Time-dependent Integrated Modeling of AT, Hybrid, and ELMy H-mode Plasmas in ITER

ITPA Confinement Database, Modeling, Steady-State and Hybrid Topical groups

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- Time-dependent modeling is needed to address the challenges of creating and maintaining steady state burning plasmas
- Integrated modeling needed for the nonlinearities and strong coupling of plasma conditions, heating, and current drive
- This study gives new simulations for ITER AT, Hybrid, and ELMy H-mode plasmas with NNBI, ICRH, LHCD, and ECH/CD

Integrated Modeling using the TSC and TRANSP codes

TSC:

- evolves free boundary equilibrium
- evolves temperatures and densities
- assumes sources and transport models

↓ boundary Temperautres densities

↑ heat sources current drive sources

TRANSP:

- Monte Carlo for NNBI, fusion products
- LHCD, ICRH, ECH/ECCD
- fast ion distributions
- neutrals

↓

Down-stream Analysis

- MHD stability (ex PEST)
- Microturbulence (ex GS2 and GYRO)
- Fast particle modes (ex NOVA-K)
- Advanced heating/CD codes (ex AORSA)
- Advanced predictive codes (ex XPTOR)

Plasmas considered

- AT plasma: low current, fully non-inductive
- Hybrid plasma: q(0) $\simeq$1.0-2.0
- Sawtoothing ELMy H-mode

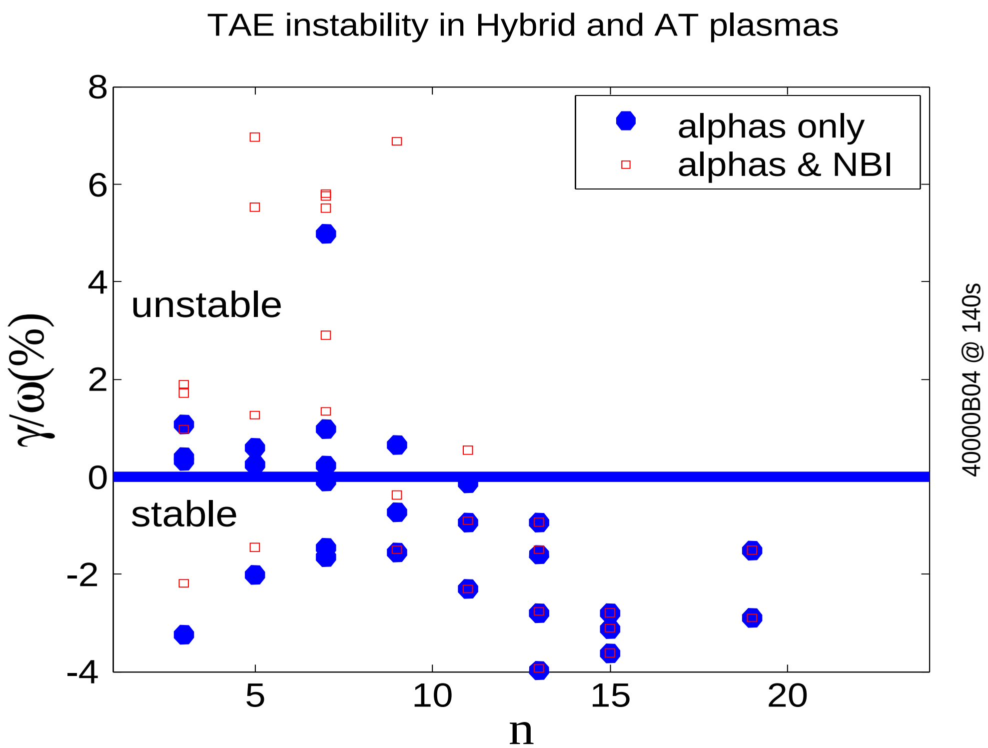
units	I_p MA	I_{boot} MA	I_{nnbi} MA	I_{Oh} / I_p	$n_e(0)$ $10^{20}/m^3$	f_{GW}	T_e keV	P_{dt} MW	$\beta_\alpha(0)$ per cent
AT	9	4.3	4.3	0.0	0.6	0.63	33	305	1.3
Hybrid	12	2.8	4.5	0.32	0.6	0.47	33	305	1.3
ELMy	15	2.7	1.1	0.70	1.1	0.80	22	403	0.6

Some examples of Findings

- Good NNBI penetration and CD
- Modest toroidal rotation from NNBI torques
- High temperatures in AT and Hybrid plasmas
- Intense TAE activity
- Difficulty maintaining high pedestal temperatures and high q_{min}
- TSC could not construct Hybrid or AT plasma from GLF23 with the planned ITER powers
- IDEAL MHD instability for conventional Kadomstev sawteeth

