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Integrated Tokamak Modeling Code TASK and Its Recent Results

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Contents

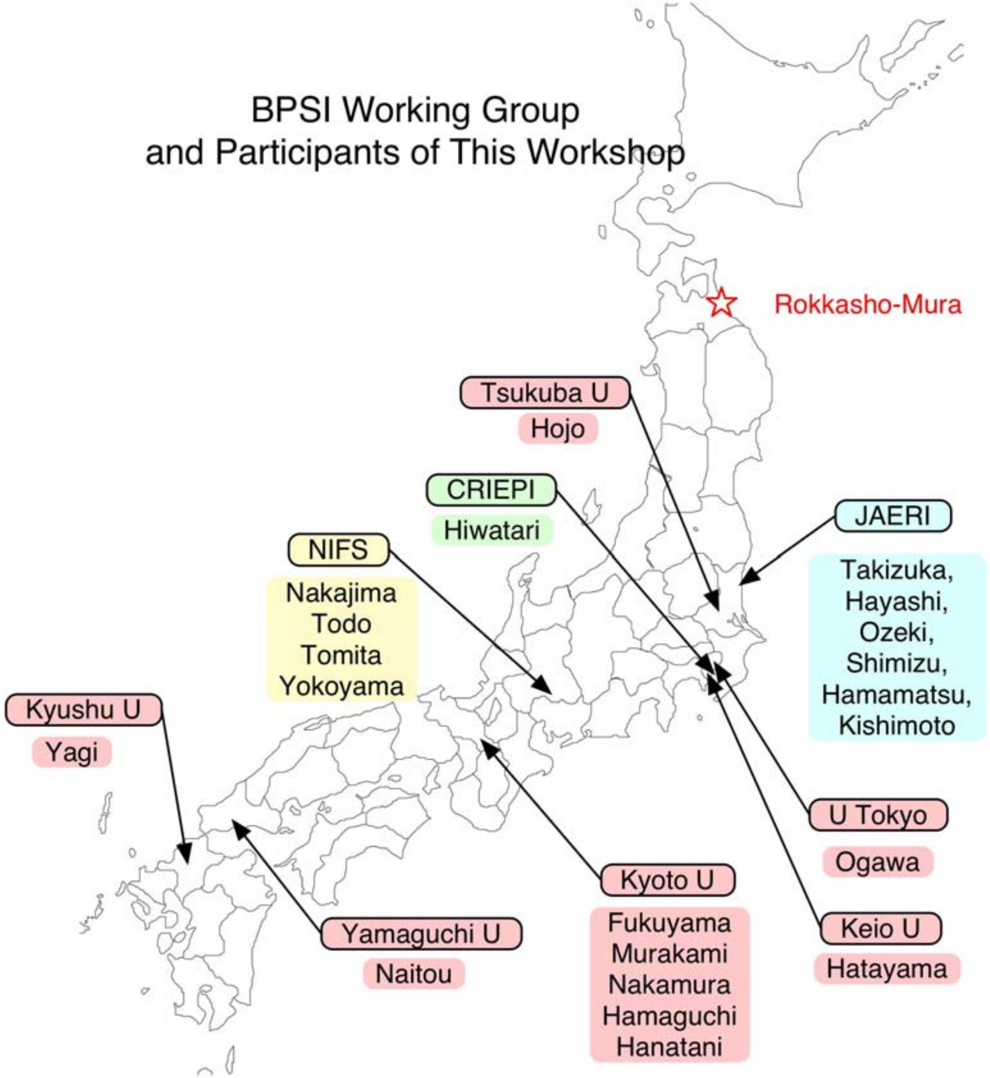
- Tokamak Modeling Code TASK
- Modules of TASK Code
- Stability Analysis TASK/WM and TASK/WA
- Diffusive Transport Analysis TASK/TR
- Future Plan

TASK Code

- **T**ransport **A**nalysing **S**ystem for Tokama**K**
- **Features**
  - **Core of Integrated Modelling Code**
    - Modular structure
    - Reference data interface
  - **Various Heating and Current Drive Scheme**
    - EC, LH, IC, AW, (NB)
  - **High Portability**
    - Most of library routine included
    - Graphic libraries (gsaf, gsgl)
    - Optional: MPI, LAPACK
  - **Development using CVS**
  - **To Be Open Source**
  - **Extension to Toroidal Helical Plasmas**

TASK as a part of BPSI

- **BPSI**: Burning Plasma Simulation Initiative
  - Collaboration of Universities, NIFS and JAERI



Activities of BPSI

- **Framework of Integrated Code:**
  - Standard interface for data transfer
  - Reference core code: **TASK**
- **Modeling of Phenomena with Different Scales:**
  - Transport-MHD hierarchical model
  - Core-SOL interface model
  - Transport modeling in the presence of islands
- **Advanced Computational Technique:**
  - Parallel processing
  - Distributed computing
  - Visualization

Modules of TASK code

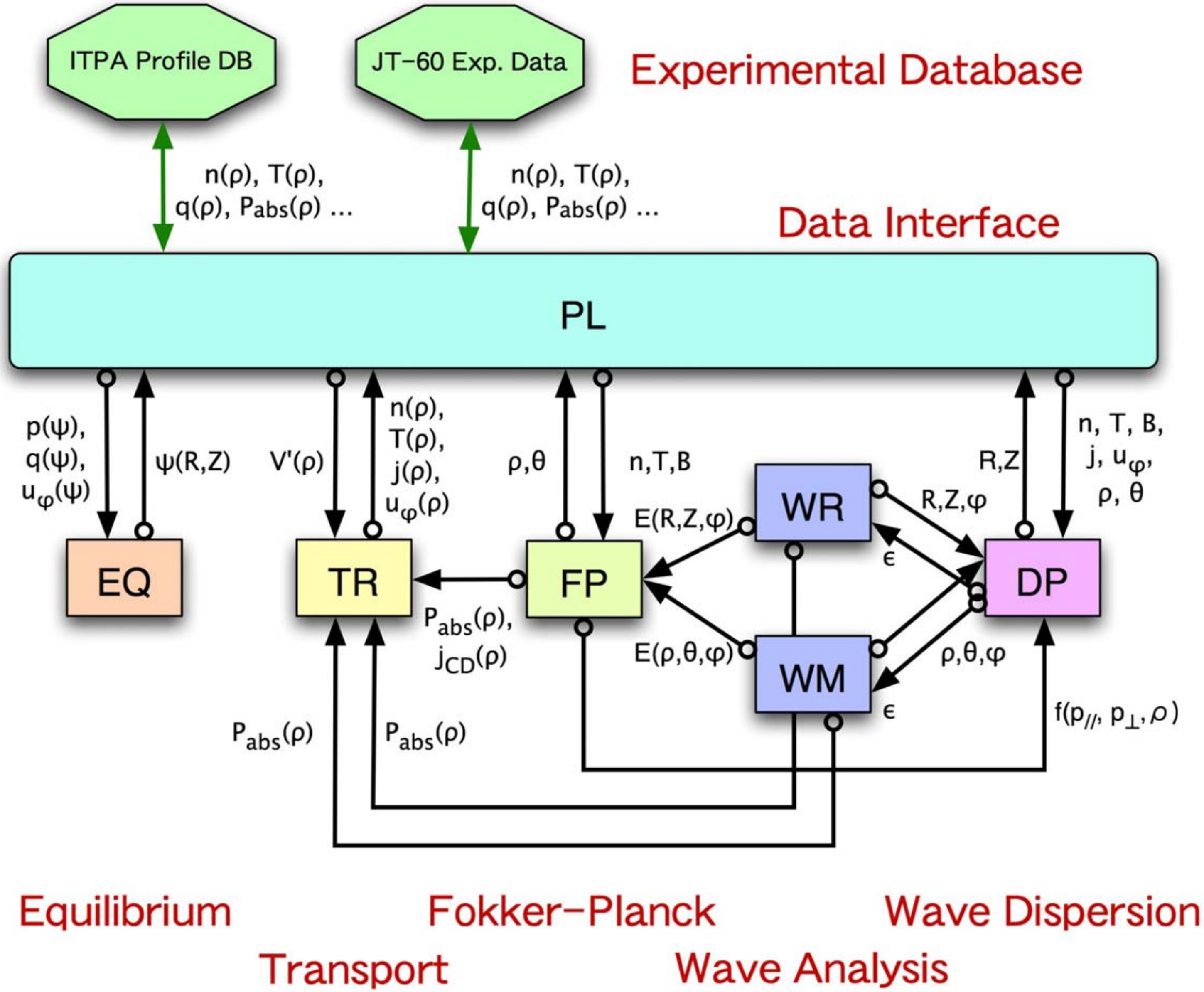
Present Modules

EQ	**2D Equilibrium**	Fixed boundary
TR	**1D Transport**	Diffusive model
FP	**3D Fokker-Planck**	Bounce averaged
WR	**Ray/Beam Tracing**	EC, LH
WM	**Full Wave Analysis**	IC,AE
DP	**Wave Dispersion**	Various models
PL	**Data Conversion**	Profile database
LIB	**Common Library**	

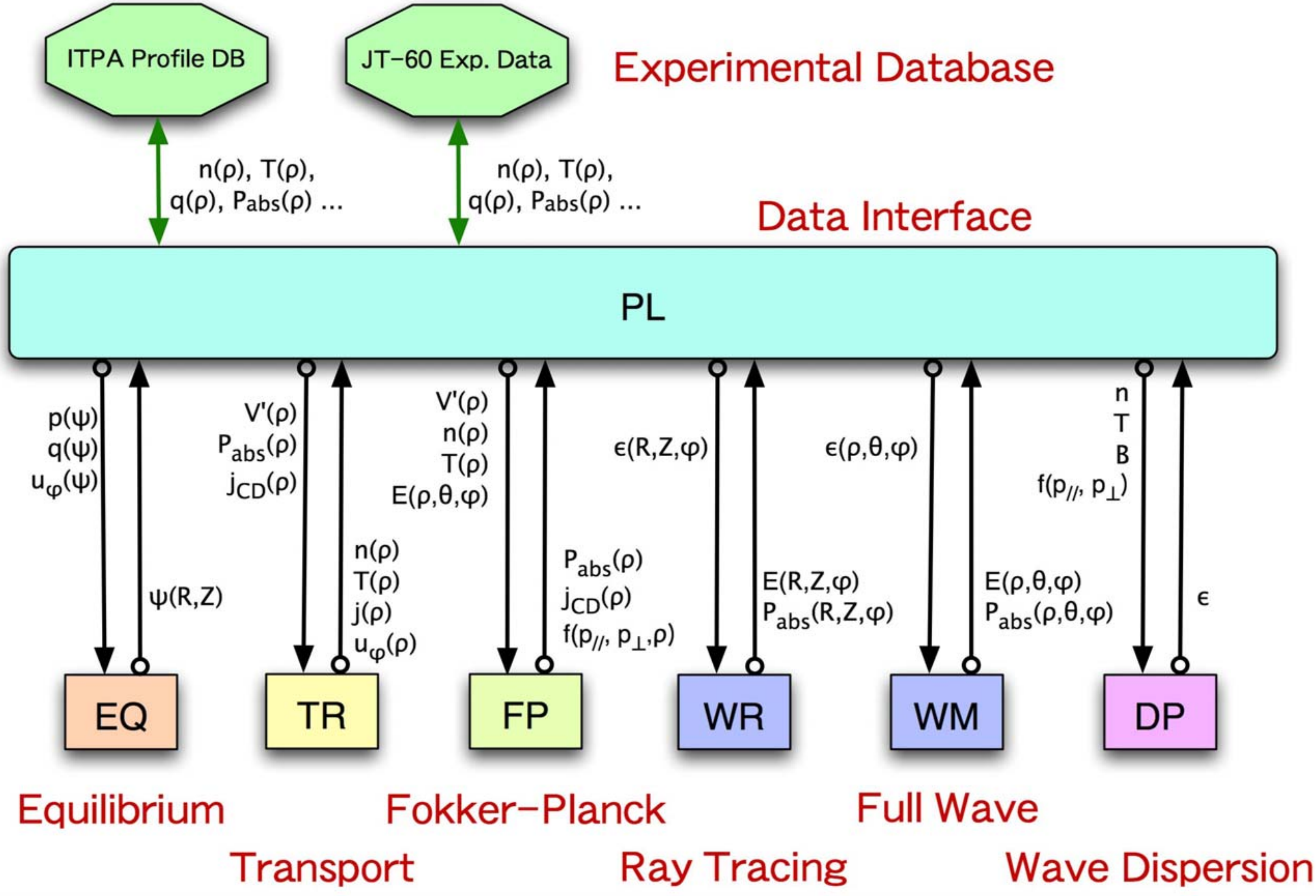
Under Development

TX	**1D Transport**	Dynamical model
WA	**Full Wave**	Stability
EX	**2D Equilibrium**	Free boundary

