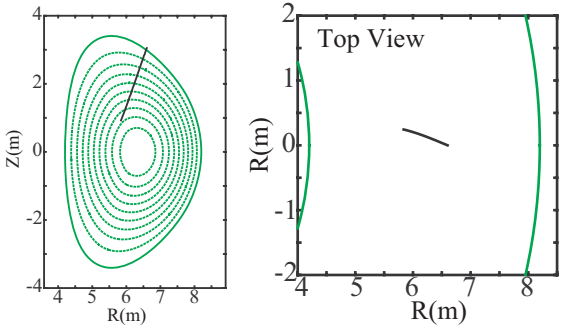
- **New Modules**
  - **EX**: 2D equilibrium with free boundary
  - **TX**: Transport analysis based on flux-averaged fluid equation
  - **WA**: Global linear stability analysis
  - **WI**: Integro-differential wave analysis (FLR, $\boldsymbol{k} \cdot \nabla B \neq 0$)
- **Extension to 3D Helical System**
  - **3D Data Structure**
  - **3D Equilibrium**: VMEC, HINT
  - **Wave Analysis**: Already 3D
  - **Transport Analysis**: New transport model
- **New Modular Structure**

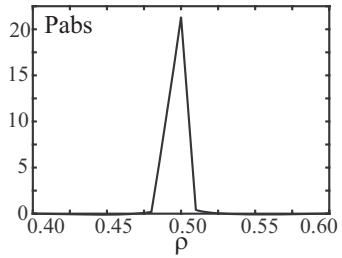
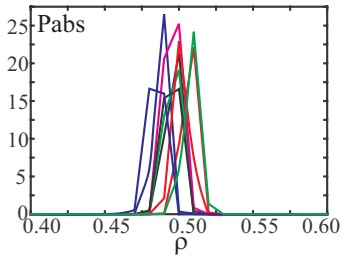
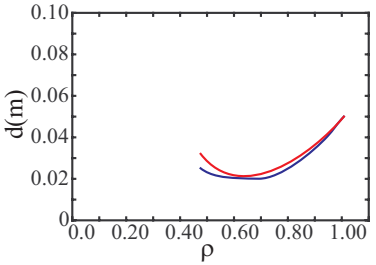
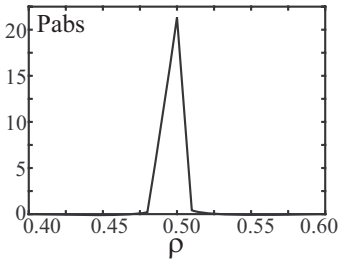
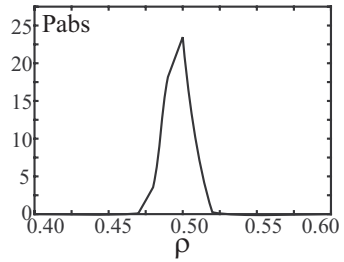
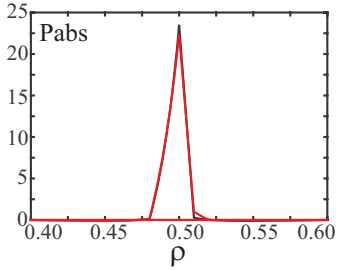
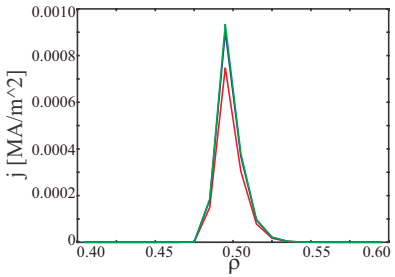
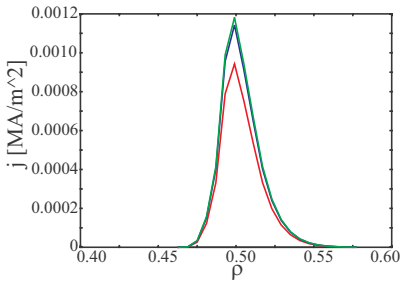
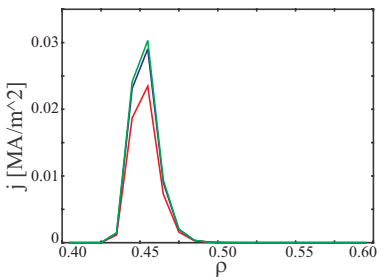
New Modular Structure of TASK



Analysis of ECCD by TASK Code

Poloidal angle	70°
Toroidal angle	20°
Initial beam radius	0.05 m
Initial beam curvature	2 m

