核燃焼プラズマ統合コード研究会
九大応力研
2004/03/18-19

TASK コード
状況報告

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TASKコード現況
インターフェース検討

TASK code

- Transport Analyzing System for Tokamak
- Modules

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

- Features:

  modular structure, various H&CD scheme, high portability, development using CVS, extension for helical plasmas

Grad-Shafranov 方程式

- 以下の仮定を行う
  1. 円柱座標系 (R, ϕ, Z) において，プラズマの対称軸を Z とし，物理的変数は角度変数 ϕ に依らない
  2. 流れの速度はトロイダル方向のみ
  3. 温度は磁気面量
- 平衡を規定する Grad-Shafranov 方程式

$$R^2\nabla\cdot\left(\frac{\nabla\psi}{R^2}\right)+FF'+R^2\left\{p'+p\frac{R^2}{2}\left(\frac{m\omega^2}{T}\right)'\right\}\exp\left(\frac{mR^2\omega^2}{2T}\right)=0$$

ψ	ポロイダル磁束関数	$T(\psi)$	プラズマ温度
R	大半径	$\omega(\psi)$	回転周波数
$p(\psi)$	プラズマ圧力	B_ϕ	トロイダル磁束密度
m	陽子の質量	$F(\psi)$	$F = B_\phi R$

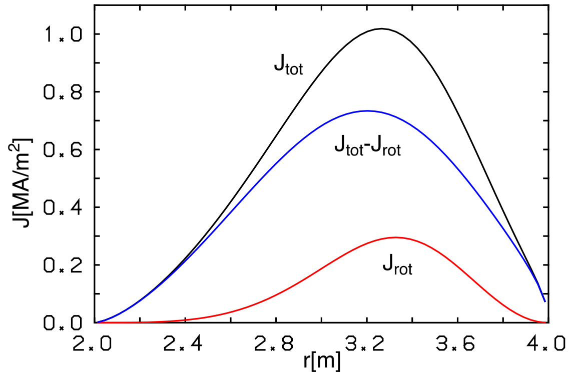
(参考文献: E. K. Maschke and H. Perrin, *Plasma Phys.* 22 1980)

- この式を組み込んだ２次元平衡コード TASK/EQ で解析を行う．

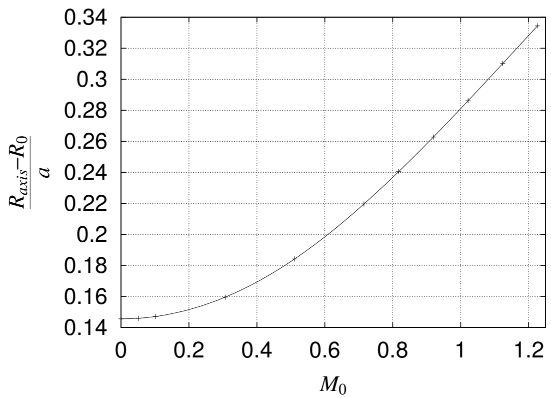
磁気軸のシフト

- 初期パラメータ

$$R = 3\ \mathrm{m} \qquad B = 3\ \mathrm{T}$$
$$a = 1\ \mathrm{m} \qquad I_\mathrm{p} = 1.6\ \mathrm{MA}$$
$$\kappa = 1.6 \qquad T_i(0) = 6\ \mathrm{keV}$$
$$\delta = 0.25 \qquad p_i(0) = 0.1\ \mathrm{MPa}$$



- 磁気面関数の分布は$(1-(r/a)^2)^{1/2}$を仮定
- 上図は回転速度をマッハ0.5にしたときの径方向電流密度分布
  $\Longrightarrow$ 回転が電流密度分布に影響を及ぼしている
- 下図は回転速度に対する磁気軸のシフト量
  - 回転速度がある程度上がるまで影響は少ない
  - M_0^2の依存性を示している
  - 温度10 keVで8 MWのNBI加熱を用いた実験ではマッハ0.2程なので，実際の磁気軸シフトへの影響は少ない



TASK/TR

- **拡散型輸送シミュレーションコード**
  - **取り扱う変数:**
    - 密度　n_s for s = D, T, He, Impurity
    - 回転　u_s for s = D, T, He, Impurity
    - 温度　T_s for s = Electron, D, T, He, Impurity
    - エネルギー密度　W_s for s = α, Beam ion
    - 中性粒子密度　n_{fs} (fast) , n_{ss} (slow) for s = D, T
    - ポロイダル磁束　Ψ
  - **拡散型輸送方程式を解く**
  - **輸送係数**
    - 新古典輸送モデル (Hinton & Hazeltine, Wilson, Sauter, NCLASS)
    - 乱流輸送モデル (CDBM, DABM, GLF23)
  - **ソース:**
    - 電離
    - 衝突による運動量とエネルギーの輸送
    - RF 加熱と電流駆動
    - 核融合反応

輸送方程式

- s 種の粒子に対する，磁気面平均された１次元拡散型輸送方程式

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

$$\frac{\partial}{\partial t}(m_s n_s u_s V') = -\frac{\partial}{\partial \rho}\left(V'\langle|\nabla\rho|\rangle m_s n_s u_s V_{us} - V'\langle|\nabla\rho|^2\rangle m_s n_s D_{us} \frac{\partial u_s}{\partial \rho}\right) + S_{us} V'$$