Present Structure of TASK



New Modular Structure of TASK



ECCD analysis : TASK/WR/FP/DP

- **Geometrical Optics: TASK/WR**
  - **Ray Tracing Method**:
    — Plane wave: beam size $d \gg \lambda$ wave length
  - **Beam Tracing Method**
    — Analysis of wave propagation with finite beam size
    — **Beam shape** : Gaussian beam

$$\boldsymbol{E}(\boldsymbol{r}) = \mathrm{Re}\left[C(\boldsymbol{r})\,\boldsymbol{e}(\boldsymbol{r})\,\mathrm{e}^{\,\mathrm{i}\,s(\boldsymbol{r})-\phi(\boldsymbol{r})}\right]$$

· C: amplitude, $\boldsymbol{e}$: polarization, $s(\boldsymbol{r}) + \mathrm{i}\,\phi(\boldsymbol{r})$: phase

$$\begin{aligned} s(\boldsymbol{r}) &= s_0(\tau) + k_\alpha^0(\tau)[r^\alpha - r_0^\alpha(\tau)] + \frac{1}{2}s_{\alpha\beta}[r^\alpha - r_0^\alpha(\tau)][r^\beta - r_0^\beta(\tau)] \\ \phi(\tau) &= \frac{1}{2}\phi_{\alpha\beta}[r^\alpha - r_0^\alpha(\tau)][r^\beta - r_0^\beta(\tau)] \end{aligned}$$

· $\boldsymbol{r}_0$: position of beam axis, $\boldsymbol{k}^0$: wave number on beam axis

· **Curvature radius**: $R_\alpha = 1/\lambda s_{\alpha\alpha}$, **Beam radius**: $d_\alpha = \sqrt{2/\phi_{\alpha\alpha}}$

— **18 Ordinary Differential Equations** for r_α, k_α, $s_{\alpha\beta}$ and $\phi_{\alpha\beta}$,

Fokker-Planck Analysis : TASK/FP

- **Fokker-Planck equation** for **velocity distribution function** $f(p_{\|}, p_{\perp}, \psi, t)$

$$\frac{\partial f}{\partial t} = E(f) + C(f) + Q(f) + L(f)$$

  - $E(f)$: Acceleration term due to DC electric field
  - $C(f)$: Coulomb collision term
  - $Q(f)$: Quasi-linear term due to wave-particle resonance
  - $L(f)$: Spatial diffusion term

- **Bounce-averaged**: Trapped particle effect, zero banana width

- **Relativistic**: momentum $\boldsymbol{p}$, weakly relativistic collision term

- **Nonlinear collision**: momentum conservation, energy conservation

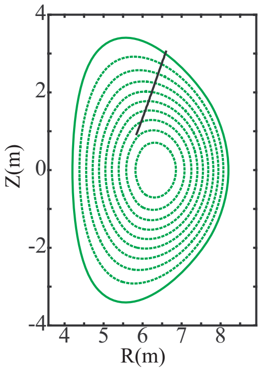
- **Three-dimensional**: spatial diffusion (classical, neoclassical, turbulence)

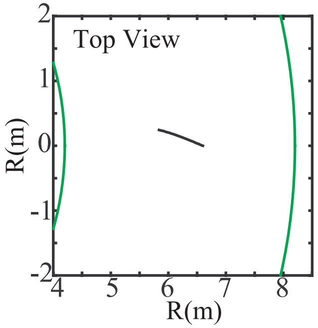
Wave Dispersion Analysis : TASK/DP

- **Various Models of Dispersion Tensor $\overleftrightarrow{\epsilon}(\omega, \boldsymbol{k}; \boldsymbol{r})$:**
  - Resistive MHD model
  - Collisional cold plasma model
  - Collisional warm plasma model
  - Kinetic plasma model (Maxwellian, non-relativistic)
  - Kinetic plasma model (Arbitrary $f(\boldsymbol{v})$, non-relativistic)
  - Kinetic plasma model (Arbitrary $f(\boldsymbol{v})$, relativistic)
  - Gyro-kinetic plasma model (Maxwellian, non-relativistic)
  - Gyro-kinetic plasma model (Arbitrary $f(\boldsymbol{v})$, non-relativistic)
- **Arbitrary $f(\boldsymbol{v})$:**
  - Relativistic Maxwellian
  - Output of TASK/FP

Analysis of ECCD by TASK Code

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



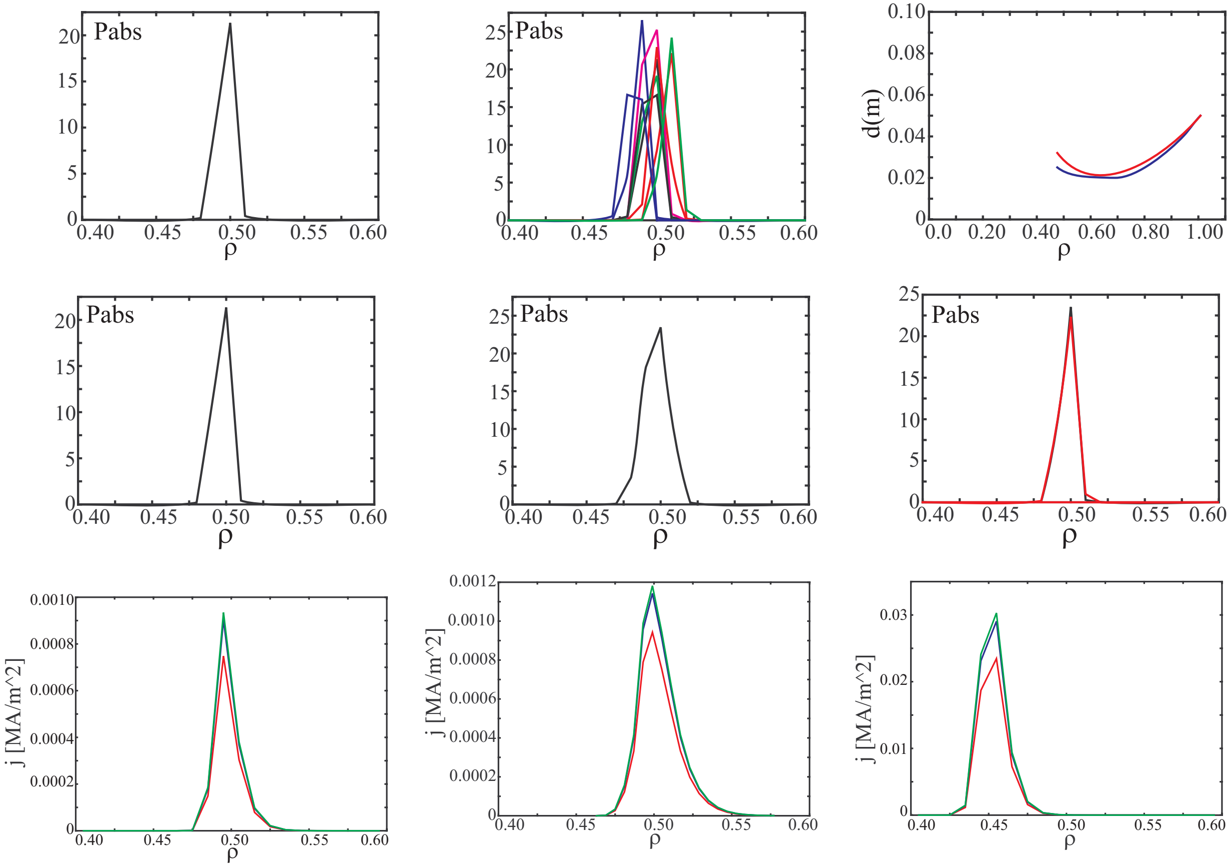


One Ray **Multi Rays** **Beam Tracing**

Ray/Beam Profile

P_{abs} Profile

j_{CD} Profile



Full wave analysis: TASK/WM

- **magnetic surface coordinate**: (ψ, θ, φ)
- Boundary-value problem of **Maxwell's equation**

$$\nabla \times \nabla \times \boldsymbol{E} = \frac{\omega^2}{c^2} \overleftrightarrow{\epsilon} \cdot \boldsymbol{E} + \mathrm{i}\,\omega\mu_0 \boldsymbol{j}_{\mathrm{ext}}$$

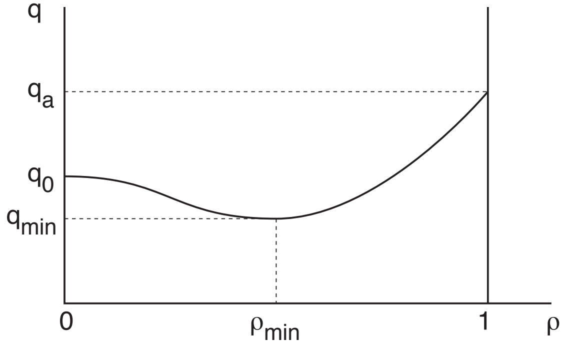
- Kinetic **dielectric tensor**: $\overleftrightarrow{\epsilon}$
    - **Wave-particle resonance**: $Z[(\omega - n\omega_{\mathrm{c}})/k_{\|}v_{\mathrm{th}}]$
    - **Fast ion: Drift-kinetic**

$$\left[\frac{\partial}{\partial t} + v_{\|}\nabla_{\|} + (\boldsymbol{v}_{\mathrm{d}} + \boldsymbol{v}_{\mathrm{E}}) \cdot \nabla + \frac{e_\alpha}{m_\alpha}(v_{\|}E_{\|} + \boldsymbol{v}_{\mathrm{d}} \cdot \boldsymbol{E})\frac{\partial}{\partial \varepsilon}\right] f_\alpha = 0$$

- Poloidal and toroidal **mode expansion**
    - **Accurate estimation of $k_{\|}$**
- Eigenmode analysis: **Complex eigen frequency** which maximize wave amplitude for fixed excitation proportional to electron density

Analysis of TAE in Reversed Shear Configuration

Assumed q profile



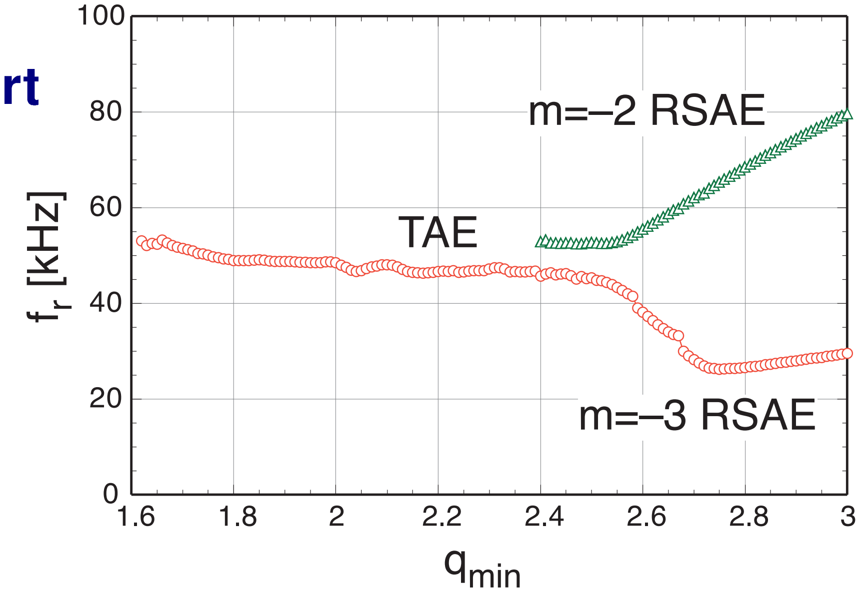
Plasma Parameters

R_0	3 m
a	1 m
B_0	3 T
$n_e(0)$	$10^{20}\,\mathrm{m}^{-3}$
$T(0)$	3 keV
$q(0)$	3
$q(a)$	5
$\rho_{\min}$	0.5
n	1