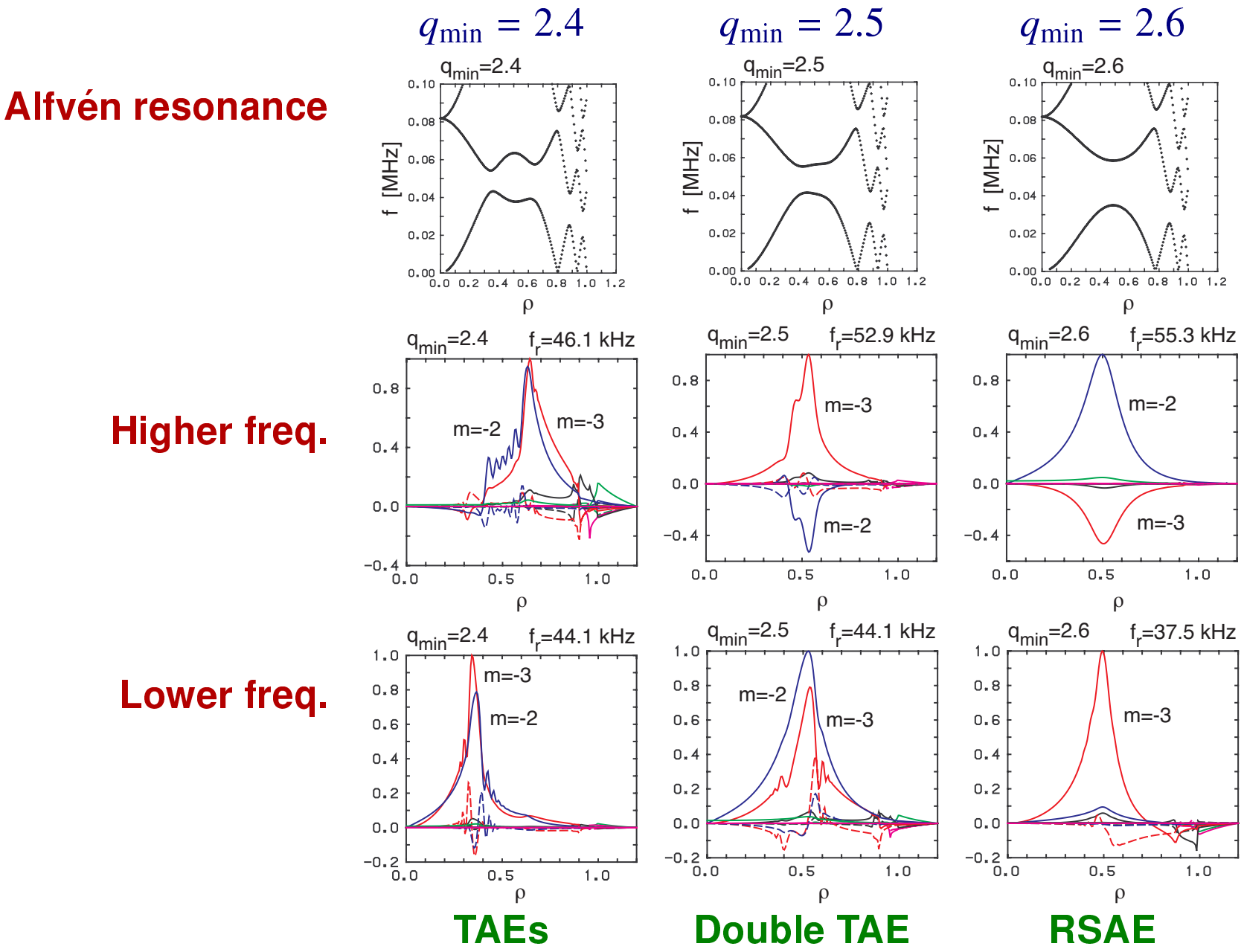


	One Ray	Multi Rays	Beam Tracing
Ray/Beam Profile			
P_{abs} Profile			
j_{CD} Profile			

Transport Analysis

- **Level of Analysis**:
  - **TASK/TR**: Diffusive transport equation:
    - Flux-Gradient relation
    - Conventional transport analysis
  - **TASK/TX**: Dynamical transport equation:
    - Flux-averaged fluid equation
    - Plasma rotation and transient phenomena
  - **TASK/FP**: Kinetic transport equation:
    - Bounce-averaged Fokker-Plank equation
    - Modification of momentum distribution

Eigenmode Structure



Diffusive Transport Analysis: TASK/TR

- **Transport Equation Based on Gradient-Flux Relation**
  - **Multi thermal species**: e.g. Electron, D, T, He
    — Density, thermal energy, (toroidal rotation)
  - **Two beam components**: Beam ion, Energetic α
    — Density, toroidal rotation
  - **Neutral**: Two component (cold and hot), Diffusion equation
  - **Impurity**: Thermal species or fixed profile
- **Transport Model**
  - **Neoclassical**: Wilson, Hinton & Hazeltine, Sauter, NCLASS
  - **Turbulent**: CDBM (current diffusive ballooning mode), GLF23 (V1.61), IFS/PPPL, Weiland
- **Interface to Experimental Data**
  - UFILE (ITPA profile DB)

CDBM Turbulence Model

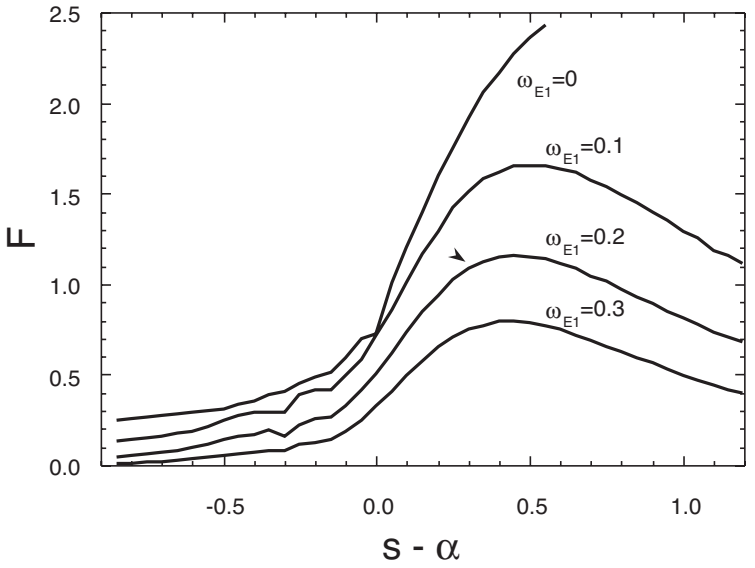
- **Marginal Stability Condition** $(\gamma = 0)$

$$\chi_{\mathrm{TB}} = F(s, \alpha, \kappa, \omega_{\mathrm{E1}})\, \alpha^{3/2} \frac{c^2}{\omega_{\mathrm{pe}}^2} \frac{v_{\mathrm{A}}}{qR}$$