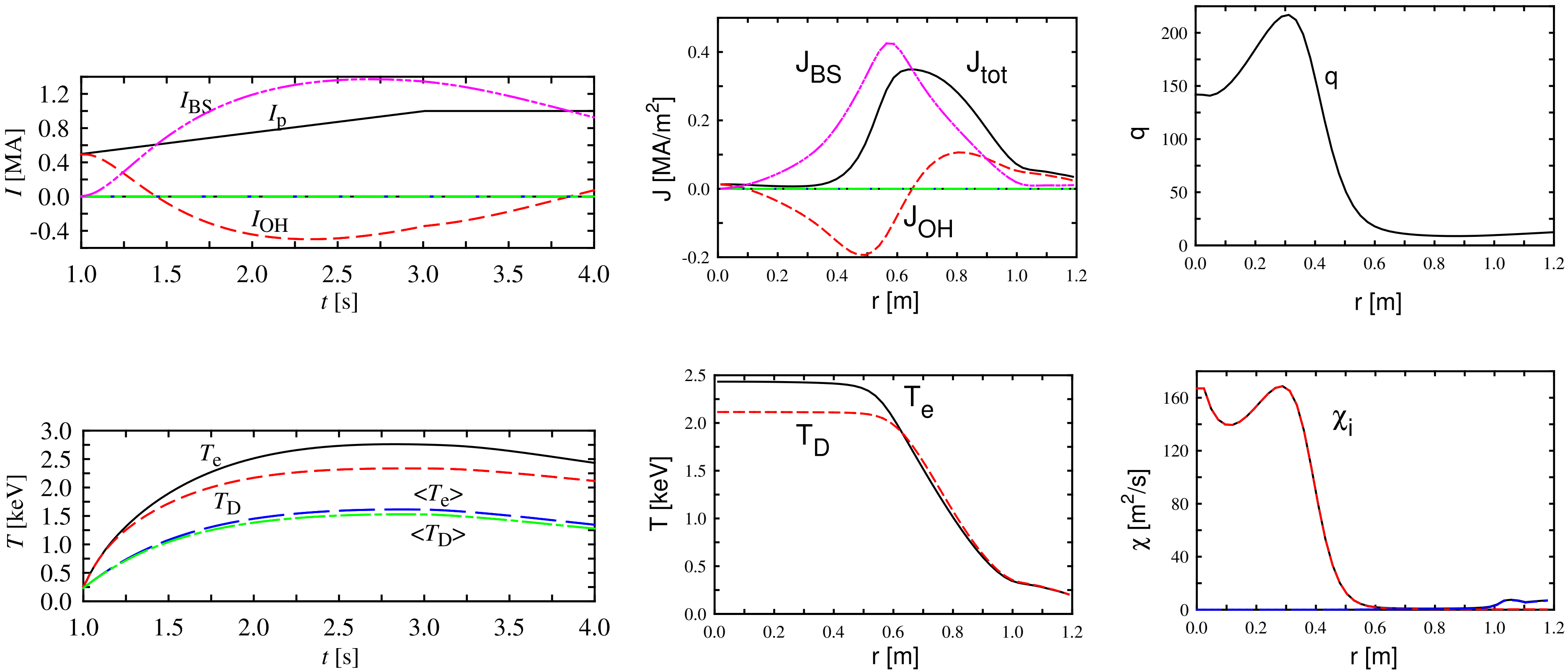
$$\frac{\partial}{\partial t}\left(\frac{3}{2} n_s T_s V'^{5/3}\right) = -V'^{2/3}\frac{\partial}{\partial \rho}\left\{V'\langle|\nabla\rho|\rangle \frac{3}{2} n_s T_s V_{Es} - V'\langle|\nabla\rho|^2\rangle \chi_s \frac{\partial (n_s T_s)}{\partial \rho}\right.$$
$$\left. - V'\langle|\nabla\rho|^2\rangle\left(\frac{3}{2}D_s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

$$\frac{\partial B_\theta}{\partial t} = \frac{\partial}{\partial \rho}\left[\frac{\eta_\parallel}{\mu_0}\frac{F}{V'\langle R^{-2}\rangle}\frac{\partial}{\partial \rho}\left(\frac{V'}{F}\left\langle\frac{|\nabla\rho|^2}{R^2}\right\rangle B_\theta\right) - \frac{\eta_\parallel}{F R_0}\frac{\langle|\nabla\rho|\rangle}{\langle R^{-2}\rangle}\langle(J_{CD} + J_{BS})B\rangle\right]$$

  - $V_{Es} = V_{Ks} + \frac{3}{2}V_s$, V_{Ks} はヒートピンチ
  - $F = B_\phi R$

Simulation of Current Hole

- **Current ramp up:** $I_{\rm p} = 0.5 \longrightarrow 1.0\,\rm MA$
- **Moderate heating:** $P_{\rm H} = 5\,\rm MW$
- **Current hole is formed.**
- **The formation is sensitive to the edge temperature.**



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)**

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

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

- **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**

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

  - **Electron source term**

$$S_{\rm e} = n_0 \langle \sigma_{\rm ion} v \rangle n_{\rm e} - \nu_{\rm L}(n_{\rm e} - n_{\rm e,div})$$

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

$$S_0 = \frac{\gamma_0}{Z_{\rm i}} \nu_{\rm L}(n_{\rm e} - n_{\rm e,div}) - \frac{1}{Z_{\rm i}} n_0 \langle \sigma_{\rm ion} v \rangle n_{\rm e} + \frac{P_{\rm b}}{E_{\rm b}}$$

- **Gas puff from wall**

Transport Model

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Dynamical Transport Equation: TASK/TX

- **Bounce-averaged transport equation** (electron, ion)