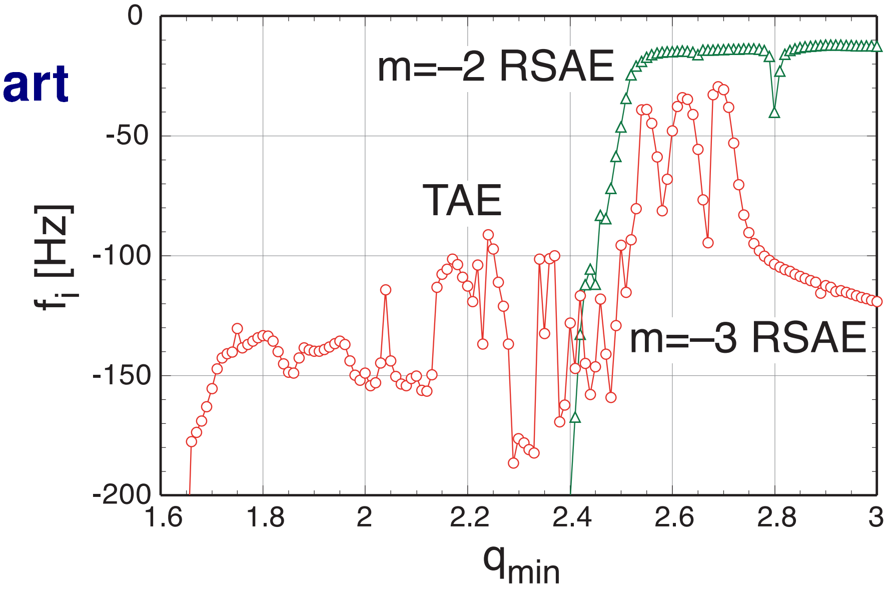
Flat density profile

$q_{\min}$ Dependence of Eigenmode Frequency

Real part



Imag part



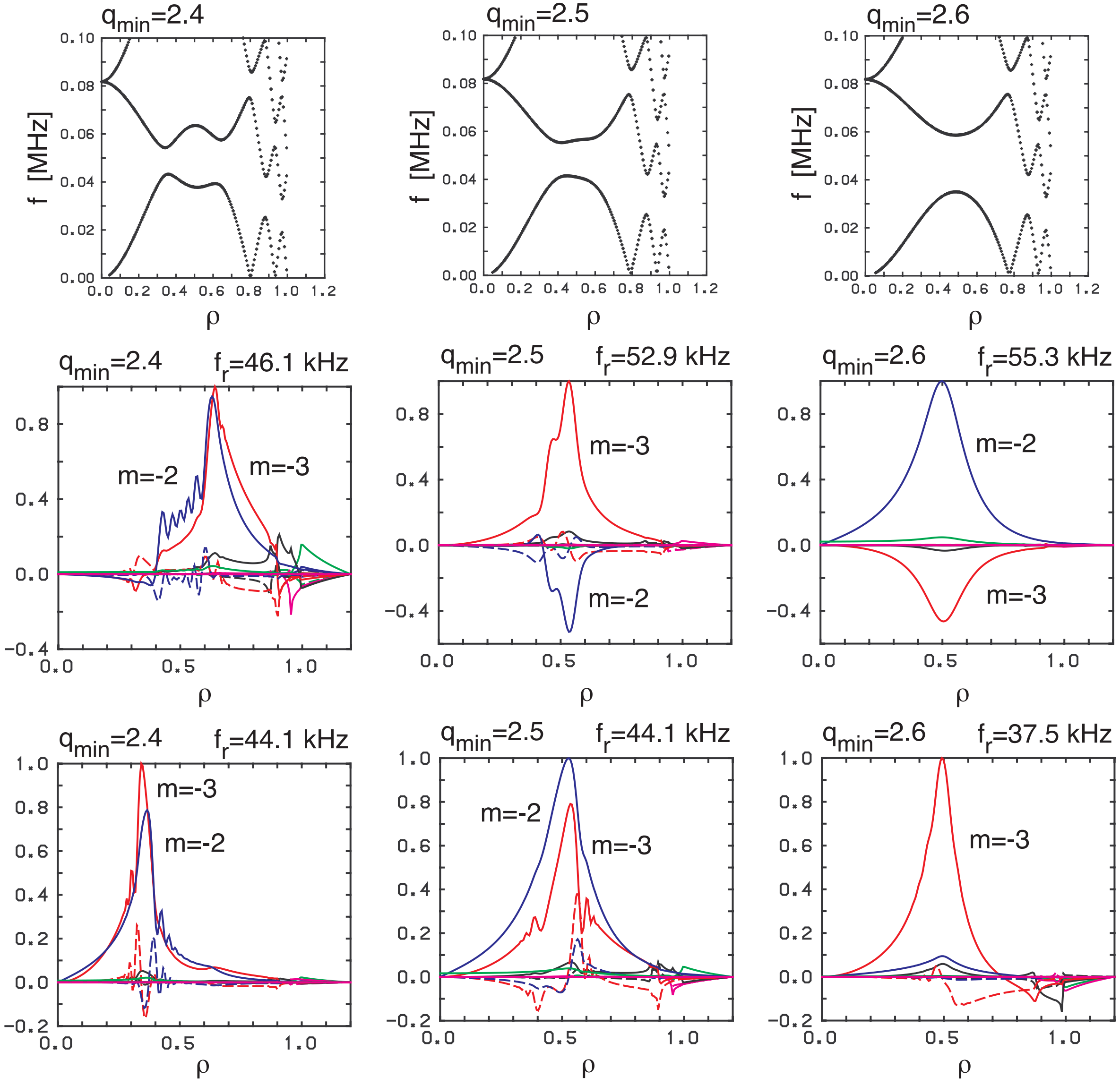
Eigenmode Structure in Reversed Shear Configuration

$q_{\min} = 2.4$ $q_{\min} = 2.5$ $q_{\min} = 2.6$

Alfvén resonance

Higher freq.

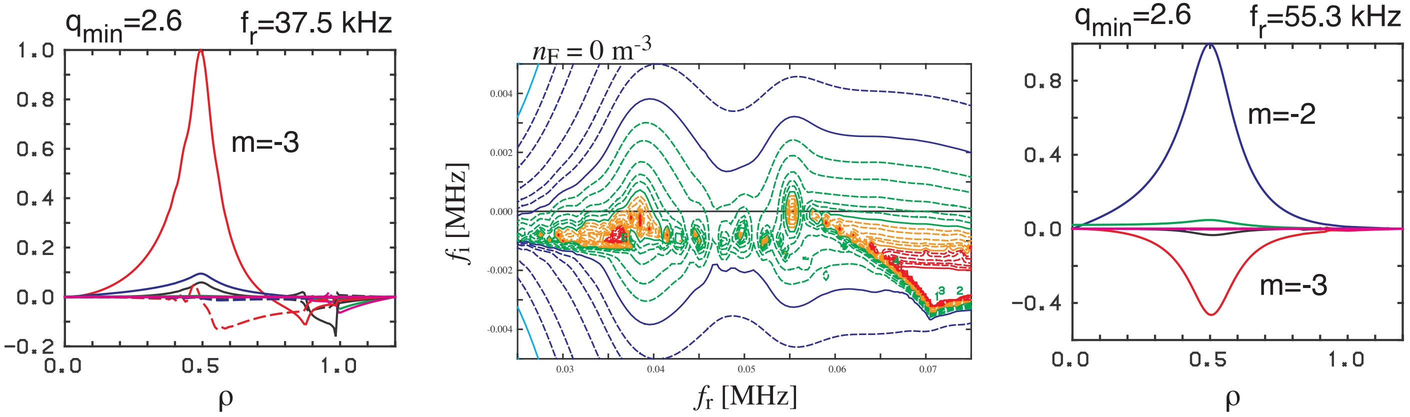
Lower freq.



TAEs **Double TAE** **RSAE**

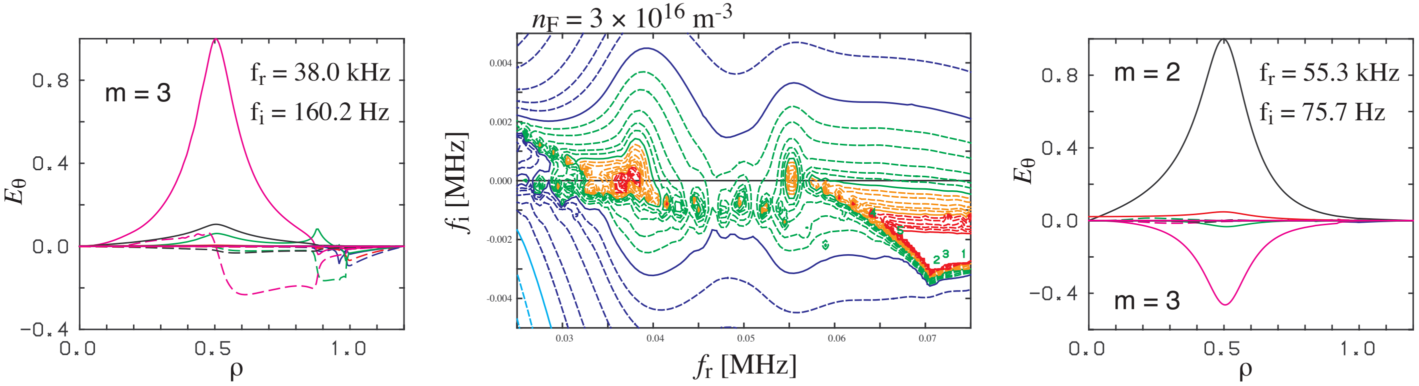
Excitation by Energetic Particles ($q_{\min} = 2.6$)