Example of down-stream analysis

- NOVA-K analysis of TAE modes in ITER AT/Hybrid plasmas



Another example of down-stream analysis

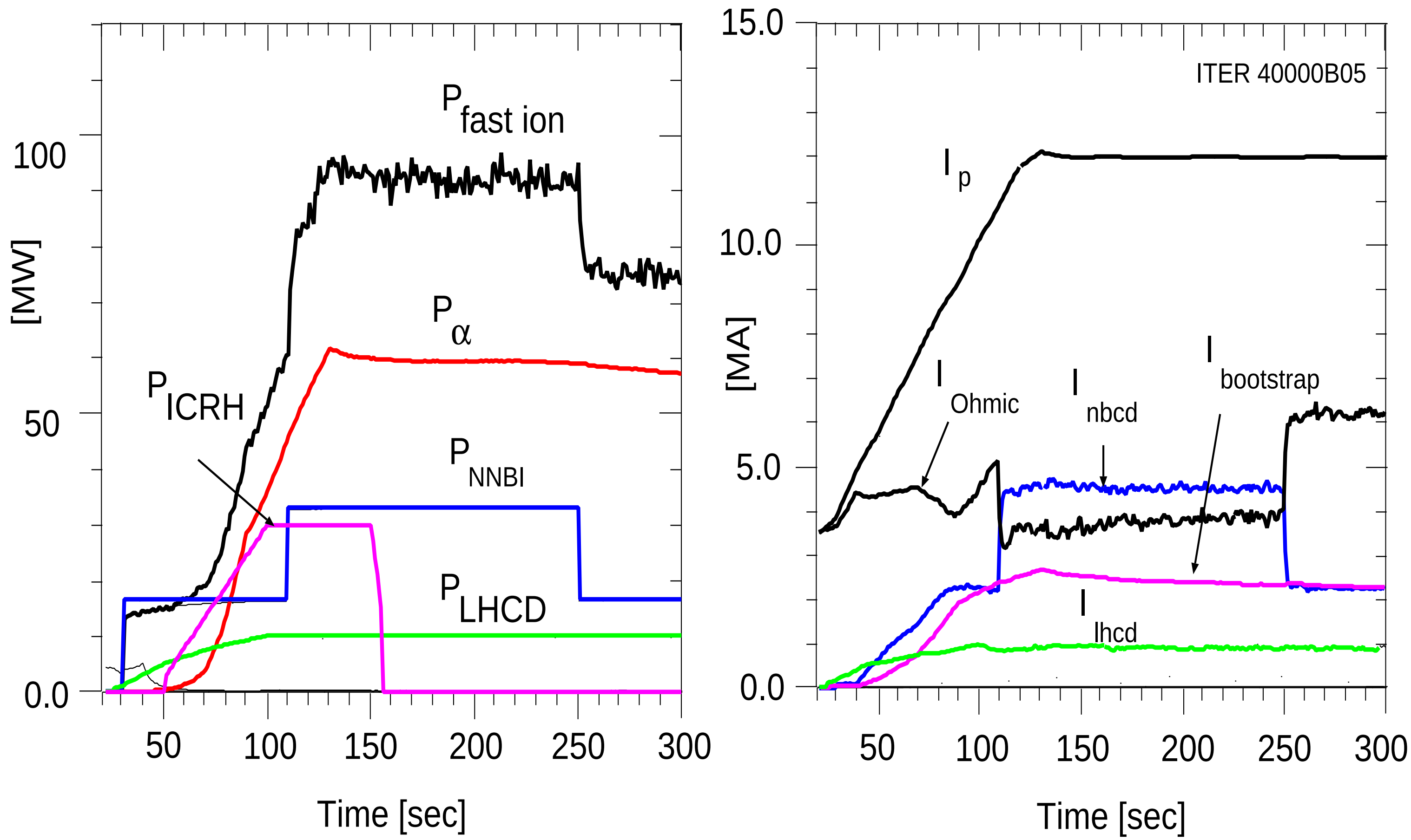
- PEST ideal MHD stability

  1. Difficulties with equilibrium for AT plasma
  2. Hybrid plasma stable to ideal MHD
  3. ELMy plasma unstable to n=1 mode if q is too flat from sawteeth

Construction of the Hybrid plasma

- Reduce I_p to 12 MA to decrease inductive-current fraction
- Assume sufficient NNBI and LH current drive to raise q(0) and cause reversal
- Assume low transport near radius of q reversal
- Assume moderate density