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

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

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

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

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

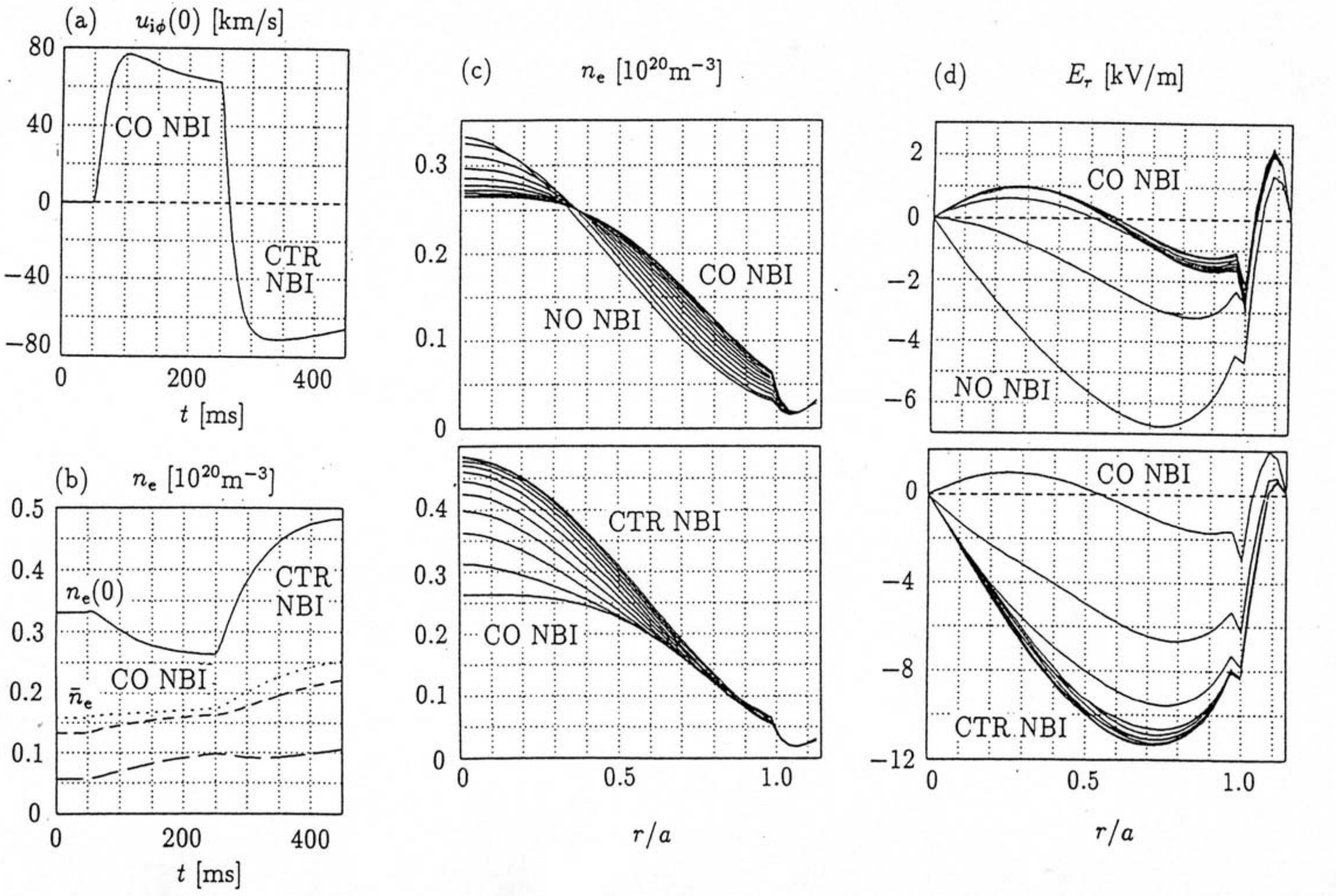
$$+ F_{s\phi}^{\mathrm{C}} + F_{s\phi}^{\mathrm{W}} + F_{s\phi}^{\mathrm{X}} + F_{s\phi}^{\mathrm{L}}$$

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

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

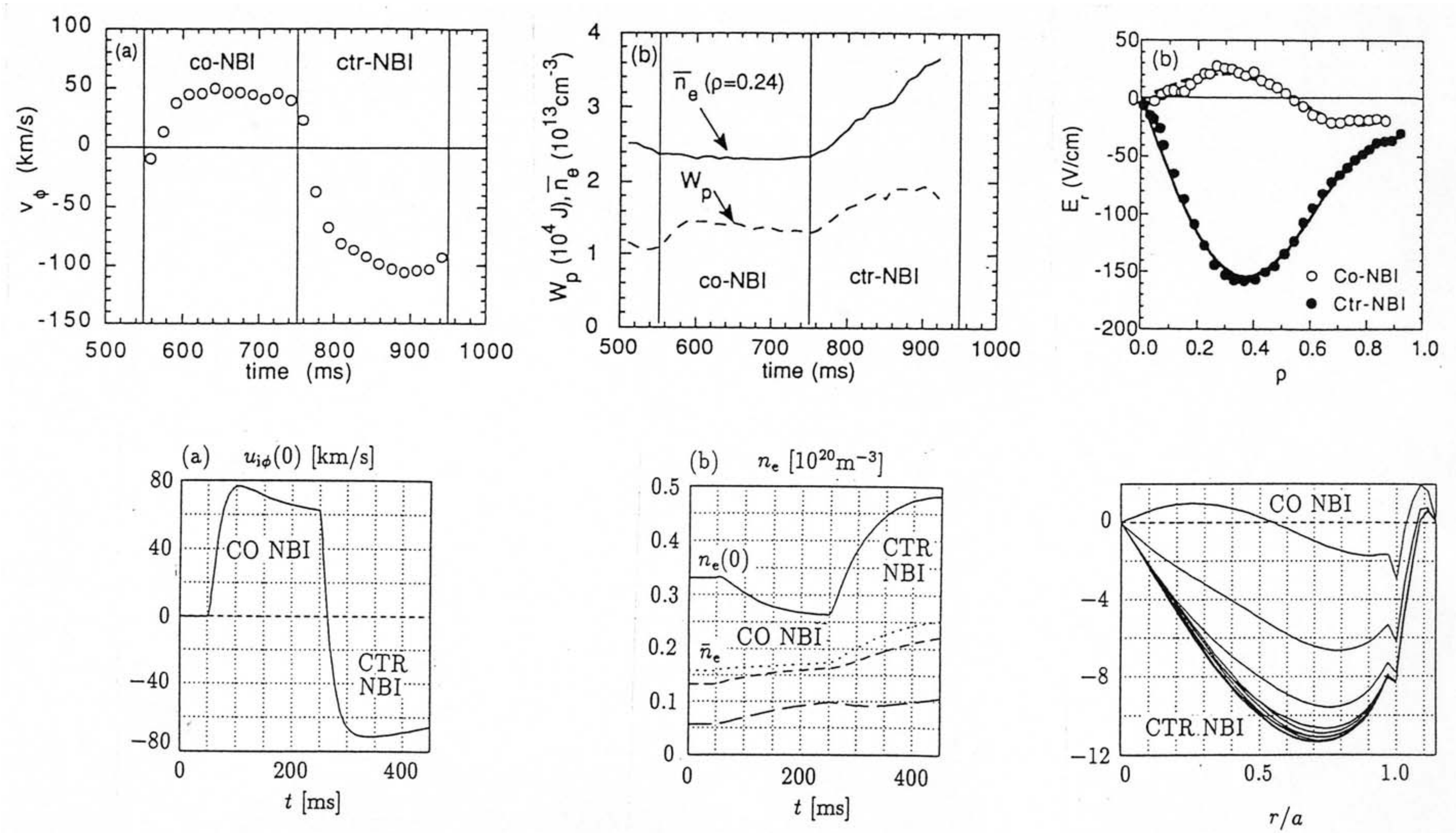
Simulation of plasma rotation and radial electric field