- Without EP



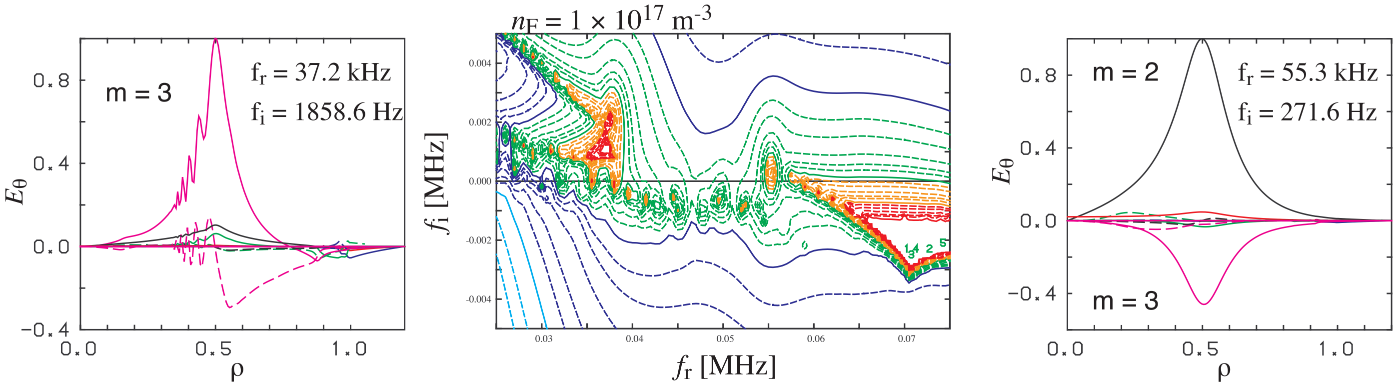
- With EP

  $3 \times 10^{16}\,\mathrm{m}^{-3}$
  360 keV
  0.5 m



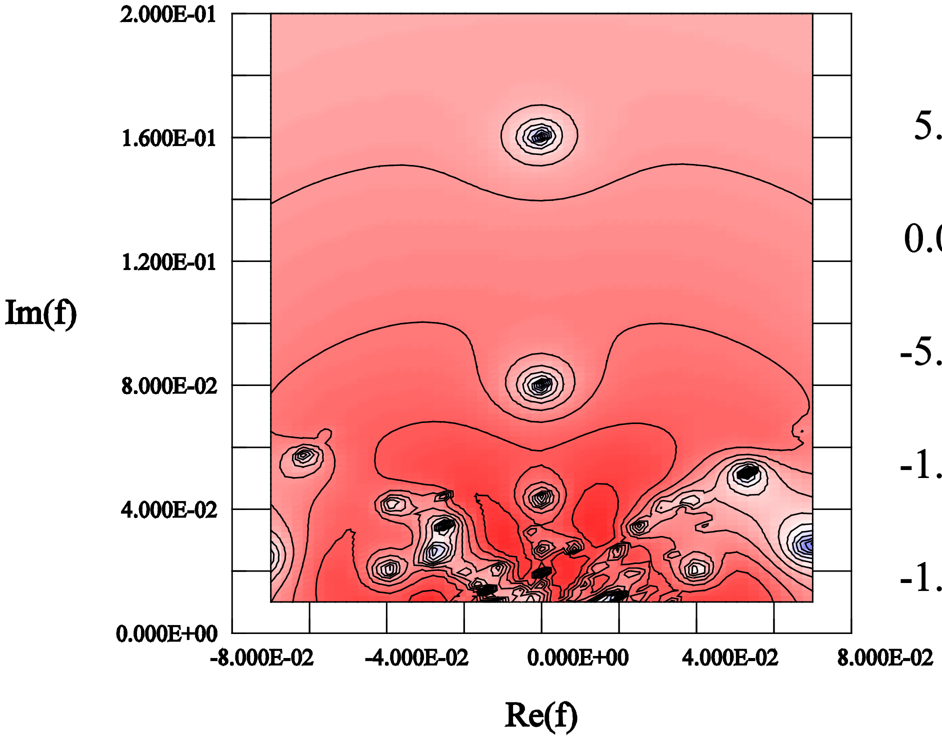
- With EP

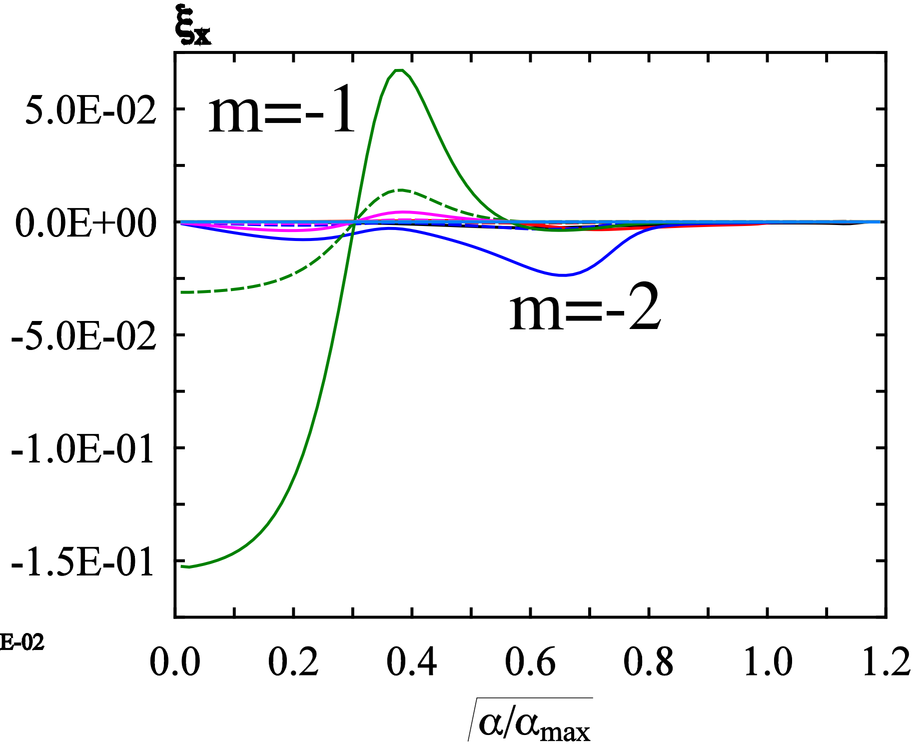
  $1 \times 10^{17}\,\mathrm{m}^{-3}$
  360 keV
  0.5 m



Internal Kink mode I

- Contour maps of $[\log(\int|\vec{E}|^2 dV)]^{-1}$ in the complex frequency space ($n = 1,\ \ q_0 = 0.7,\ \ q_a = 3$).





Displacement in the radial direction

Derivation of Kinetic Dielectric Tensor 3

- In order to integrate Eq.(1) with respect to $\vec{x}'$, we apply the Fourier series expansion for $\vec{A}(\vec{x}'(\vec{J},\vec{\Theta}))$ and $\phi(\vec{x}'(\vec{J},\vec{\Theta}))$, expand them into power series around a guiding center position $(\alpha_{gc}, \beta_{gc}, \varphi_{gc})$ with respect to the larmor radius ρ, and integrate Eq.(1) with respect to Θ_g and Φ. Finally we have

$$\begin{aligned}\vec{j}_{kmn}(\vec{x}) = \frac{1}{2\pi}\int d^3J \sum_{\vec{l}} \frac{\vec{l}}{\vec{l}\cdot\vec{\omega}-\omega}\cdot\frac{\partial f_0}{\partial \vec{J}}(\vec{J})\,\vec{j}^{\,*}_{\vec{l}}(\vec{x}|\vec{J})\,e_j \\ \times \int d\Theta_P\, e^{\mathrm{i}(-l_p\Theta_p+k\alpha_{gc}+m\beta_{gc}+n\tilde{\varphi}_{gc})} \\ \times \Big[-\Big\{\vec{v}_{gc}J_0(k_\perp\rho)+\mathrm{i}v_{\mathrm{larmor}}(\hat{\vec{k}}_\perp\times\vec{b})J_1(k_\perp\rho)\Big\}\vec{A}_{kmn} \\ +\phi_{kmn}J_0(k_\perp\rho)\Big].\end{aligned}$$

where J_0 and J_1 are the Bessel functions, $\tilde{\varphi}_{gc}=\varphi_{gc}-\Phi$, $v_{\mathrm{larmor}}=\sqrt{2\mu B_0/m_j}$, $\vec{v}_{gc}=(\dot{\alpha}_{gc},\dot{\beta}_{gc},\dot{\varphi}_{gc})$, and $\vec{v}_{gc}$ satisfies the following equations.

Transport Analysis

- **Level of Analysis**:
  - **TASK/TR**: Diffusive transport equation: Flux-Gradient relation
  - **TASK/TX**: Dynamical transport equation: Flux-averaged fluid equation (plasma rotation, transient phenomena)
  - **TASK/FP**: Kinetic transport equation: Bounce-averaged Fokker-Plank equation
- **Diffusive transport equation**: V: Volume, ρ: Normalized radius, $V' = \mathrm{d}V/\mathrm{d}\rho$
  - **Particle transport**

$$\frac{1}{V'}\frac{\partial}{\partial t}(n_s V') = -\frac{\partial}{\partial\rho}\left(\langle|\nabla\rho|\rangle n_s V_s - \langle|\nabla\rho|^2\rangle D_s \frac{\partial n_s}{\partial\rho}\right) + S_s$$

  - **Heat transport**

$$\frac{1}{V'^{5/3}}\frac{\partial}{\partial t}\left(\frac{3}{2}n_s T_s V'^{5/3}\right) = -\frac{1}{V'}\frac{\partial}{\partial\rho}\left(V'\langle|\nabla\rho|\rangle\frac{3}{2}n_s T_s V_{Es} - V'\langle|\nabla\rho|^2\rangle n_s \chi_s \frac{\partial T_s}{\partial\rho}\right) + P_s$$

  - **Current diffusion**

$$\frac{\partial B_\theta}{\partial t} = \frac{\partial}{\partial\rho}\left[\frac{\eta}{FR_0\langle R^{-2}\rangle}\frac{R_0}{\mu_0}\frac{F^2}{V'}\frac{\partial}{\partial\rho}\left(\frac{V' B_\theta}{F}\left\langle\frac{|\nabla\rho|^2}{R^2}\right\rangle\right) - \frac{\eta}{FR_0\langle R^{-2}\rangle}\langle \boldsymbol{J}\cdot\boldsymbol{B}\rangle_{\mathrm{ext}}\right]$$

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)
- **Sources**
  - Heating and current data: Interface to TASK/WR/WM/FP, Analytical
  - Simple NBI, Nuclear fusion, Ionization, Charge exchange, Radiation
- **Interface to Experimental Data**
  - UFILE

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 $s \equiv \frac{r}{q} \frac{\mathrm{d}q}{\mathrm{d}r}$

Pressure gradient $\alpha \equiv -q^2 R \frac{\mathrm{d}\beta}{\mathrm{d}r}$

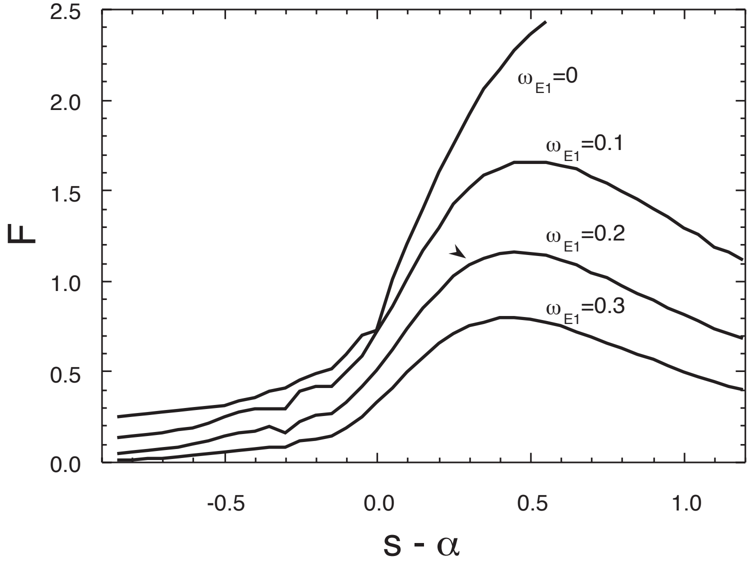
Magnetic curvature $\kappa \equiv -\frac{r}{R}\left(1 - \frac{1}{q^2}\right)$

$E \times B$ **rotation shear** $\omega_{\mathrm{E1}} \equiv \frac{r^2}{s v_{\mathrm{A}}} \frac{\mathrm{d}}{\mathrm{d}r} \frac{E}{rB}$

- **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

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

Typical Profile (CDBM+NCLASS)