Heating powers and plasma currents in the Hybrid plasma



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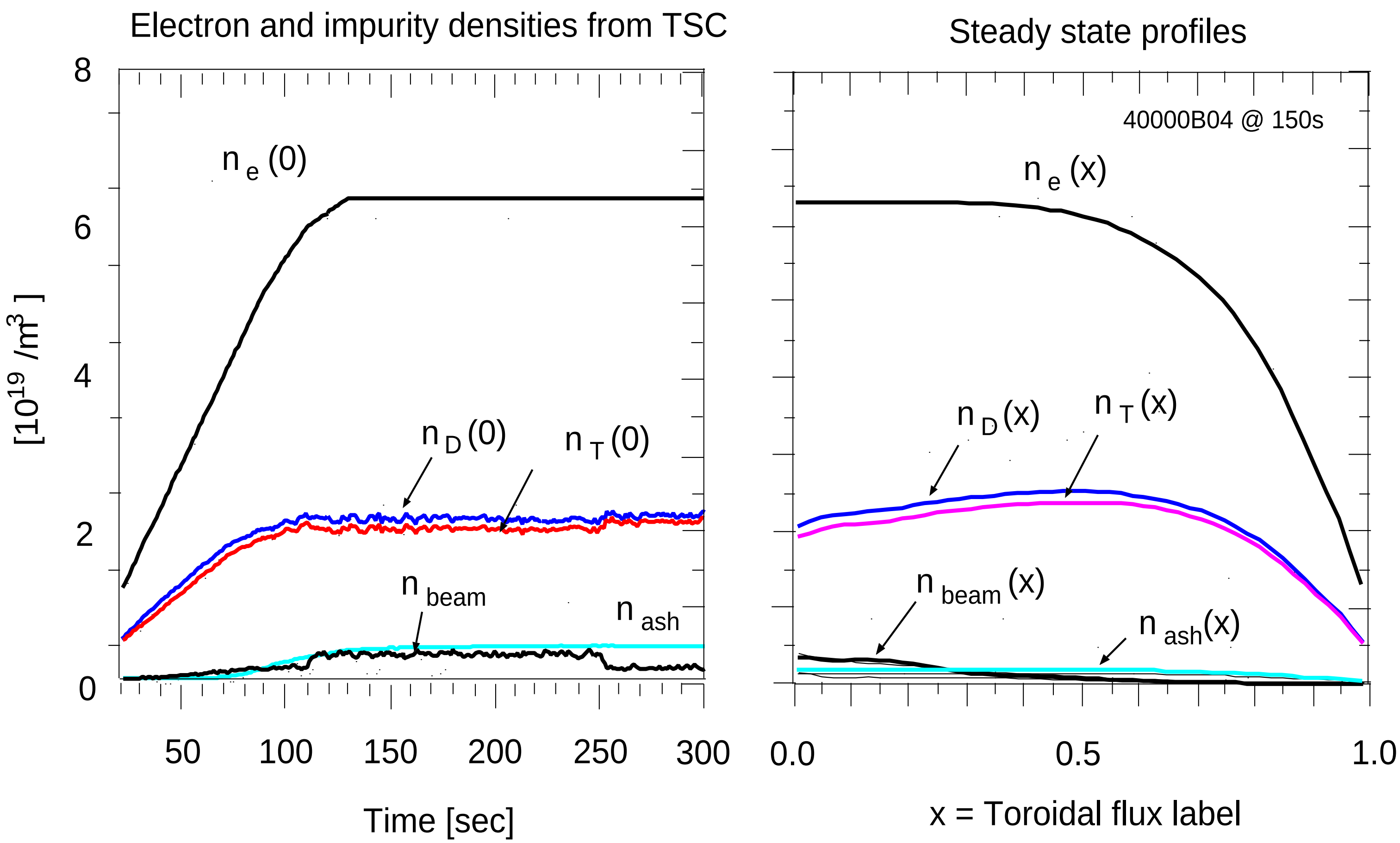