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



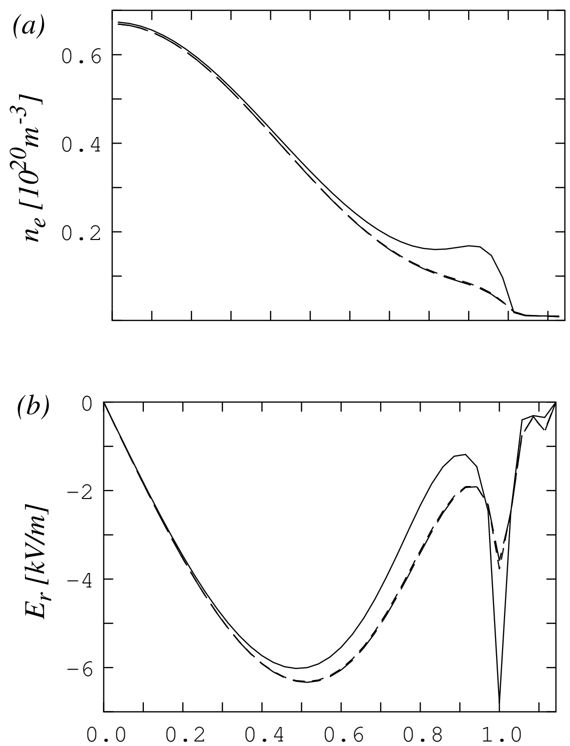
Comparison with JFT-2M Experiment

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

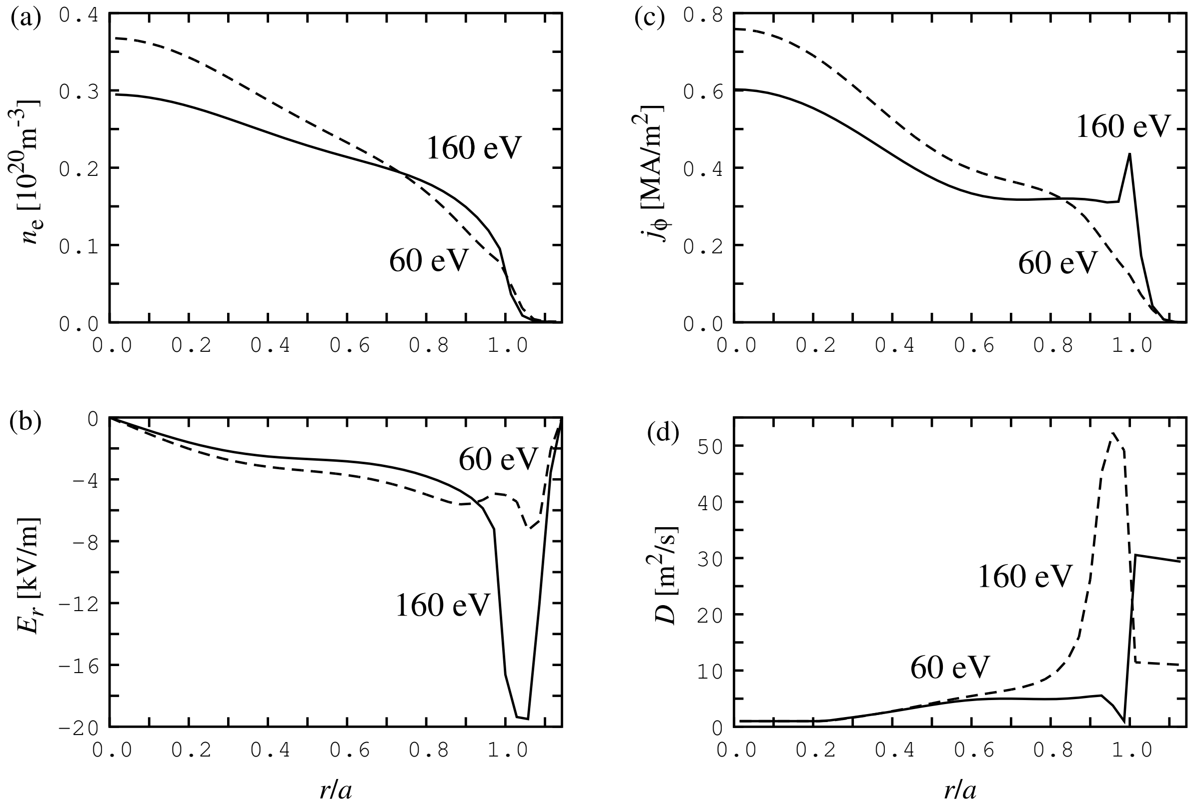


Typical Profiles

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

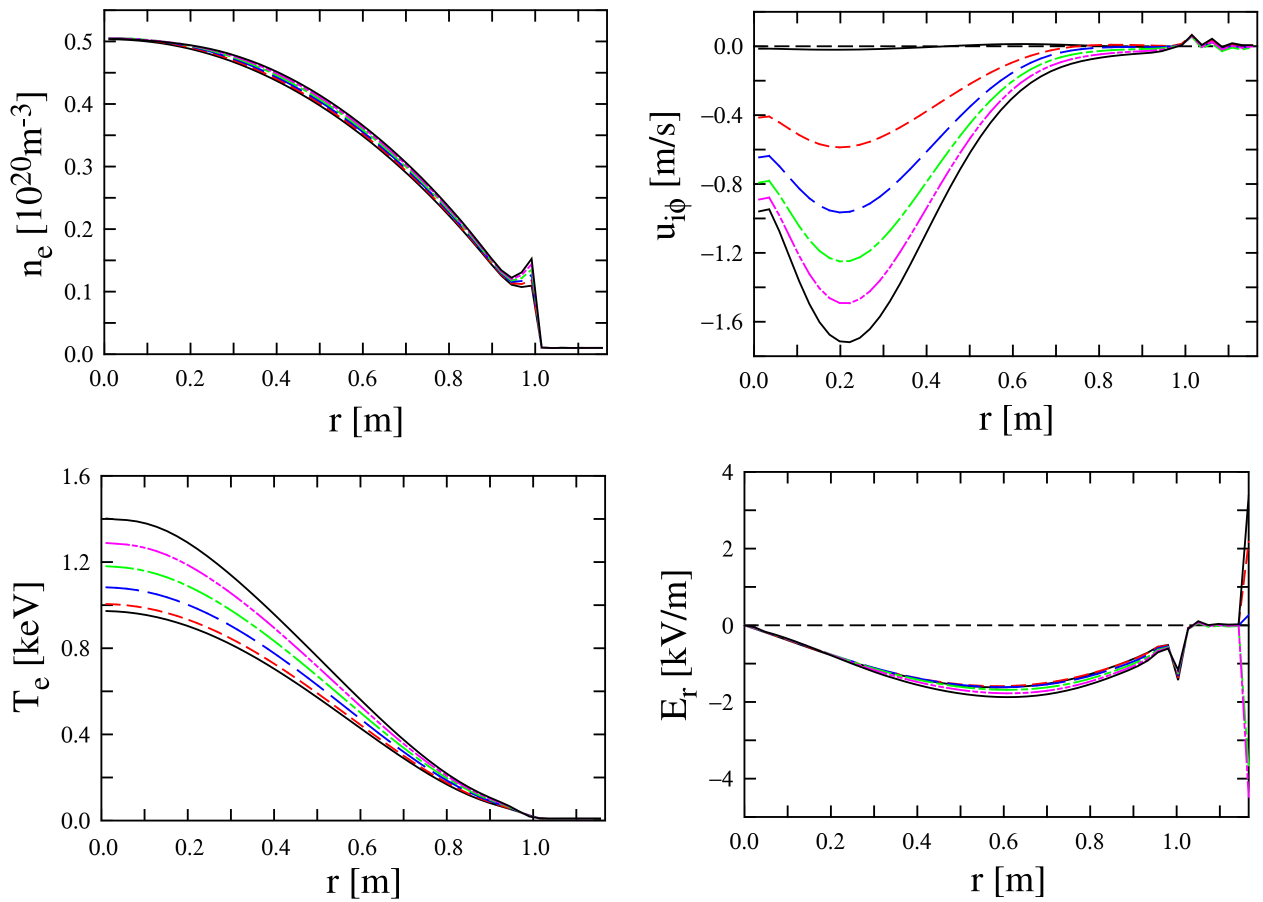


Edge Temperature Dependence



Transport Modeling in Helical Plasma

- **Neoclassical toroidal viscosity**
- **Negative magnetic shear**
- **Preliminary Result**
  - **NBI heating** ($P = 5\,\mathrm{MW}$) **: Order of magnitude slower rotation**



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

$$s(\boldsymbol{r}) = s_0(\tau) + k^0_\alpha(\tau)[r^\alpha - r^\alpha_0(\tau)] + \frac{1}{2}s_{\alpha\beta}[r^\alpha - r^\alpha_0(\tau)][r^\beta - r^\beta_0(\tau)]$$

$$\phi(\tau) = \frac{1}{2}\phi_{\alpha\beta}[r^\alpha - r^\alpha_0(\tau)][r^\beta - r^\beta_0(\tau)]$$

· $\boldsymbol{r}_0$: 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 Ordinally 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

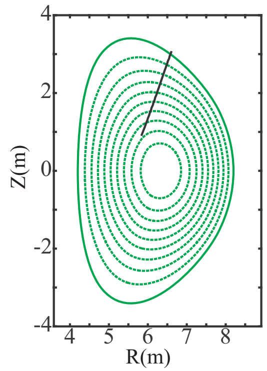
- **Bounce-averaged**: Trapped particle effect, zero banana width
- **Relativistic**: momentum $\boldsymbol{p}$, weakly relativistic collision term
- **Nonlinear collision**: momentum conservation, energy conservation
- **Three-dimensional**: spatial diffusion (classical, neoclassical, turbulence)