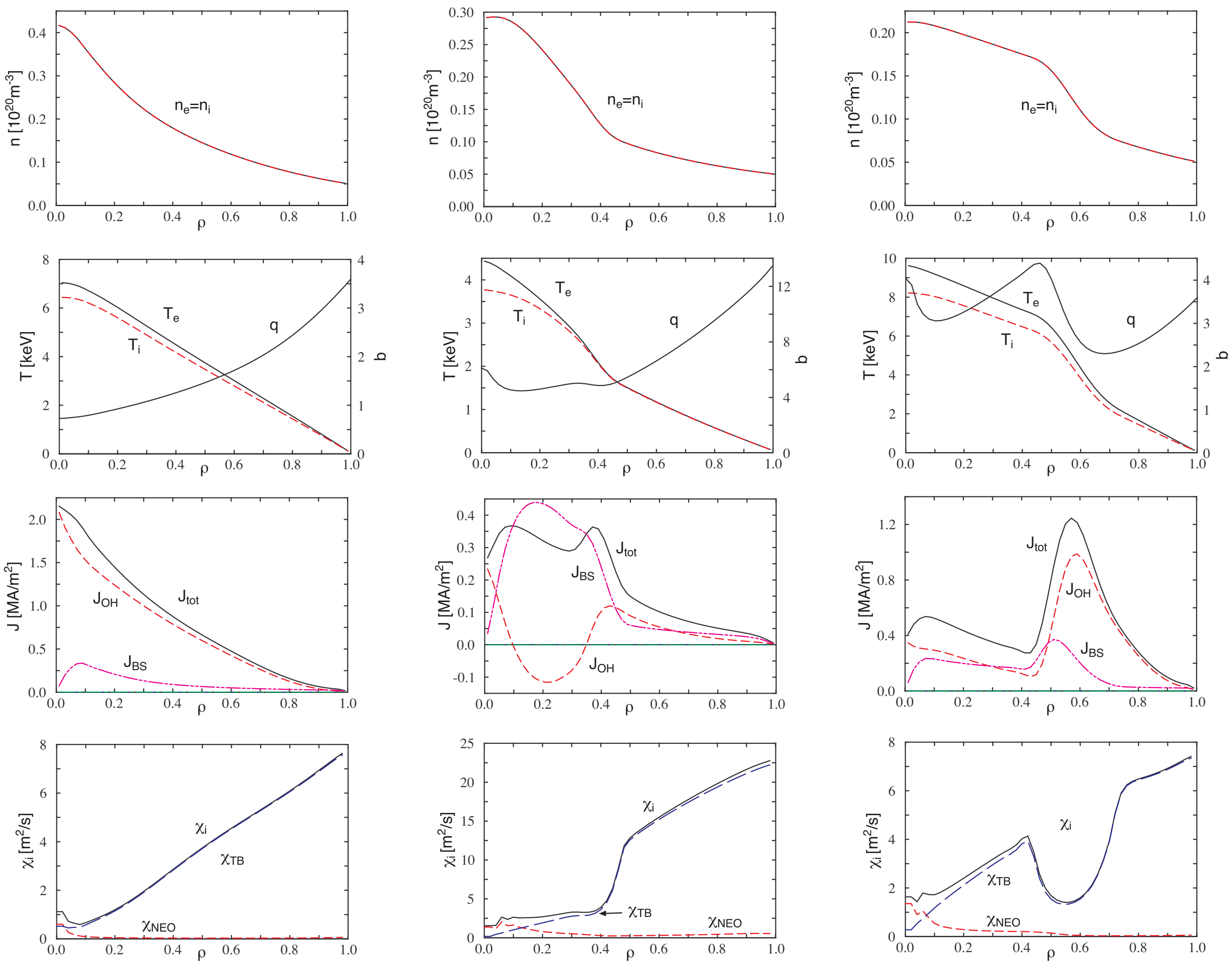
L-mode | High β_p | Reversed shear

$n(\rho)$

$T(\rho)$, $q(\rho)$

$j(\rho)$

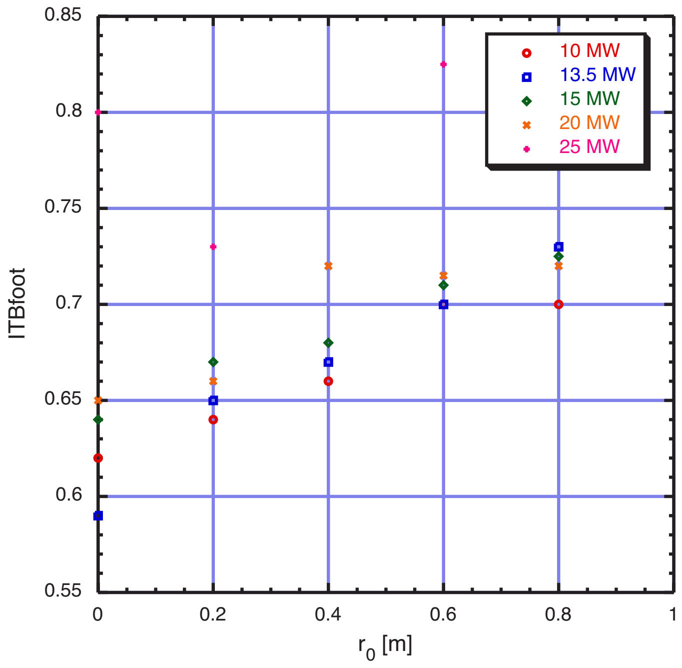
$\chi_i(\rho)$



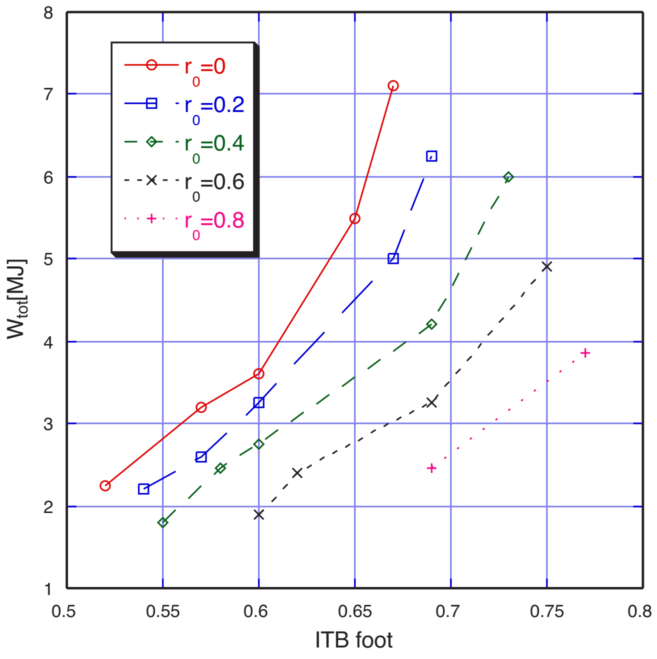
ITB Foot Location and Store Energy

- **High β_p mode**
- Heating center radius r_0 and heating power P_H are changed.
- **ITB foot location r_{foot}, Stored energy W_{store}**

r_{foot} vs r_0



W_{store} vs r_{foot}



- **With the increase of P_H, r_{foot} and W_{store}** increases.
- **If P_H fixed, W_{store} decreases with the increase of r_0.**

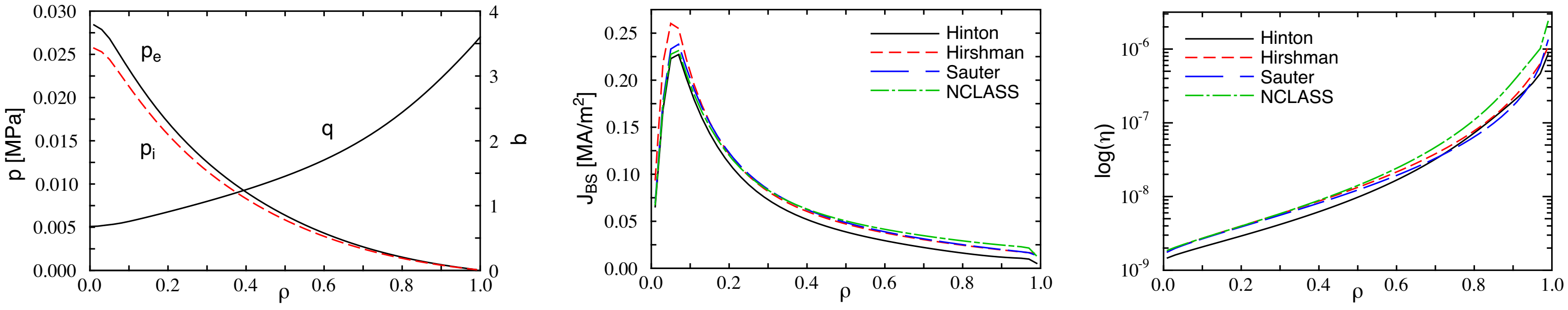
Dependence on Bootstrap Current and Resistivity Models

L-mode ··· heating of 10 MW

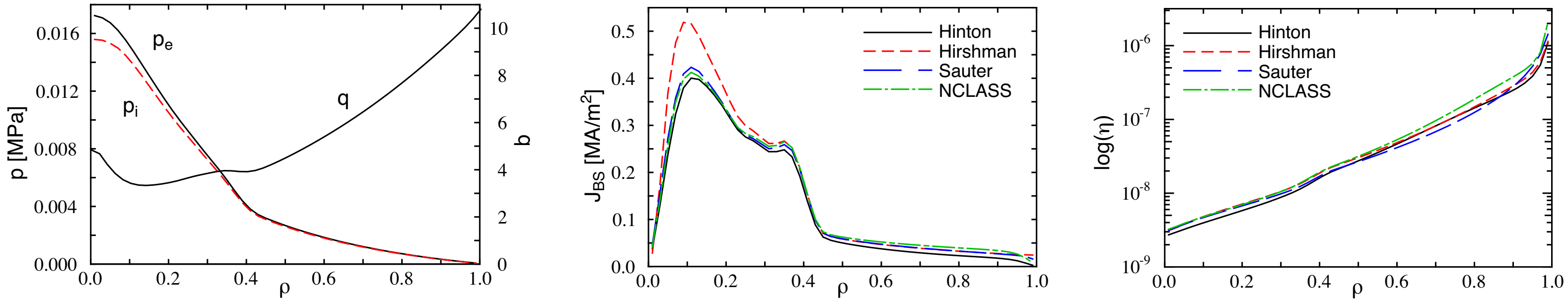
high β_p mode ··· $I_p = 1$ MA, heating of 15 MW

reversed shear (RS) configuration ··· Ramping up I_p from 1 MA to 3 MA during 1 second, heating of 10 MW

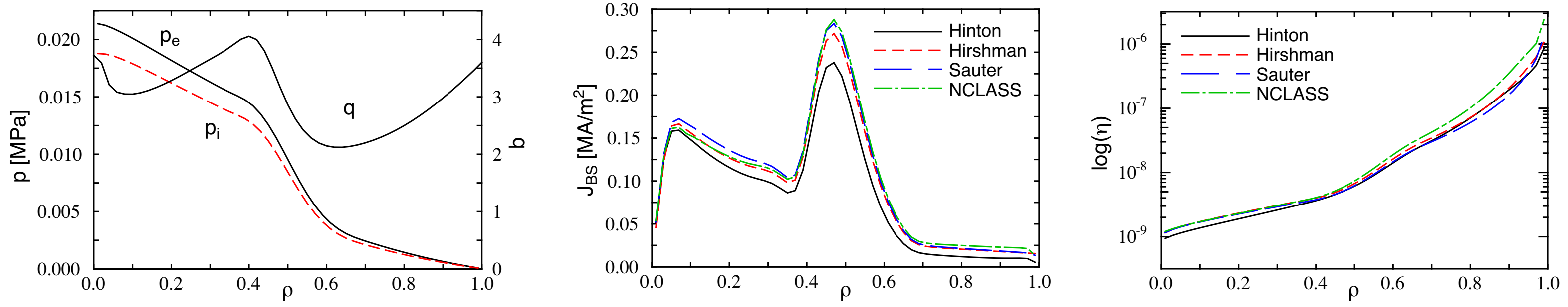
L-mode



high β_p mode



RS configuration



DIII-D (steady state)

#69627 (t = 2.4 s)
L-mode, C = 12

#81507 (t = 3.8 s)
H-mode, C = 2.5

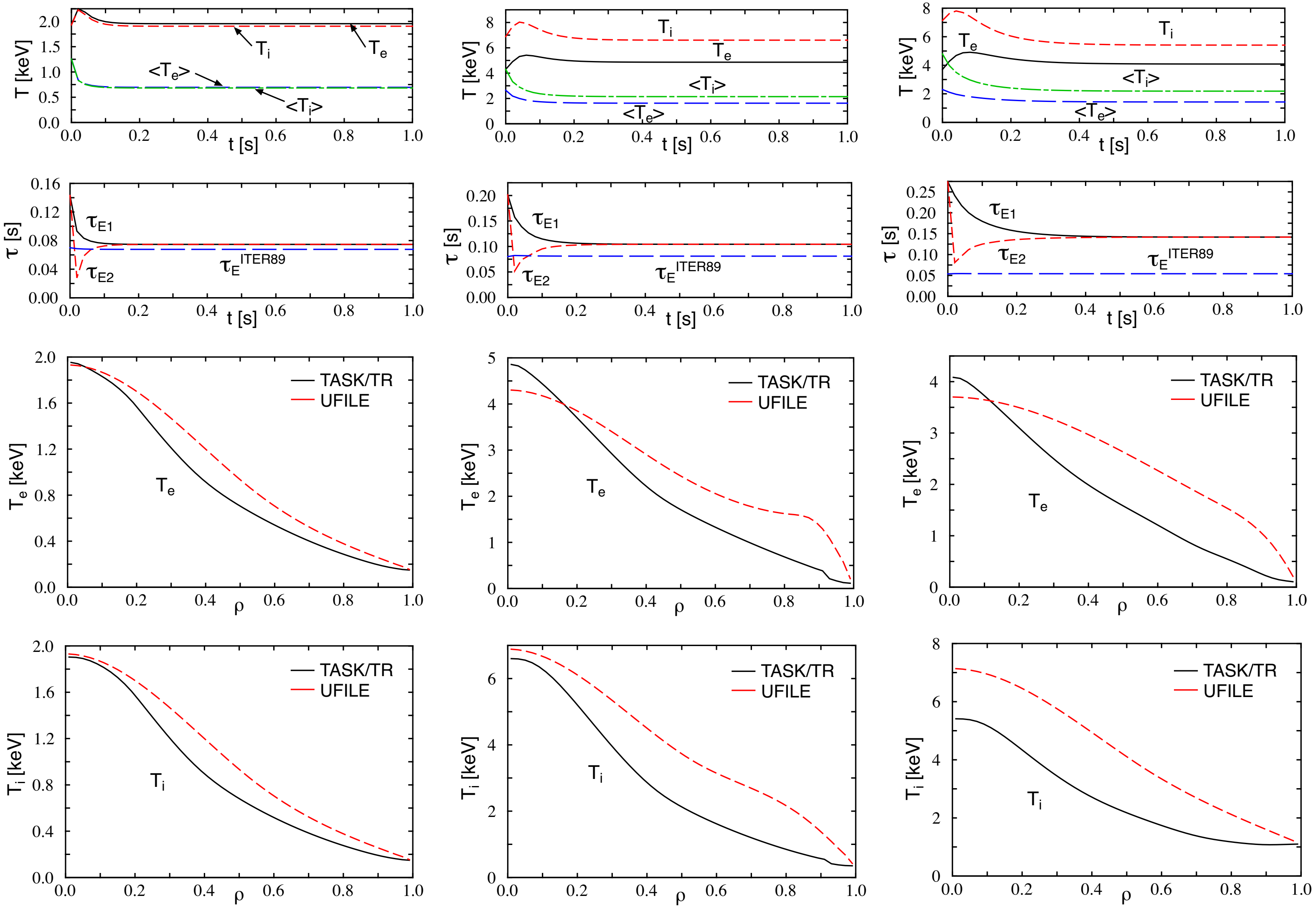
#104276 (t = 3.5 s)
H-mode, C = 2.5

$T(t)$

$\tau(t)$

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

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



JET (steady state)