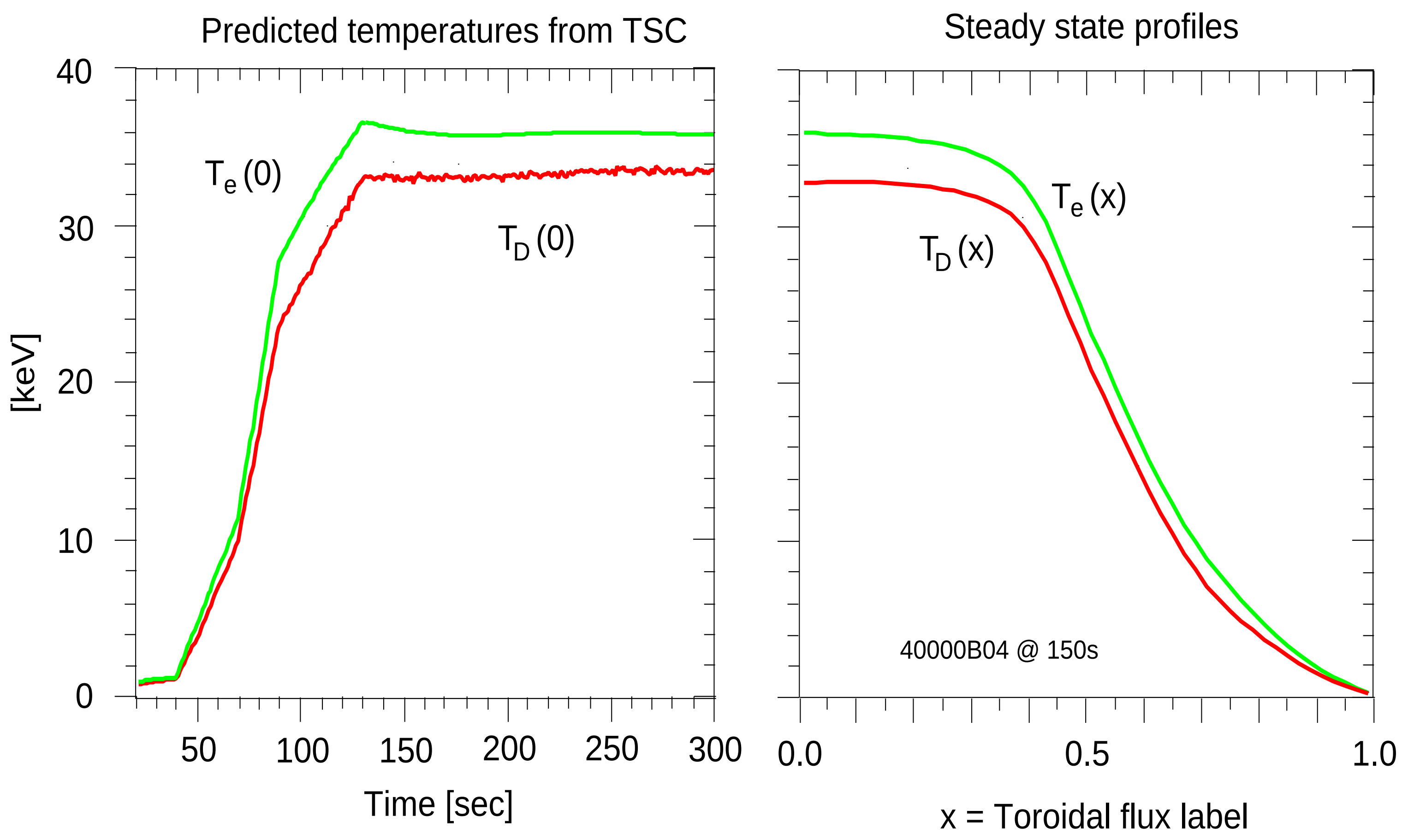
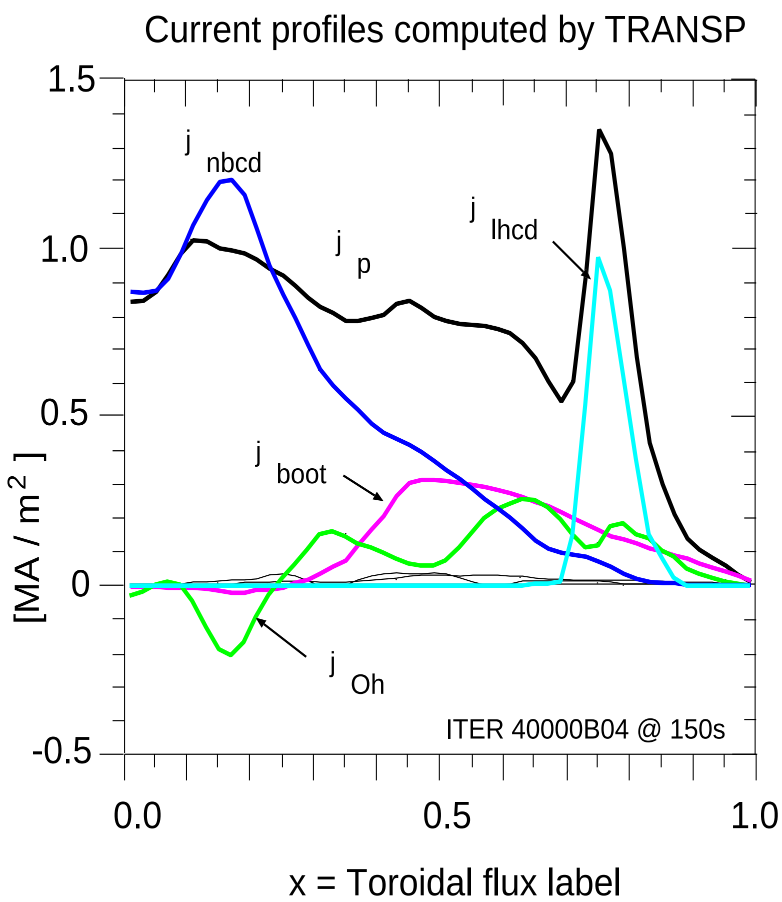
Densities in the Hybrid plasma