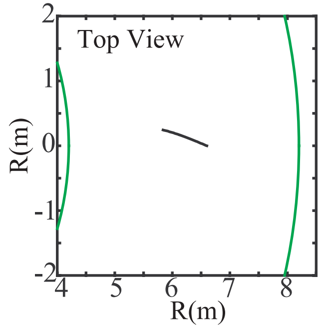
Wave Dispersion Analysis : TASK/DP

- **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



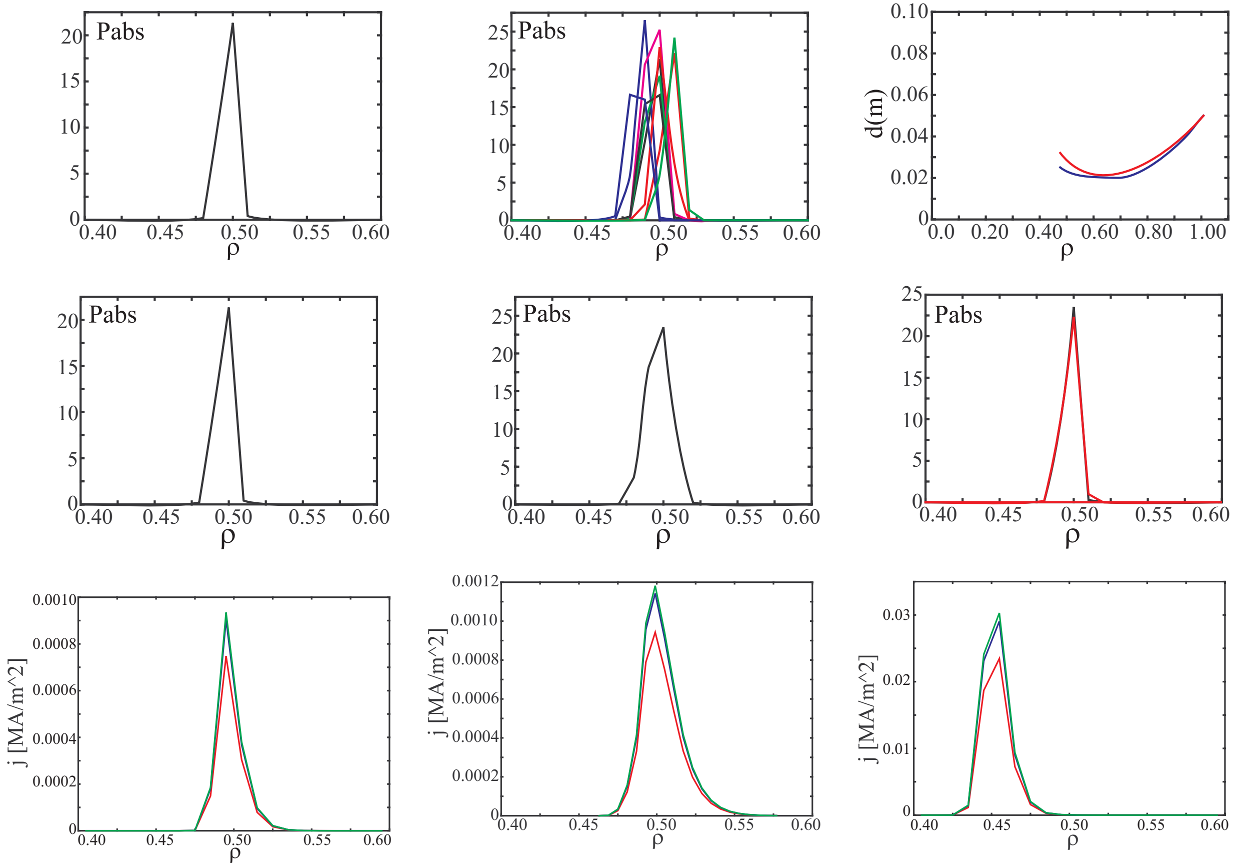


One Ray | **Multi Rays** | **Beam Tracing**

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**: $Z[(\omega - n\omega_{\mathrm{c}})/k_{\parallel} v_{\mathrm{th}}]$
  - **Fast ion: Drift-kinetic**