#35171 (t = 61 s)
L-mode, C = 12

#35171 (t = 65.85 s)
H-mode, C = 12

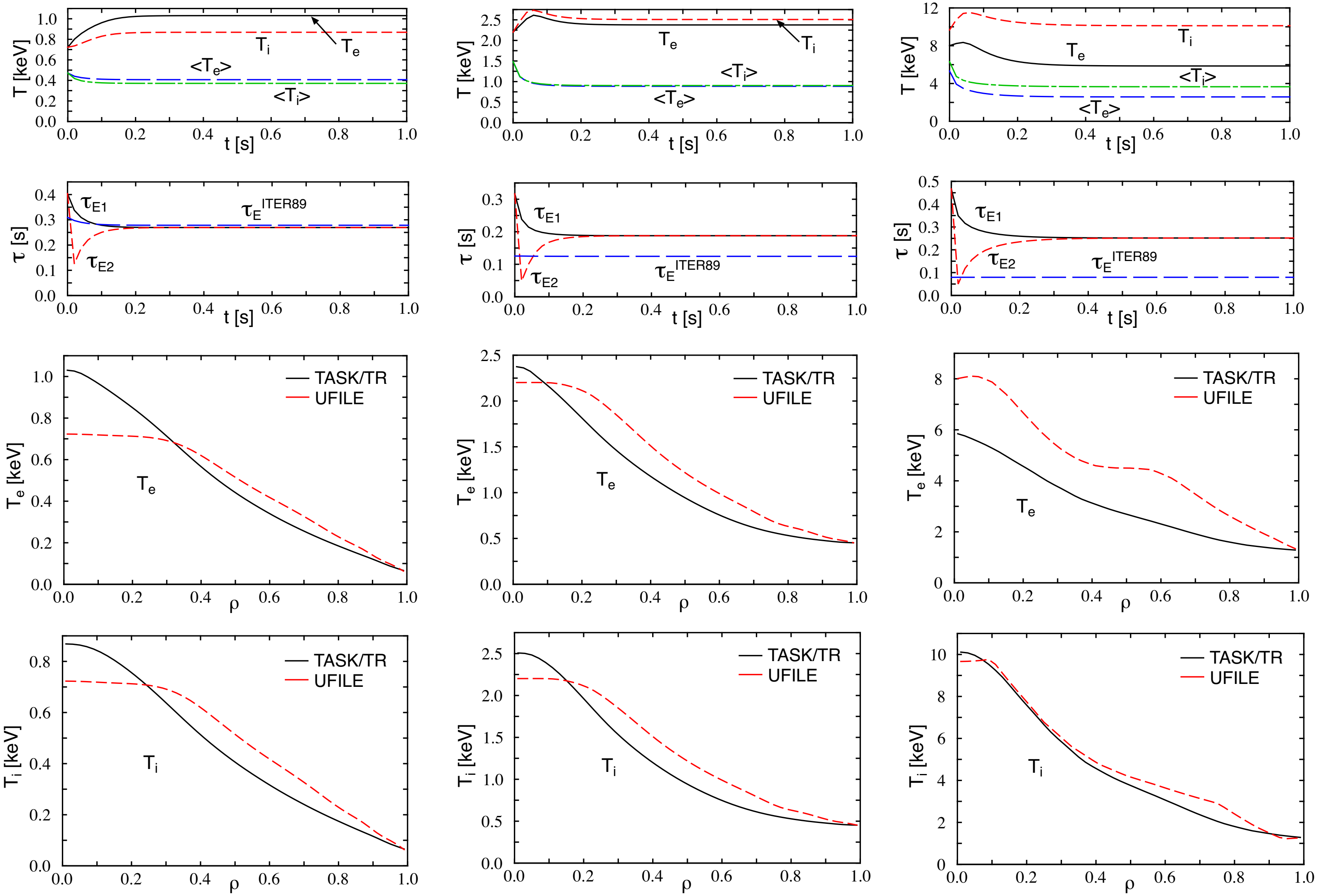
#58159 (t = 10.4 s)
ETB+ITB, C = 6

$T(t)$

$\tau(t)$

$T_e(\rho)$

$T_i(\rho)$



TFTR (time evolution)

	#43480	**#52182**	**#76535**
	Ohmic, C = 12	**L-mode, C = 12**	**Supershot, C = 12**

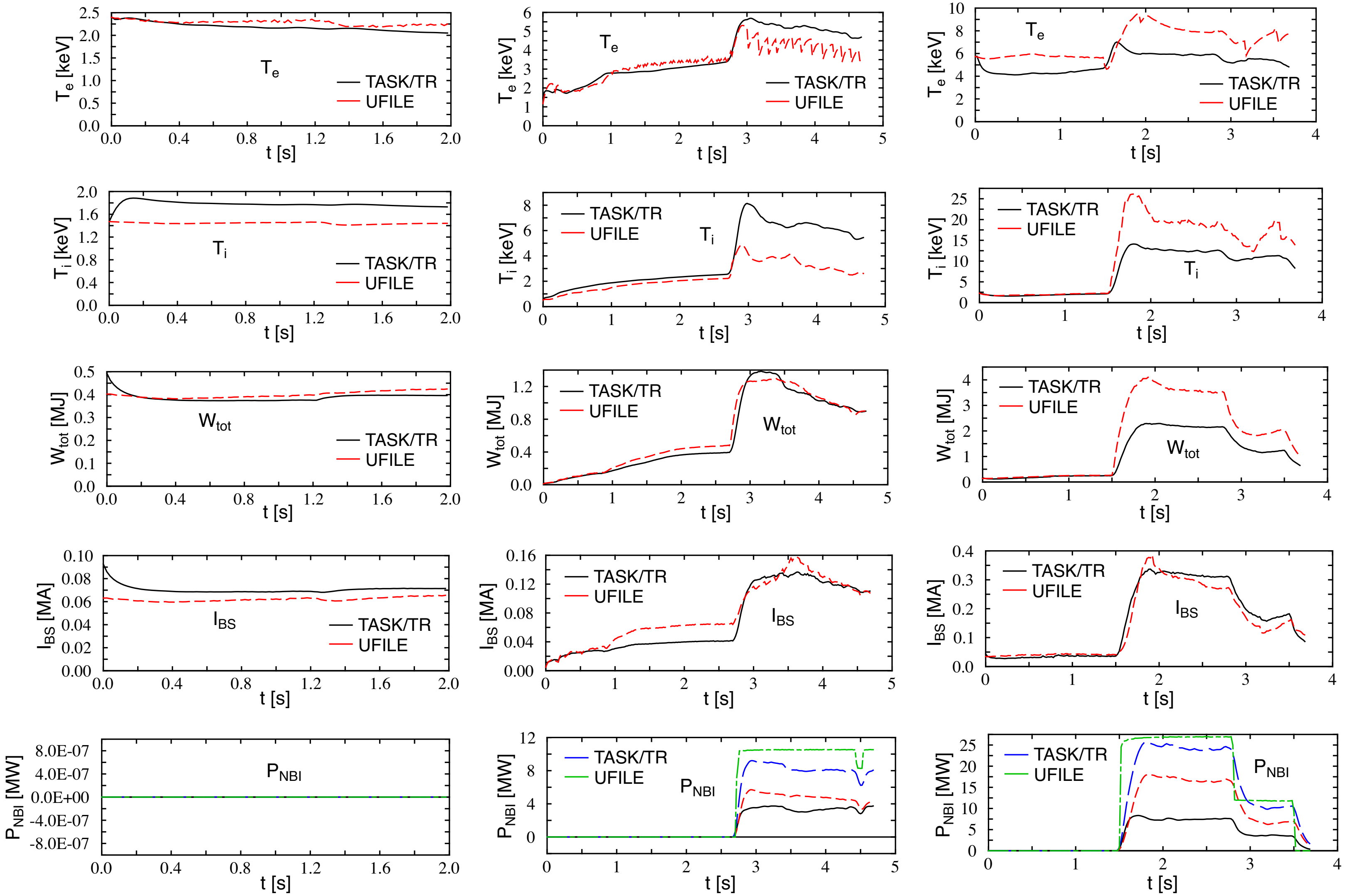
$T_e(t)$

$T_i(t)$

$W_{tot}(t)$

$I_{BS}(t)$

$P_{NBI}(t)$



JET & DIII-D (time evolution)