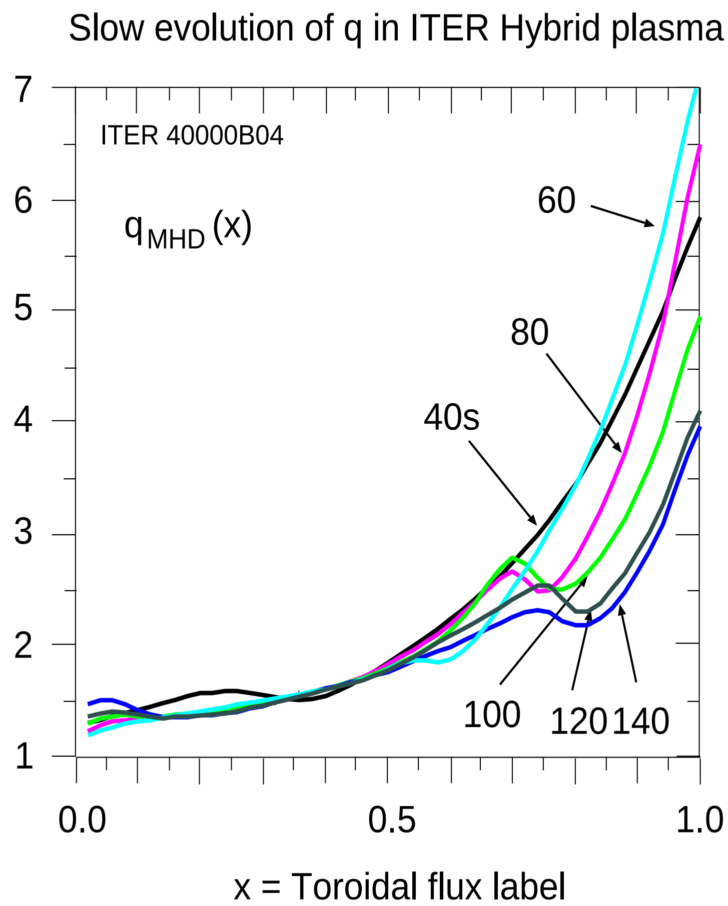


Temperatures in the Hybrid plasma



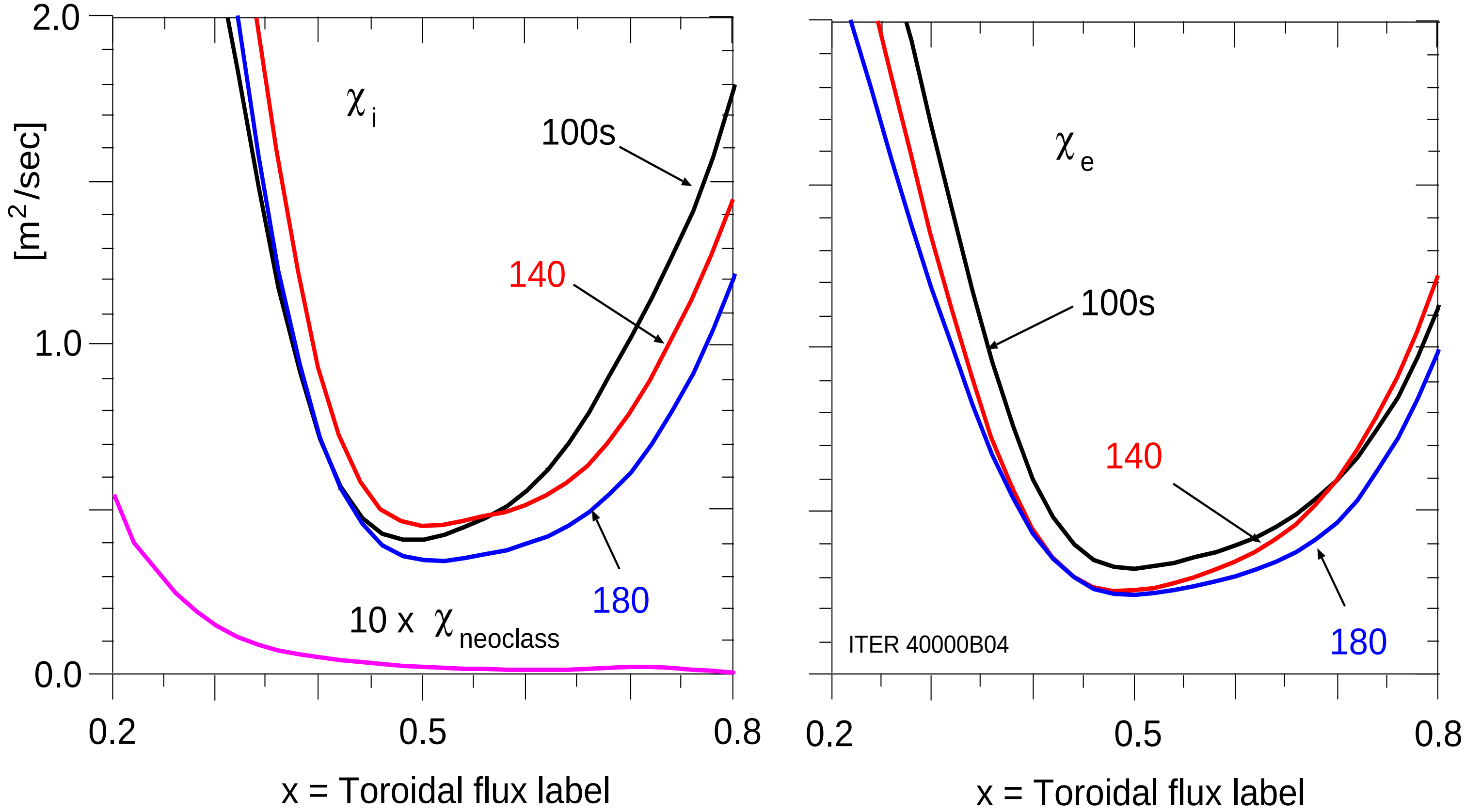
Current densities and q_{MHD} in the Hybrid plasma





Transport in the Hybrid plasma