Magnetic shear	$s \equiv \dfrac{r}{q}\dfrac{\mathrm{d}q}{\mathrm{d}r}$
Pressure gradient	$\alpha \equiv -q^2 R \dfrac{\mathrm{d}\beta}{\mathrm{d}r}$
Magnetic curvature	$\kappa \equiv -\dfrac{r}{R}\left(1 - \dfrac{1}{q^2}\right)$
$E \times B$ **rotation shear**	$\omega_{\mathrm{E1}} \equiv \dfrac{r^2}{s v_{\mathrm{A}}} \dfrac{\mathrm{d}}{\mathrm{d}r}\dfrac{E}{rB}$

- **Weak and negative magnetic shear, Shafranov shift and $E \times B$ rotation shear reduce thermal diffusivity.**

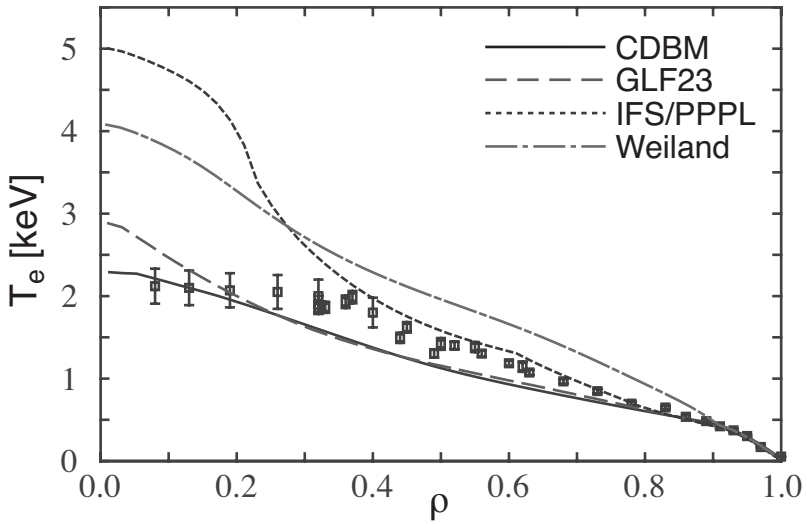
$s - \alpha$ dependence of $F(s, \alpha, \kappa, \omega_{\mathrm{E1}})$

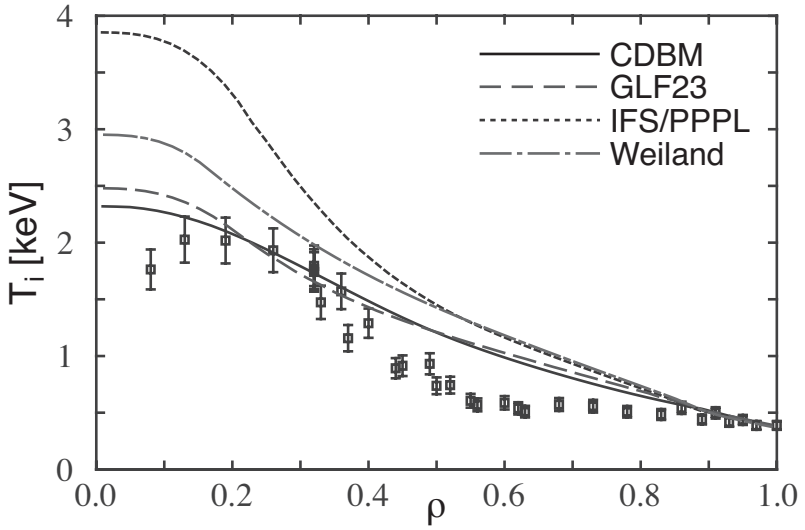


Fitting Formula

$$F = \begin{cases} \dfrac{1}{1 + G_1 \omega_{\mathrm{E1}}^2} \dfrac{1}{\sqrt{2(1 - 2s')(1 - 2s' + 3s'^2)}} \\ \quad \text{for} \quad s' = s - \alpha < 0 \\ \dfrac{1}{1 + G_1 \omega_{\mathrm{E1}}^2} \dfrac{1 + 9\sqrt{2}s'^{5/2}}{\sqrt{2}(1 - 2s' + 3s'^2 + 2s'^3)} \\ \quad \text{for} \quad s' = s - \alpha > 0 \end{cases}$$