JET

#19649
L-mode, $C = 12$

#38285
H-mode, $C = 12$

DIII-D
#104276
H-mode, $C = 3.5$

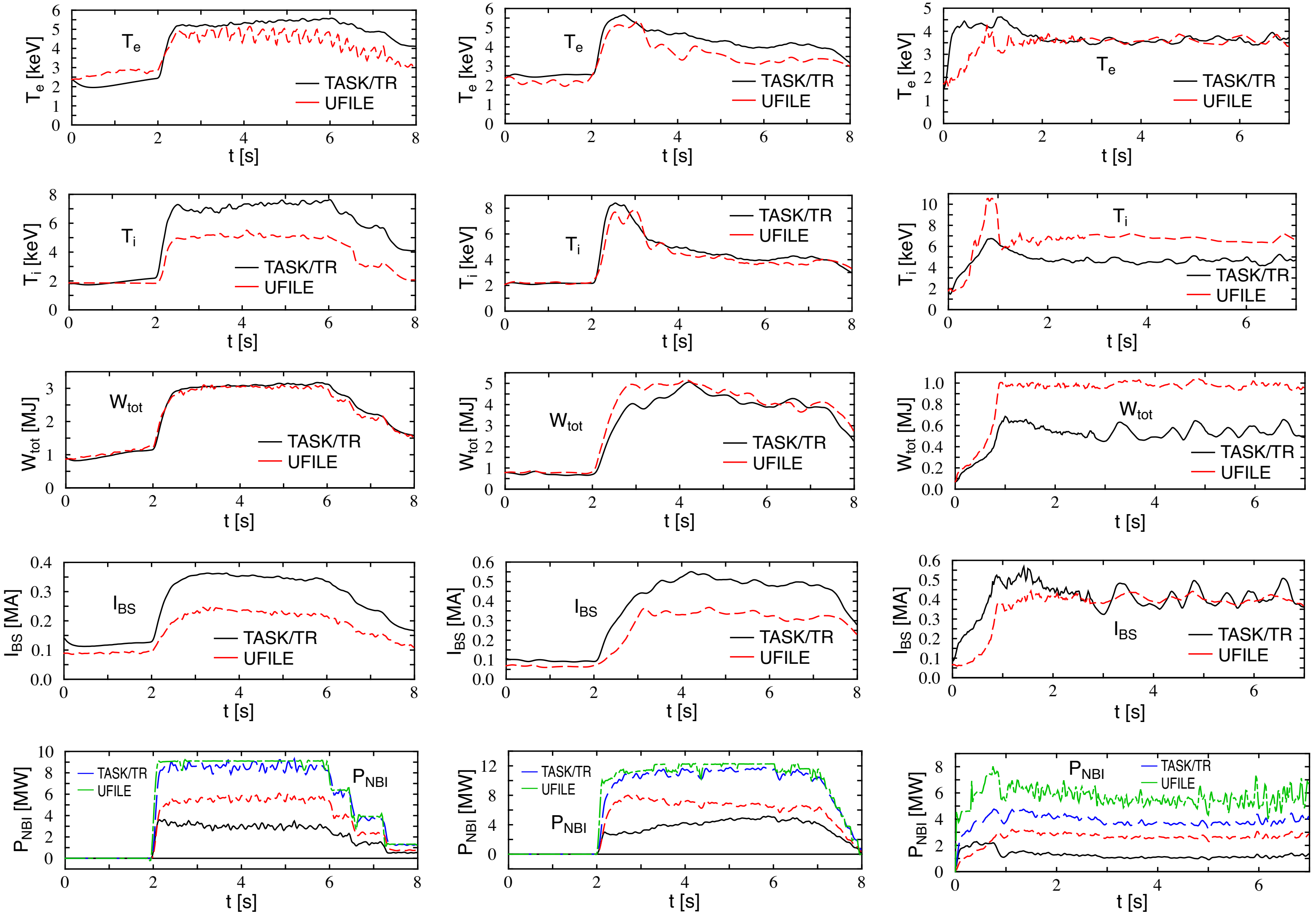
$T_e(t)$

$T_i(t)$

$W_{tot}(t)$

$I_{BS}(t)$

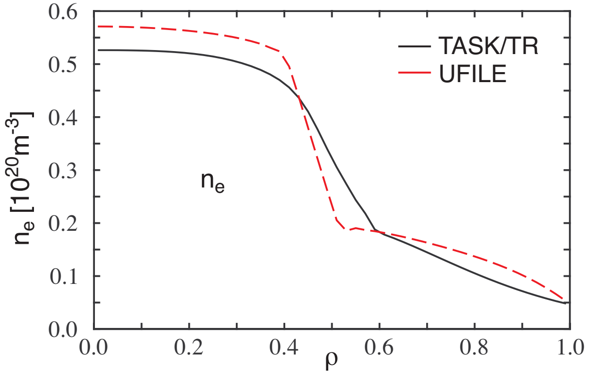
$P_{NBI}(t)$



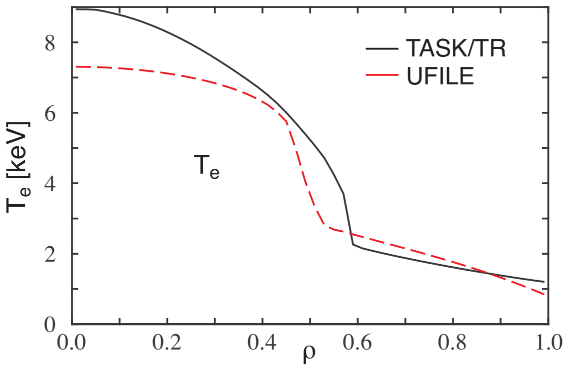
Comparison with JT-60 Experiment

- **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)

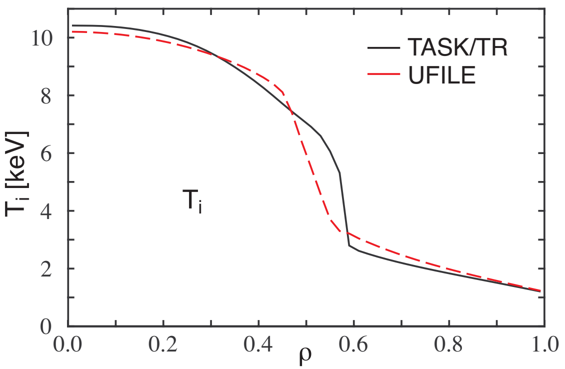
$n_\mathrm{e}(\rho)$



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



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



Modeling of ETB Formation

- **Transport Simulation including Core and SOL Plasmas**
- **Role of Separatrix**
  - **Closed magnetic surface ⟺ Open magnetic field line**
  - **Difference of dominant transport process**
- **Radial Electric Field**
  - **Poloidal rotation, Toroidal rotation**
  - **Polarization current**
  - **Poisson equation**
- **Atomic Processes**
  - **Ionization, Charge exchange, Recycling**

Transport Model

- **1D Transport code (TASK/TX)** *Ref. Fukuyama et al.*
- **Two fluid equation for electrons and ions**
    - **Flux surface average**
    - **Coupled with Maxwell equation**
    - **Neutral diffusion equation**
- **Neoclassical transport**
    - **Included as a poloidal viscosity term**
    - **Diffusion, resistivity, bootstrap current, Ware pinch**
- **Anomalous transport**
    - **Current diffusive ballooning mode**
    - **Ambipolar diffusion through poloidal momentum transfer**
    - **Perpendicular viscosity**

Model Equation (1)

- **Fluid equations** **(electrons and ions)**

$$\frac{\partial n_s}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r}(r n_s u_{sr}) + S_s$$

$$\frac{\partial}{\partial t}(m_s n_s u_{sr}) = -\frac{1}{r}\frac{\partial}{\partial r}(r m_s n_s u_{sr}^2) + \frac{1}{r} m_s n_s u_{s\theta}^2 + e_s n_s (E_r + u_{s\theta} B_\phi - u_{s\phi} B_\theta) - \frac{\partial}{\partial r} n_s T_s$$

$$\frac{\partial}{\partial t}(m_s n_s u_{s\theta}) = -\frac{1}{r^2}\frac{\partial}{\partial r}(r^2 m_s n_s u_{sr} u_{s\theta}) + e_s n_s (E_\theta - u_{sr} B_\phi) + \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^3 n_s m_s \mu_s \frac{\partial}{\partial r}\frac{u_{s\theta}}{r}\right)$$

$$+F_{s\theta}^{\mathrm{NC}} + F_{s\theta}^{\mathrm{C}} + F_{s\theta}^{\mathrm{W}} + F_{s\theta}^{\mathrm{X}} + F_{s\theta}^{\mathrm{L}}$$

$$\frac{\partial}{\partial t}\left(m_s n_s u_{s\phi}\right) = -\frac{1}{r}\frac{\partial}{\partial r}(r m_s n_s u_{sr} u_{s\phi}) + e_s n_s (E_\phi + u_{sr} B_\theta) + \frac{1}{r}\frac{\partial}{\partial r}\left(r n_s m_s \mu_s \frac{\partial}{\partial r} u_{s\phi}\right)$$

$$+F_{s\phi}^{\mathrm{C}} + F_{s\phi}^{\mathrm{W}} + F_{s\phi}^{\mathrm{X}} + F_{s\phi}^{\mathrm{L}}$$

$$\frac{\partial}{\partial t}\frac{3}{2} n_s T_s = -\frac{1}{r}\frac{\partial}{\partial r} r \left(\frac{5}{2} u_{sr} n_s T_s - n_s \chi_s \frac{\partial}{\partial r} T_{\mathrm{e}}\right) + e_s n_s (E_\theta u_{s\theta} + E_\phi u_{s\phi})$$

$$+P_s^{\mathrm{C}} + P_s^{\mathrm{L}} + P_s^{\mathrm{H}}$$

Model Equation (2)

- **Neutral Transport**

$$\frac{\partial n_0}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r}\left(-rD_0\frac{\partial n_0}{\partial r}\right) + S_0$$

- **Maxwell equations**

$$\frac{1}{r}\frac{\partial}{\partial r}(rE_r) = \frac{1}{\epsilon_0}\sum_s e_s n_s$$

$$\frac{\partial B_\theta}{\partial t} = \frac{\partial E_\phi}{\partial r}, \qquad \frac{\partial B_\phi}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r}(rE_\phi)$$

$$\frac{1}{c^2}\frac{\partial E_\theta}{\partial t} = -\frac{\partial}{\partial r}B_\phi - \mu_0\sum_s n_s e_s u_{s\theta}, \qquad \frac{1}{c^2}\frac{\partial E_\phi}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}(rB_\theta) - \mu_0\sum_s n_s e_s u_{s\phi}$$

Transport Model (1)

- Neoclassical transport
  - Viscosity force arises when plasma rotates in the poloidal direction.
  - Banana-Plateau regime

$$F_{s\theta}^{\mathrm{NC}} = -\sqrt{\pi}q^2 n_s m_s \frac{v_{\mathrm{T}s}}{qR}\frac{\nu_s^*}{1+\nu_s^*}u_{s\theta}$$

$$\nu_{\mathrm{s}}^* \equiv \frac{\nu_s qR}{\epsilon^{3/2}v_{\mathrm{T}s}}$$

- This poloidal viscosity force induces
  - Neoclassical radial diffusion
  - Neoclassical resistivity
  - Bootstrap current
  - Ware pinch

Transport Model (2)

- **Turbulent Diffusion**
  - **Poloidal momentum exchange between electron and ion through the turbulent electric field**
  - **Ambipolar flux (electron flux = ion flux)**

$$F^{\mathrm{W}}_{\mathrm{i}\theta} = - \ F^{\mathrm{W}}_{\mathrm{e}\theta}$$

$$= - ZeB_\phi n_\mathrm{i} D_\mathrm{i} \left[-\frac{1}{n_\mathrm{i}}\frac{dn_\mathrm{i}}{dr} + \frac{Ze}{T_\mathrm{i}}E_r - \langle\frac{\omega}{m}\rangle \frac{ZeB_\phi}{T_\mathrm{i}} - \left(\frac{\mu_\mathrm{i}}{D_\mathrm{i}} - \frac{1}{2}\right)\frac{1}{T_\mathrm{i}}\frac{dT_\mathrm{i}}{dr}\right]$$

- **Perpendicular viscosity**
  - **Non-ambipolar flux (electron flux ≠ ion flux):** $\mu_\mathrm{s} =$ **constant** $\times D$
- **Diffusion coefficient (proportional to $|E|^2$)**
  - **Current-diffusive ballooning mode turbulence model**

Modeling of Scrape-Off Layer Plasma

- **Particle, momentum and heat losses along the field line**
  - **Decay time**

$$\nu_L = \begin{cases} 0 & (0 < r < a) \\ \dfrac{C_s}{2\pi r R\{1 + \log[1 + 0.05/(r - a)]\}} & (a < r < b) \end{cases}$$

  - **Electron source term**

$$S_e = n_0 \langle \sigma_{\mathrm{ion}} v \rangle n_e - \nu_L (n_e - n_{e,\mathrm{div}})$$

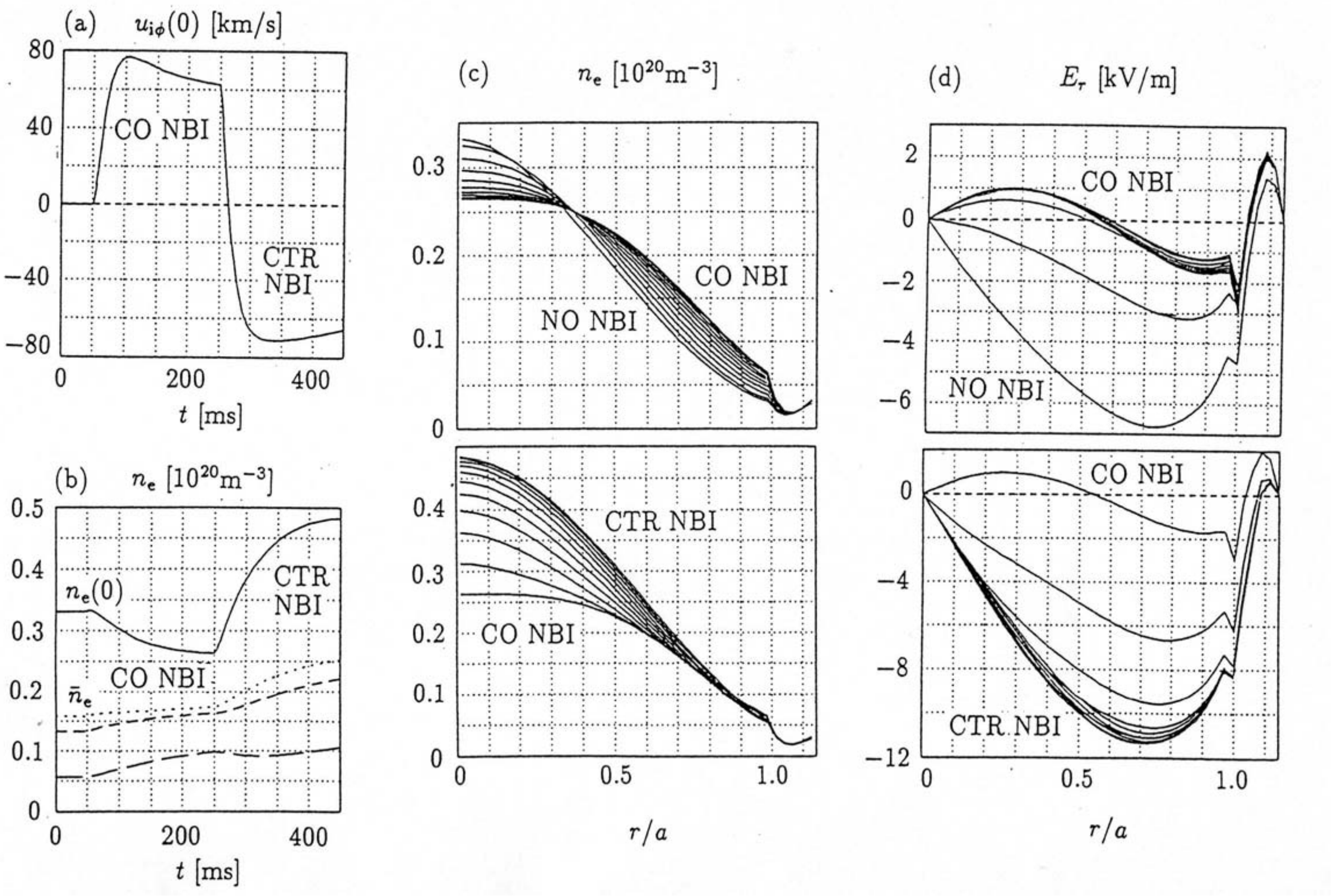
- **Recycling from divertor**
  - **Recycling rate:** $\gamma_0 = 0.8$
  - **Neutral source**