Transport calculated by TRANSP from TSC profiles, TRANSP sources



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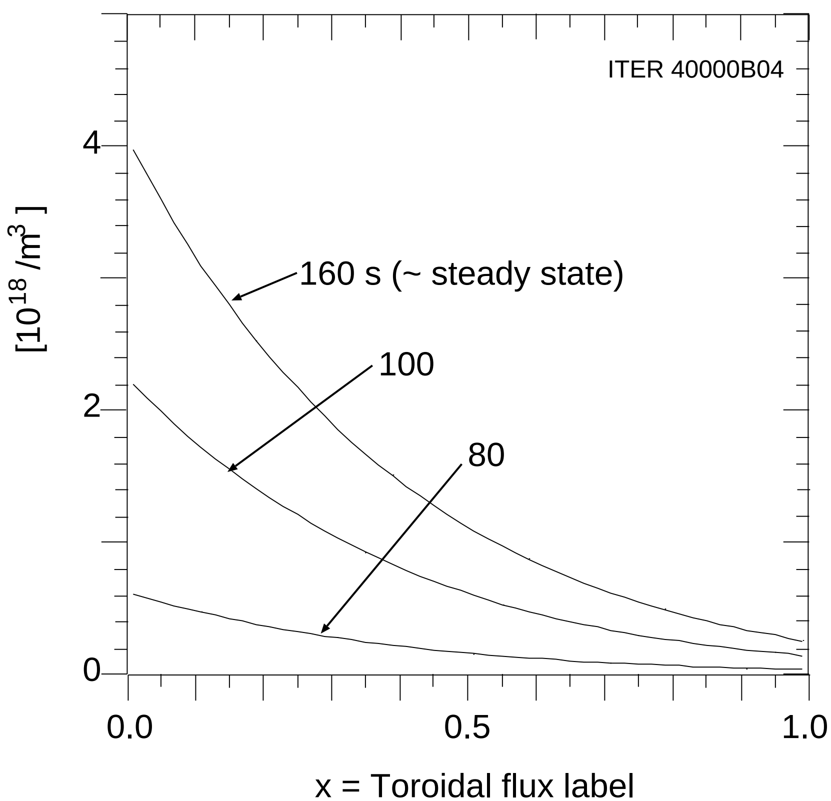
Predict ash accumulation in the Hybrid plasma