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

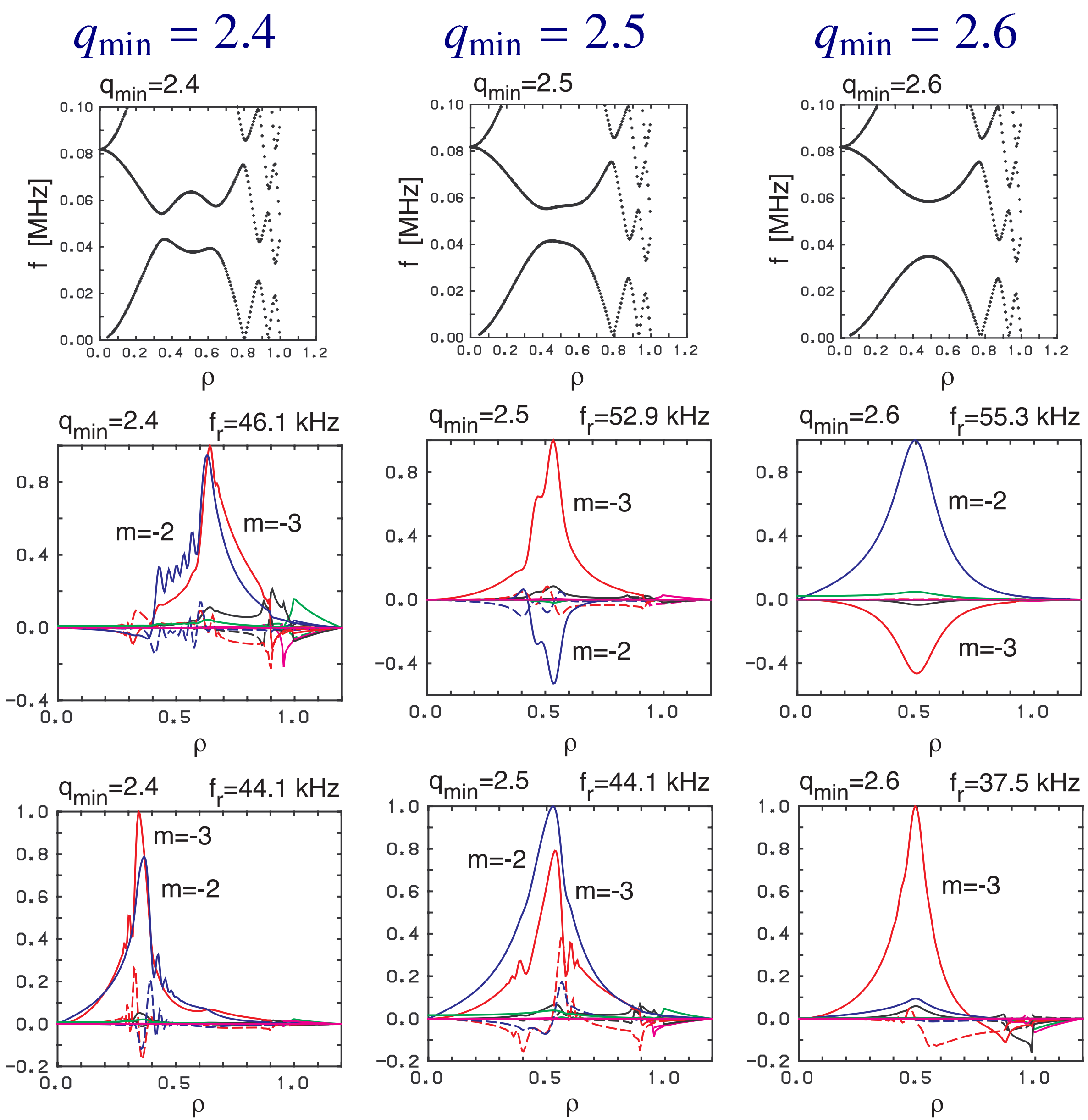
- Poloidal and toroidal **mode expansion**
  - **Accurate estimation of $k_{\parallel}$**
- Eigenmode analysis: **Complex eigen frequency** which maximize wave amplitude for fixed excitation proportional to electron density

Eigenmode Structure in Reversed Shear Configuration

Alfvén resonance

Higher freq.

Lower freq.