$$S_0 = \frac{\gamma_0}{Z_i} \nu_L (n_e - n_{e,\mathrm{div}}) - \frac{1}{Z_i} n_0 \langle \sigma_{\mathrm{ion}} v \rangle n_e + \frac{P_b}{E_b}$$

- **Gas puff from wall**

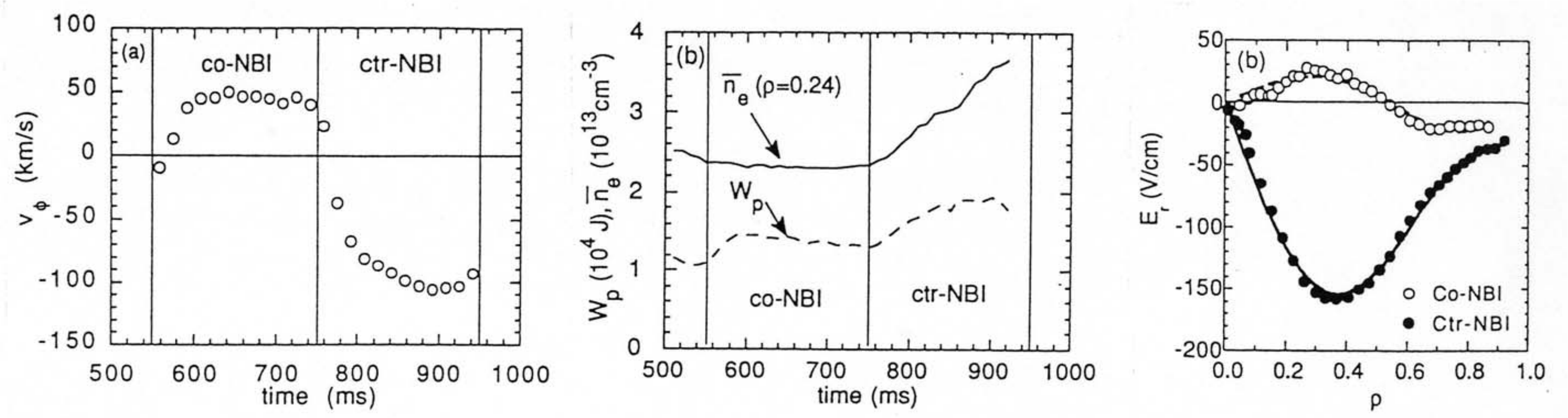
Simulation of plasma rotation and radial electric field

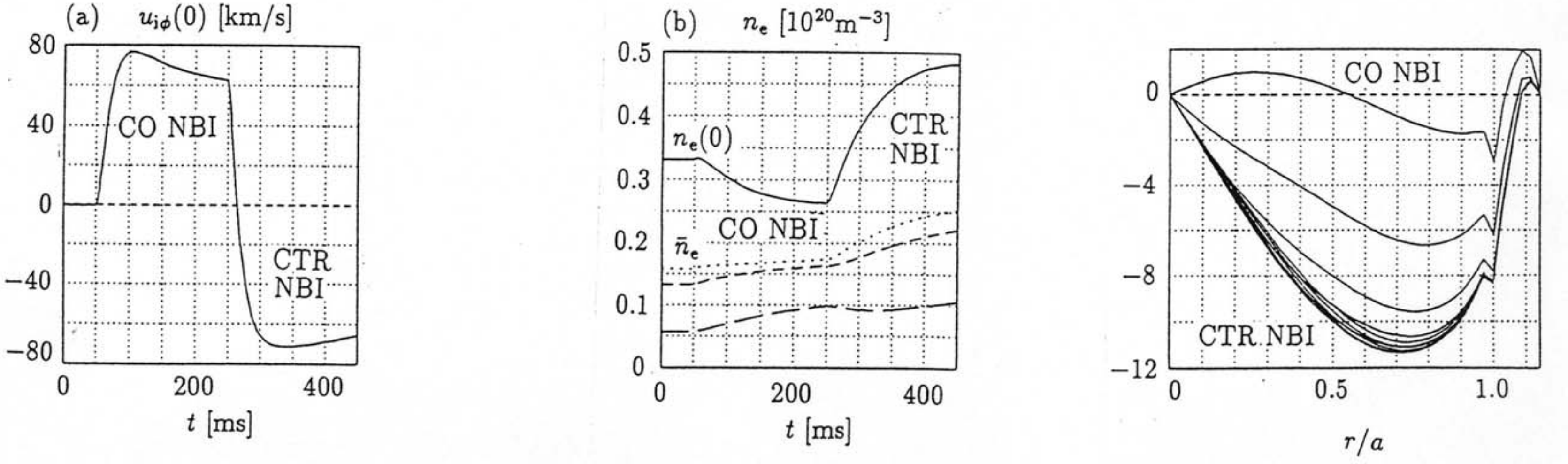
- **JFT-2M parameter**: NBI co-injection ⟶ counter-injection
- Toroidal rotation $\Longrightarrow$ Negative E_r $\Longrightarrow$ Density peaking
- **TASK/TX**: Particle Diffusivity: $0.3\,\mathrm{m}^2/\mathrm{s}$, Ion viscosity: $10\,\mathrm{m}^2/\mathrm{s}$



Comparison with JFT-2M Experiment

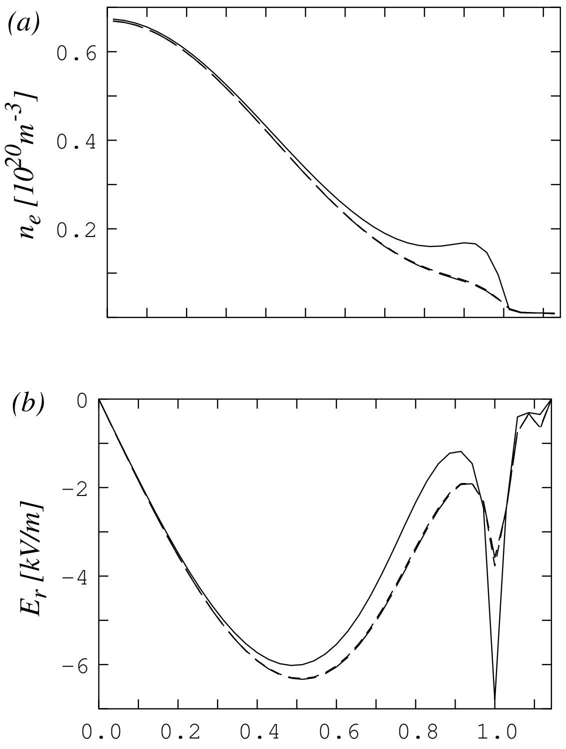
- **JFT-2M Experiment**: **Ida et al.: Phys. Rev. Lett. 68 (1992) 182**
- Good agreement with experimental observation



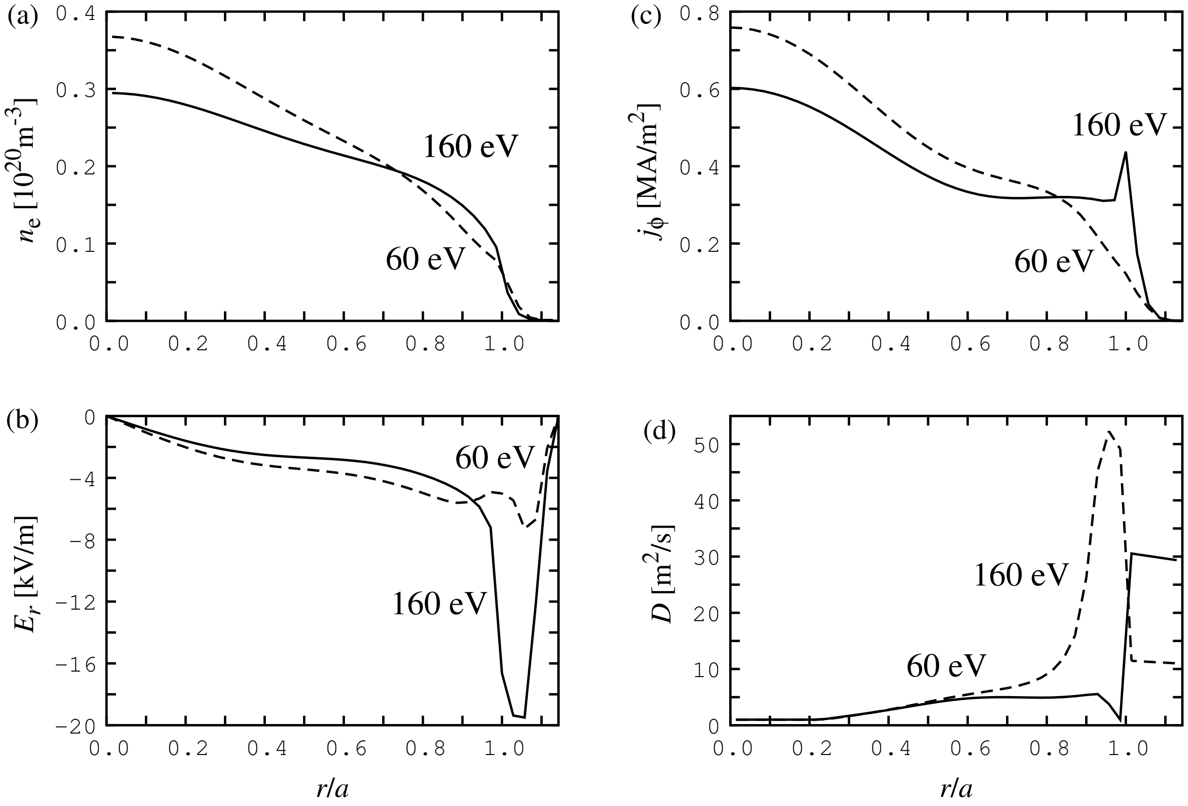


Typical Profiles

$D_{\mathrm{TB}} = 0$



Edge Temperature Dependence



Summary (1)

- We are developing TASK code as a reference core code for burning plasma simulation based on transport analysis.
- The TASK code is composed of modules: equilibrium, transport, wave analysis, velocity space analysis, and data interface.
- Full wave module TASK/WM was applied to the analysis of Alfvén eigenmode and TASK/WA is under development for kinetic analysis of MHD instabilities.
- Comparison of transport models using TASK/TR and ITPA profile database is ongoing and a dynamical transport module TASK/TX is under reorganization.

Summary (2)

- To Dos
  - Improvement of modules: Full modular structure
  - Standard data interface with other simulation code
  - Systematic comparison with experimental data
  - Development of new modules: WA, TX