Heat transport simulation for the L-mode shot #82188 on DIII-D tokamak



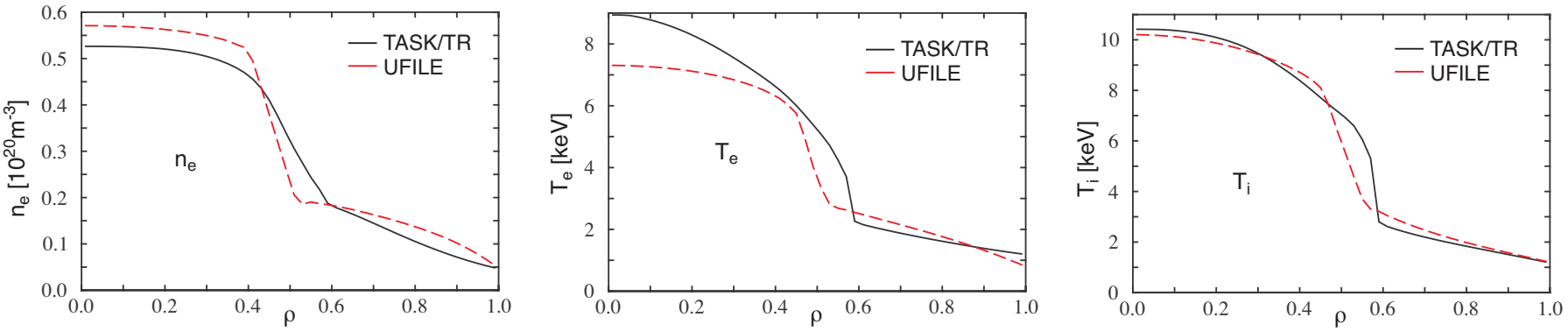


- **Incidental agreement of CDBM and GLF23 results**
- **Fairly good agreement with experiments**

Comparison with JT-60 Experiment

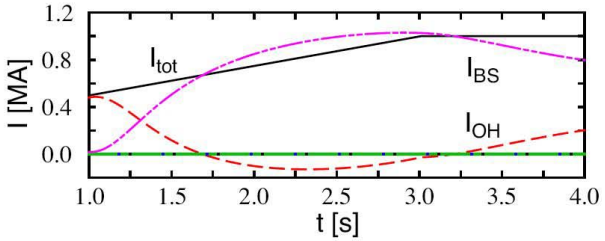
- **Reversed Shear Configuration**
  - **Shot number: 29728**
  - Profiles q, P_{e}, P_{i}: given
  - Metric data: given
  - Edge density and temperature: given
  - Transport model: Sauter + CDBM(with $E \times B$ rotation)

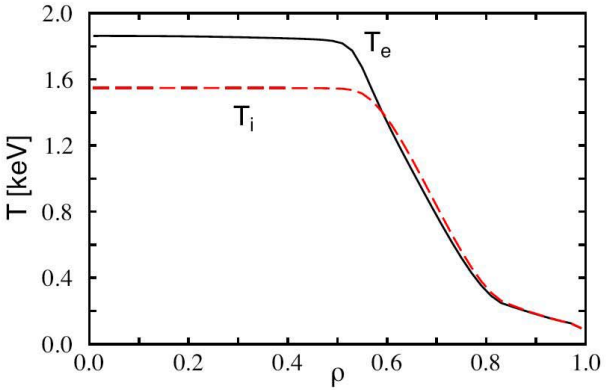
$n_{\mathrm{e}}(\rho)$ $T_{\mathrm{e}}(\rho)$ $T_{\mathrm{i}}(\rho)$

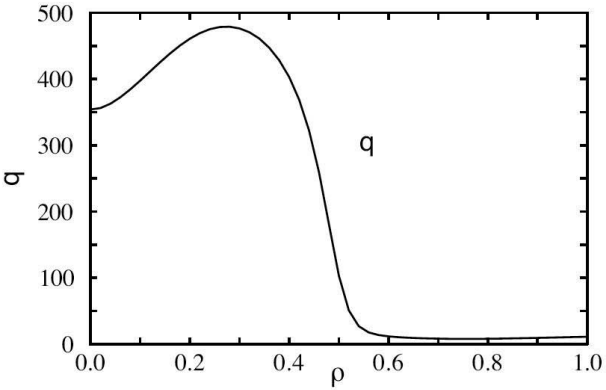


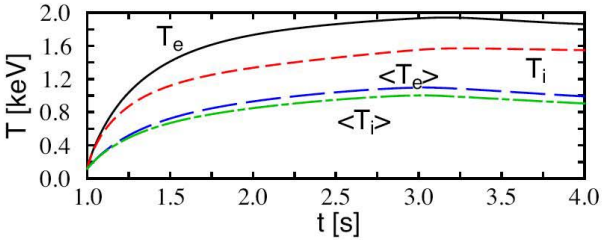
Simulation of Current Hole Formation

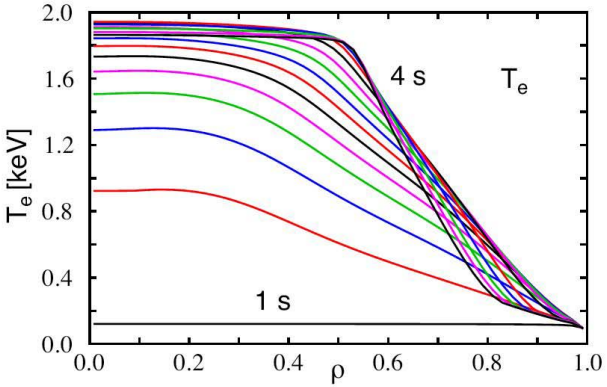
- Current ramp up: $I_{\mathrm{p}} = 0.5 \longrightarrow 1.0\,\mathrm{MA}$
- Moderate heating: $P_{\mathrm{H}} = 6.5\,\mathrm{MW}$
- **Current hole** is formed.