He ash accumulation in ITER Hybrid plasma



Sources:

Core - He^4 thermalization

Edge - Ash recycling coeff = 0.8

Transport

$\Gamma = -D \nabla n_{He^4} + V n_{He^4}$

$D = 1.0\ m^2/s$

$V = -1.0\ m/s$

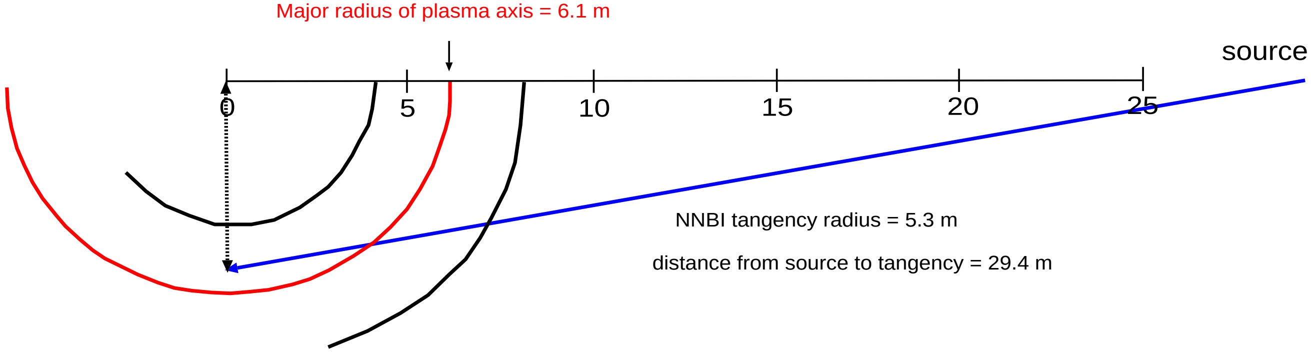
Confinement

$\tau_{He^4} = 6.2\ s$

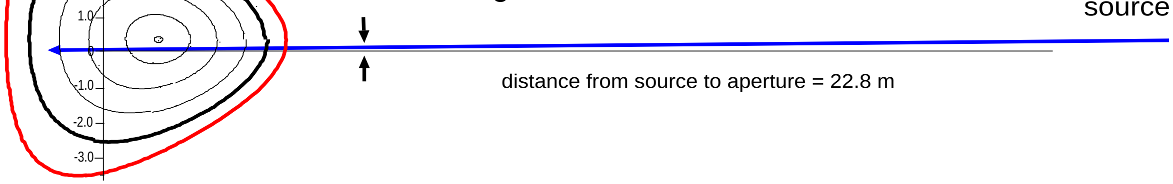
$\tau^*_{He^4} = 30.9\ s$

Layout of NNBI geometry in ITER

Plan view



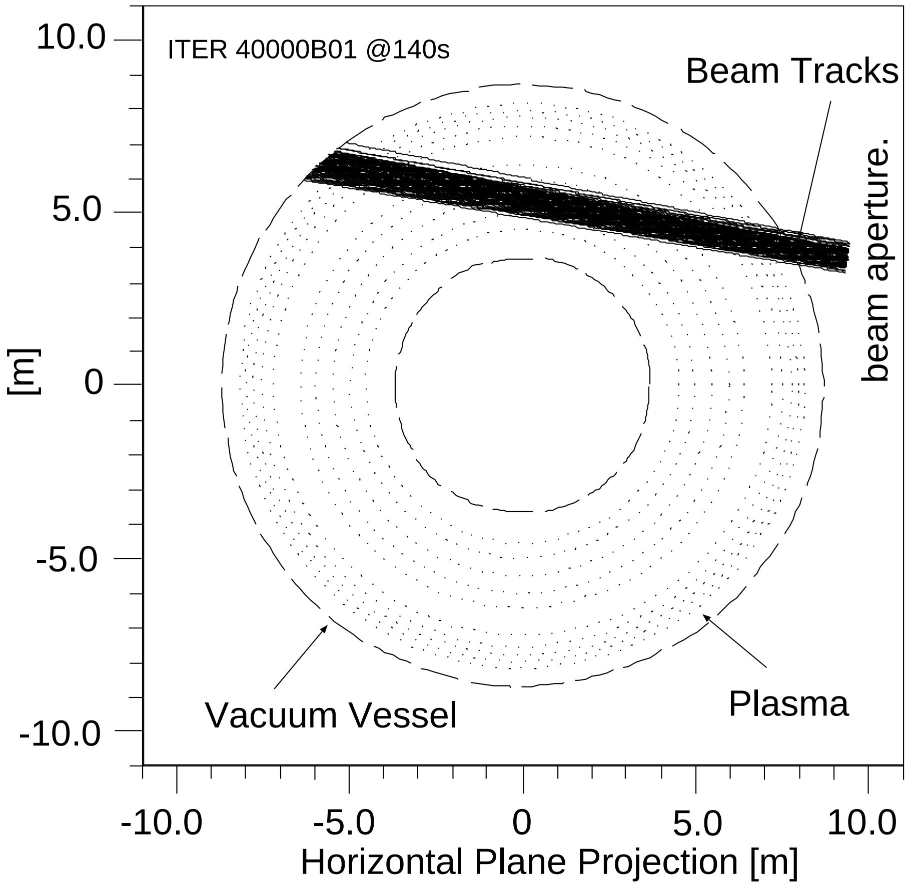