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

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

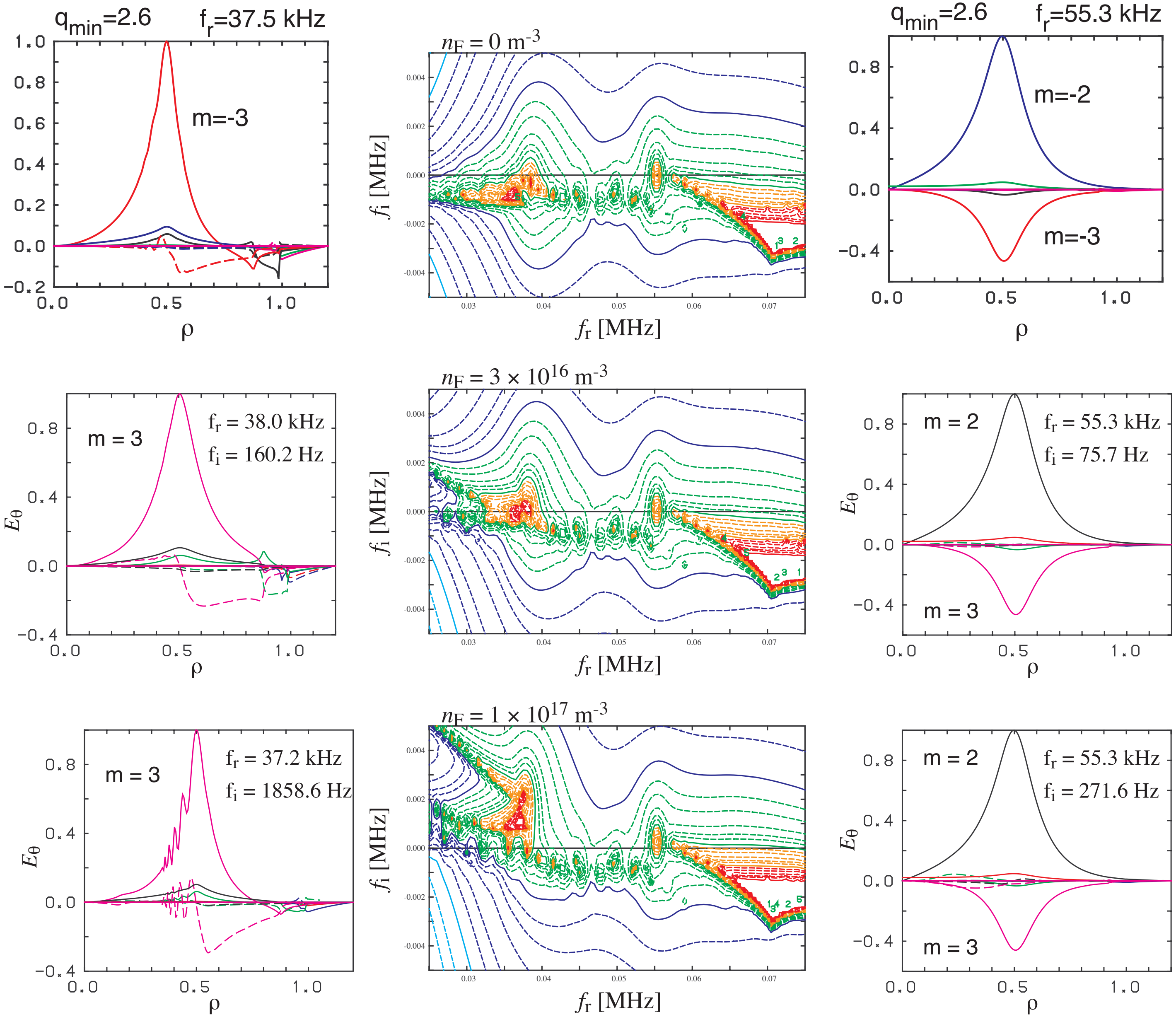
- Without EP

- 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



2004/03/13

Burning Plasma Simulation

Interface Design Proposal

— version 0.1 —

Contents

1 Coordinates

1.1 One dimensional

`RHO`	Radial (ρ)	Square root of the toroidal magnetic flux normalized by the value on a plasma surface: $\rho = \sqrt{\psi_\mathrm{t}/\psi_\mathrm{t}\|_\mathrm{surface}}$, $\rho = 0$ on the magnetic axis and $\rho = 1$ on the plasma surface.

1.2 Two dimensional

`RZ`	Cyrindrical (R, Z)
`RT`	Toroidal (r, θ)
`RC`	Flux (ρ, χ)

1.3 Three dimensional

`XYZ`	Rectangular (X, Y, Z)	
`RPZ`	Cyrindrical 1 (R, ϕ, Z)	
`RZP`	Cyrindrical 2 (R, Z, ϕ)	
`RTP`	Toroidal 1 (r, θ, ϕ)	
`RCP`	Flux 1 (ρ, χ, ϕ)	VMEC
`RCX`	Flux 2 (ρ, χ, ξ)	Boozer

2 Data Interface

2.1 Device data

RR	$R\,\mathrm{m}$	Geometrical major radius
RA	$a\,\mathrm{m}$	Average minor radius $(R_{\mathrm{max}} - R_{\mathrm{min}})/2$
RB	$b\,\mathrm{m}$	Wall radius
BB	$b\,\mathrm{T}$	Vacuum toroidal magnetic field at $(RR, 0)$
RKAP	κ	Elongation of plasma boundary
RDLT	δ	Triangularity of plasma boundary
RIP	$I_{\mathrm{p}}\,\mathrm{MA}$	Typical plasma current

2.2 Magnetic field data

2.2.1 Tokamak

PSIP	$\psi_{\mathrm{p}}(R, Z)\,\mathrm{Tm}^2$	2D poloidal magnetic flux
PSIR	$\psi(\rho)\,\mathrm{Tm}^2$	Poloidal magentic flux
PPSI	$p(\rho)\,\mathrm{MPa}$	Plasma pressure
TPSI	$T(\rho)\,\mathrm{Tm}$	$B_\phi R$
qPSI	$q(\rho)$	Safety factor

2.2.2 Tokamak with toroidal rotation

2.2.3 Helical magnetic field

2.3 Fluid plasma data

NSMAX	s	Number of particle species
PA	A_s	Atomic mass
PZ	Z_s	Charge number
PNR	$n(\rho)\,10^{20}\mathrm{m}^3$	Number density
PTR	$T(\rho)\,\mathrm{keV}$	Temperature
PUR	$u_\phi(\rho)\,\mathrm{m/s}$	Toroidal rotation velocity
AJTOT	$j_{\mathrm{tot}}(\rho)\,\mathrm{MA/m}^2$	Toroidal current density

2.4 Kinetic plasma data

FP	$f(p, \theta_p, \rho)$	momentum distribution at $theta = 0$

2.5 Wave field data

2.5.1 Local wave field

CE	$\vec{E}(\rho, \chi, \xi)$	Complex wave electric field
CB	$\vec{B}(\rho, \chi, \xi)$	Complex wave magnetic field

2.5.2 Ray trajectory

`RRAY`	$R(\ell)$	R of ray at length *ell*
`ZRAY`	$Z(\ell)$	Z of ray at length *ell*
`PRAY`	$\phi(\ell)$	ϕ of ray at length *ell*
`CERAY`	$\vec{E}(\ell)$	Wave electric field of ray at length *ell*
`DRAY`	$\vec{d}(\ell)$	Beam radius at length *ell*
`VRAY`	$\vec{v}(\ell)$	Beam curvature at length *ell*

3 Program Interface

3.1 Initialization

`BPSM_INIT('XX')`	Initialize module XX by setting default values
`BPSM_RESET('XX')`	Set initial profile to variables in module XX

3.2 Execution

`BPSM_EXEC('XX')`	Exec module XX
`BPSM_ADVANCE('XX',DT)`	Advance module XX with time step DT sec

3.3 Termination

`BPSM_TERM('XX')`	Terminate module XX

3.4 Data transfer

```
BPSM_SET1('VAR',VAR,NVAR1)
BPSM_SET2('VAR',VAR,NVAR1,NVAR2)
BPSM_SET3('VAR',VAR,NVAR1,NVAR2,NVAR3)
BPSM_SET4('VAR',VAR,NVAR1,NVAR2,NVAR3,NVAR4)
```

Set multi-dimensional variable VAR

```
BPSM_GET1('VAR',VAR,NVAR1)
BPSM_GET2('VAR',VAR,NVAR1,NVAR2)
BPSM_GET3('VAR',VAR,NVAR1,NVAR2,NVAR3)
BPSM_GET4('VAR',VAR,NVAR1,NVAR2,NVAR3,NVAR4)
```

Get four-dimensional variable VAR

3.5 Data allocation (F95)

```
BPSM_ALOC1('VAR',VAR,NVAR1)
BPSM_ALOC2('VAR',VAR,NVAR1,NVAR2)
BPSM_ALOC3('VAR',VAR,NVAR1,NVAR2,NVAR3)
BPSM_ALOC4('VAR',VAR,NVAR1,NVAR2,NVAR3,NVAR4)
```

Allocate multi-dimensional variable VAR

`BPSM_FREE('VAR',VAR)`	Free variable VAR