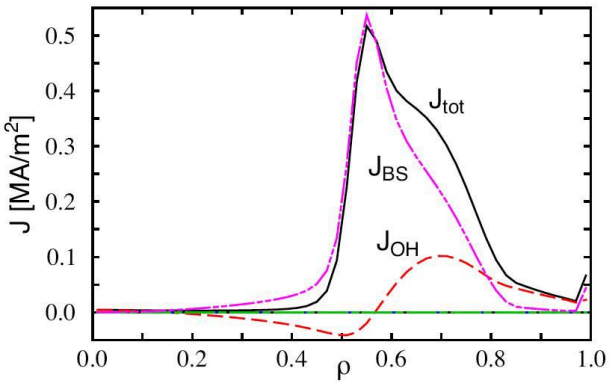






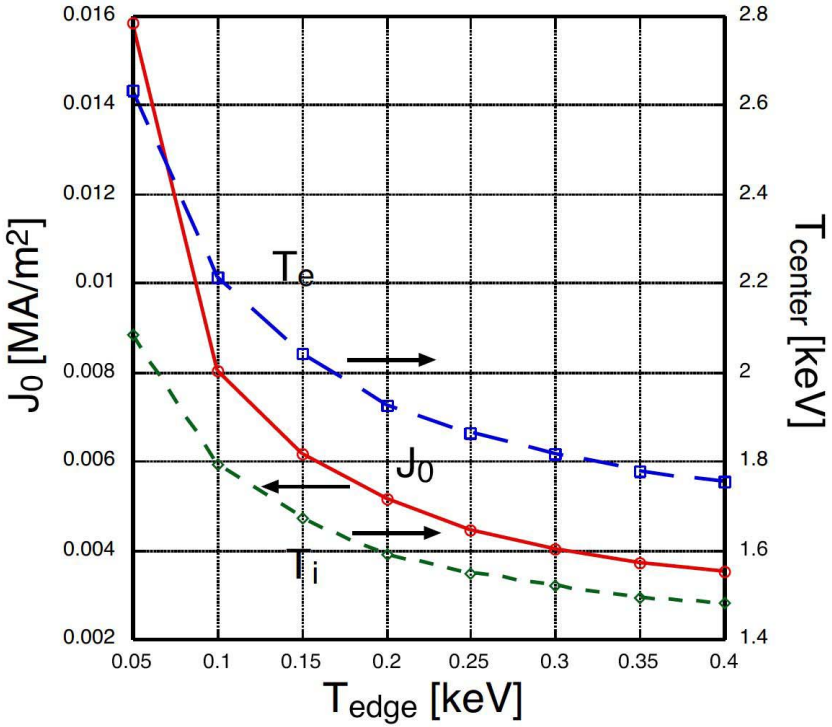


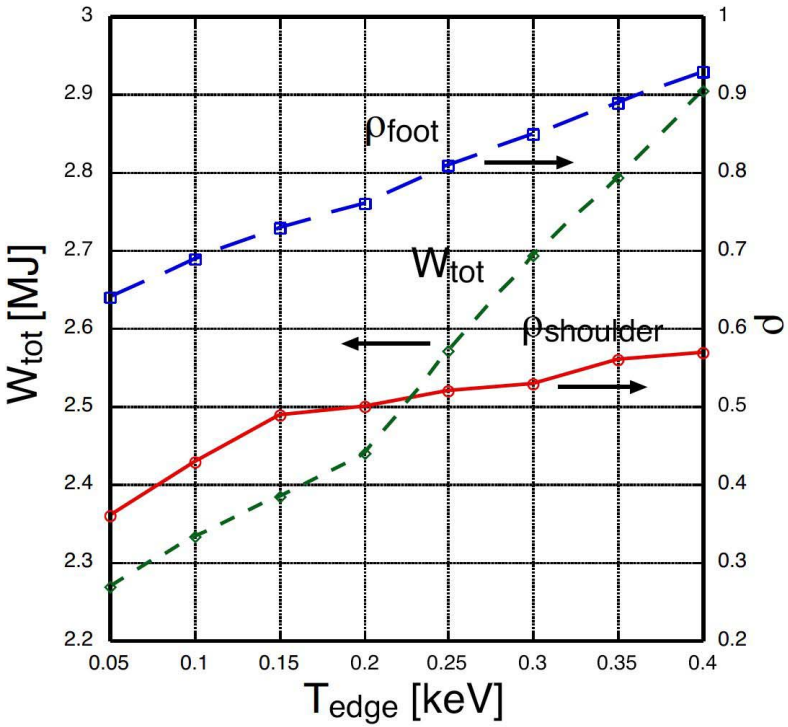




Dependence on Edge Temperature (P_{in} = 6.5 MW, r_H = 0.25 m)

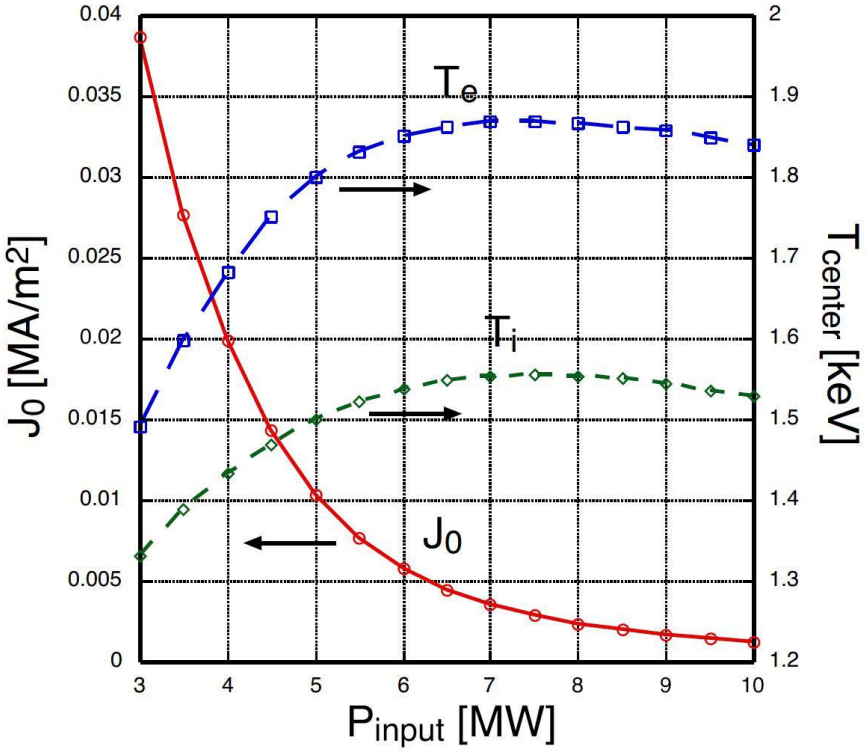
- **Sensitive to the Edge Temperature**
  - Increase of Edge Temperature
  - Slow Penetration of Current
  - Outer ITB Foot

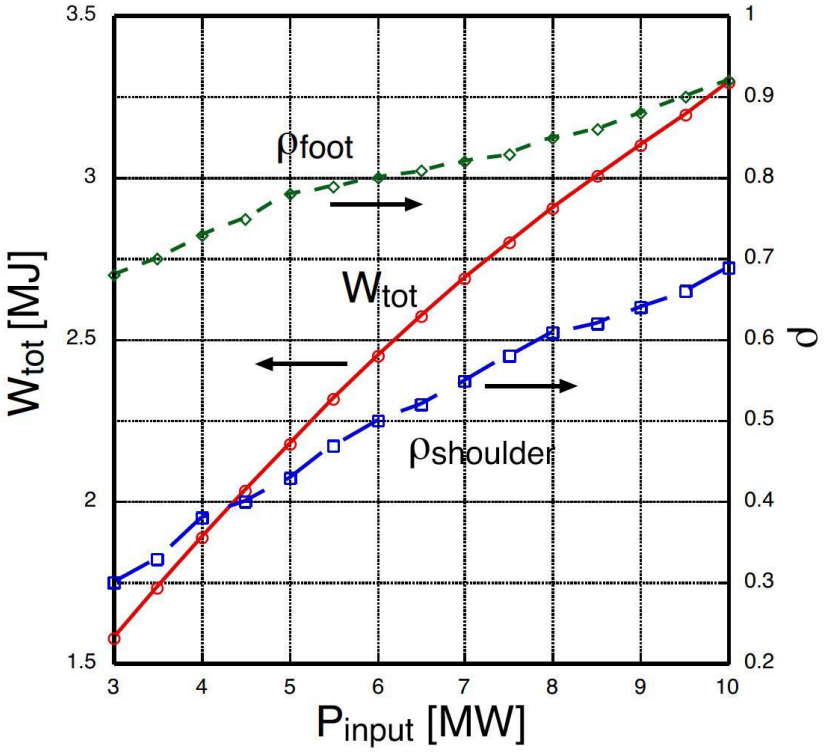


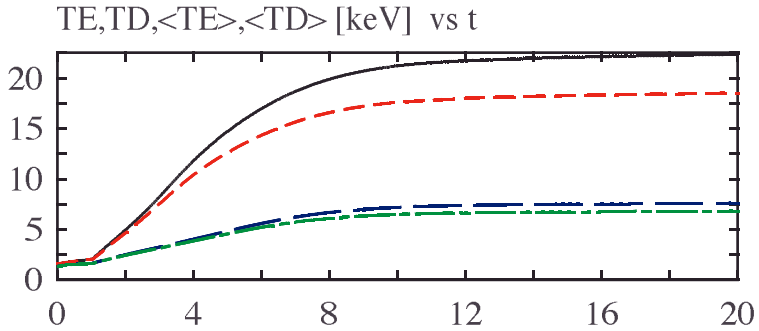


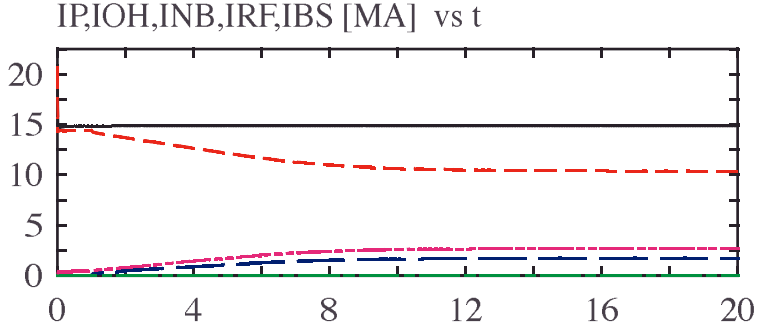
Dependence on Input Power (T_{edge} = 0.25 keV, r_H = 0.25 m)

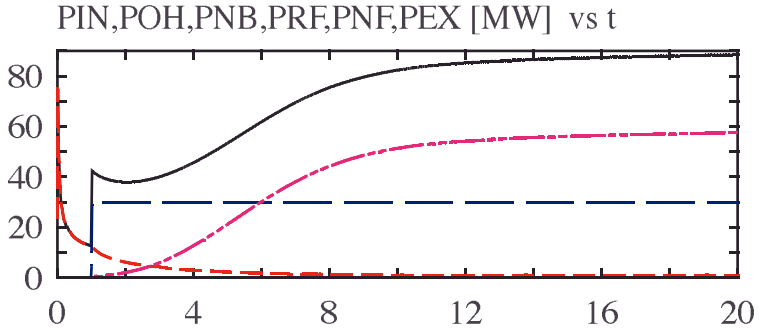
- Current density on axis decays exponentially, no negative
- Increase of ITB foot leads to decrease of central temperature

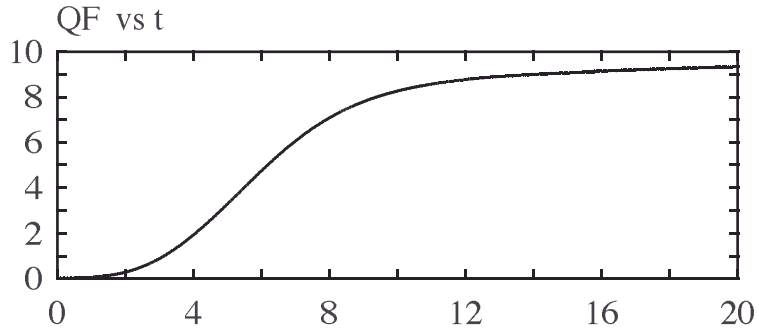


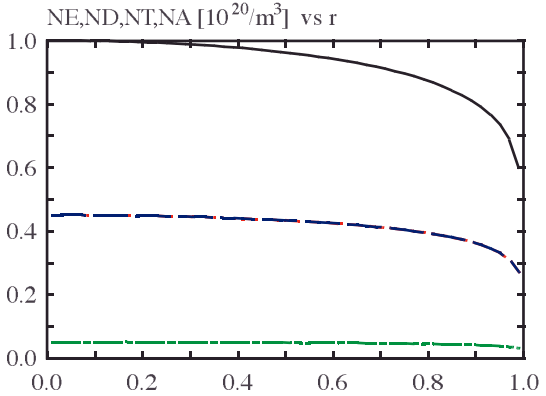


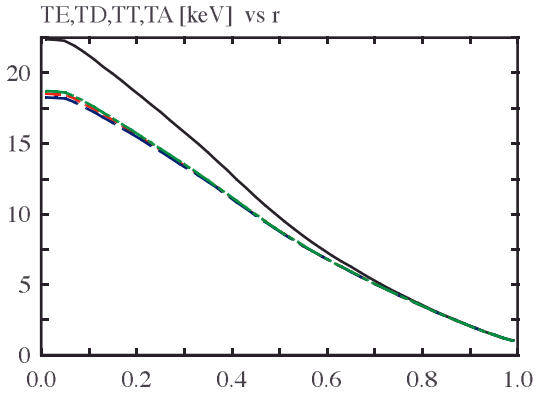


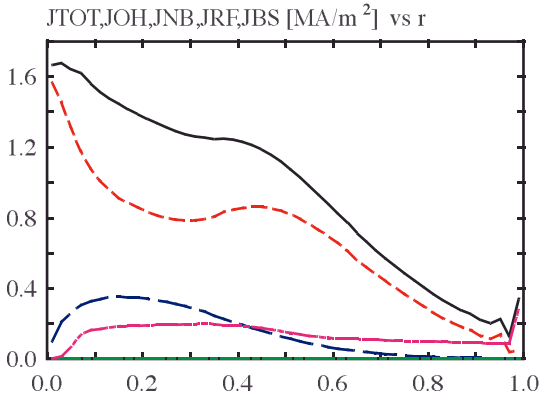








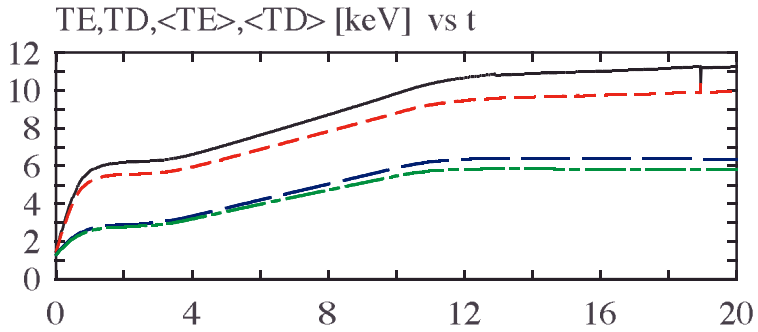


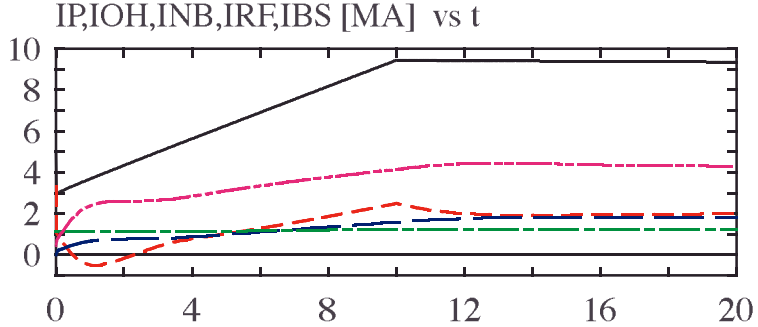


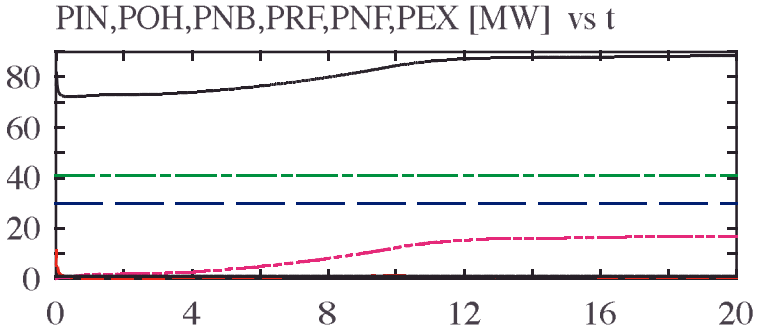
IP = 15MA

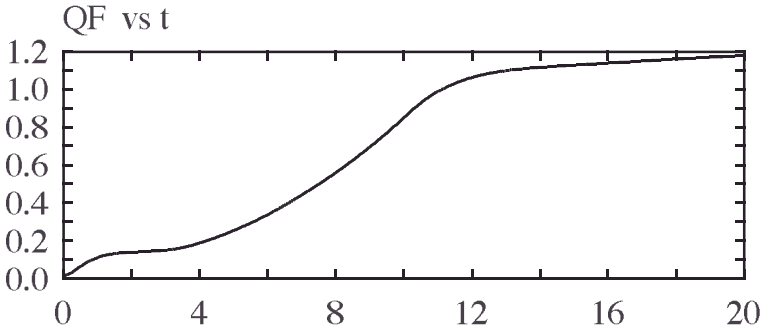
PNB = 30 MW

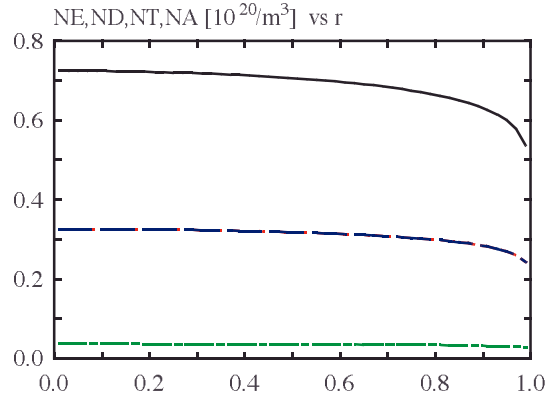
Q = 9

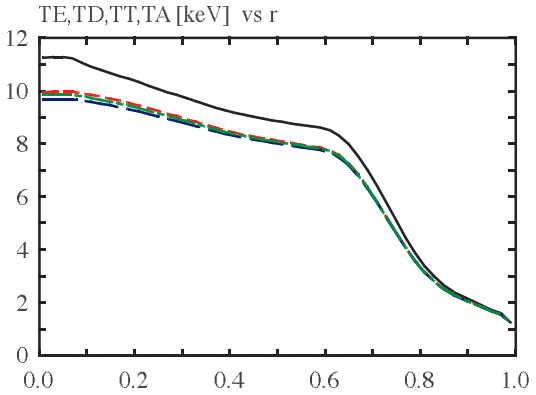


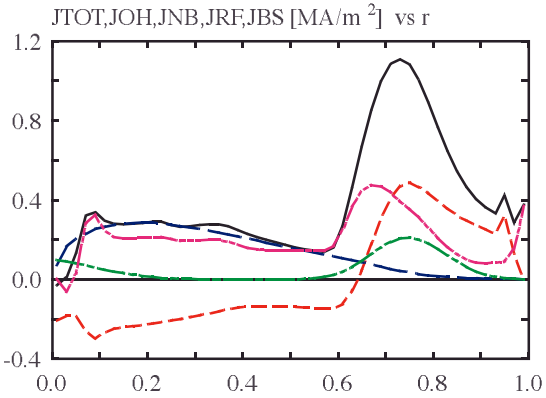












Ip = 9 MA

PNB = 30 MW

PLH = 20 MW

PIC= 20 MW

PEC = 2 MW

Q = 1.2

Summary

- We are developing TASK code as a reference core code for burning plasma simulation based on transport analysis. Typical size of total code including these module is 800MB. New modular structure is under construction.
- We have shown preliminary results of ITER current profile simulation for standard operation and advanced tokamak operation. At present, power absorption profile is not provided by the wave modules yet.
- Near future work
  - Complete full modular structure
  - Systematic comparison with experimental data
  - Survey optimum current profile and necessary launching conditions
  - Improvement of NBI module