Vertical view along beam



Aperture height adjusted in TRANSP to mock up source swing

source angle rotates 0.16 deg in vertical plane

Diagnostics of NNBI in TRANSP



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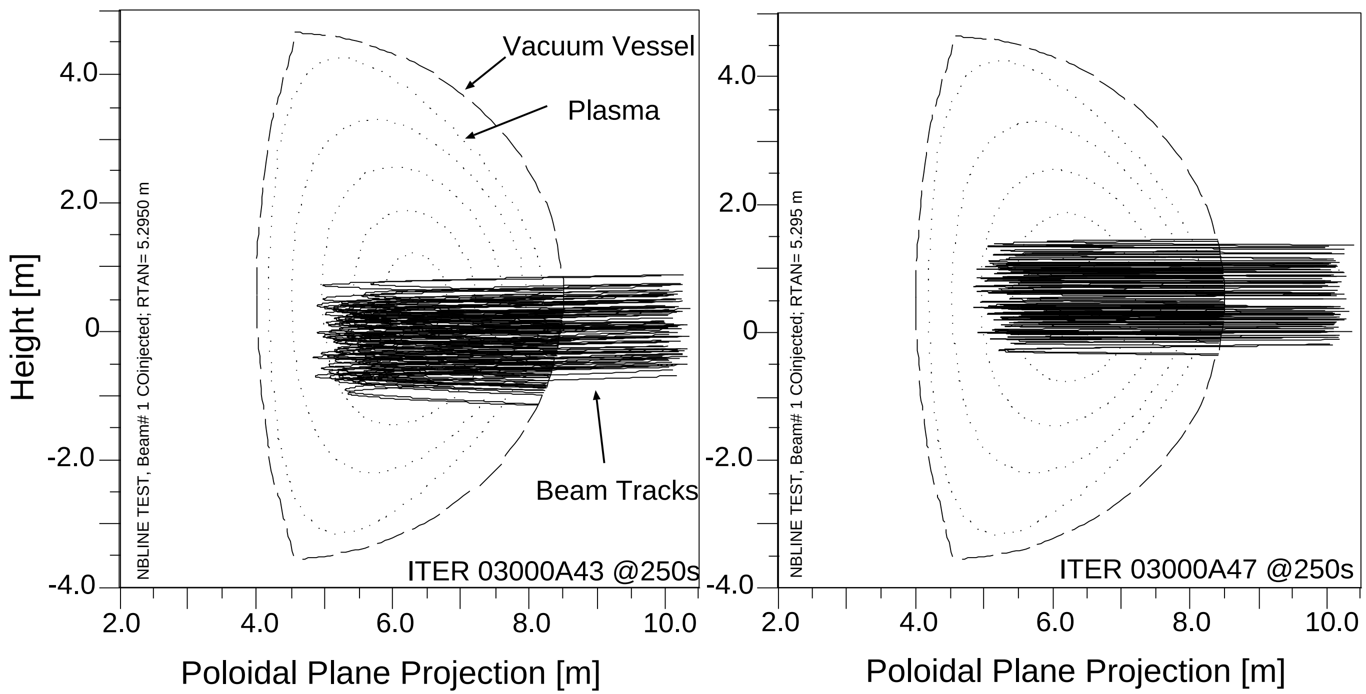
Diagnostics of NNBI in TRANSP - (2)

Effects of changing NNBI aiming

0.5 m below magnetic axis midplane

along magnetic axis midpland



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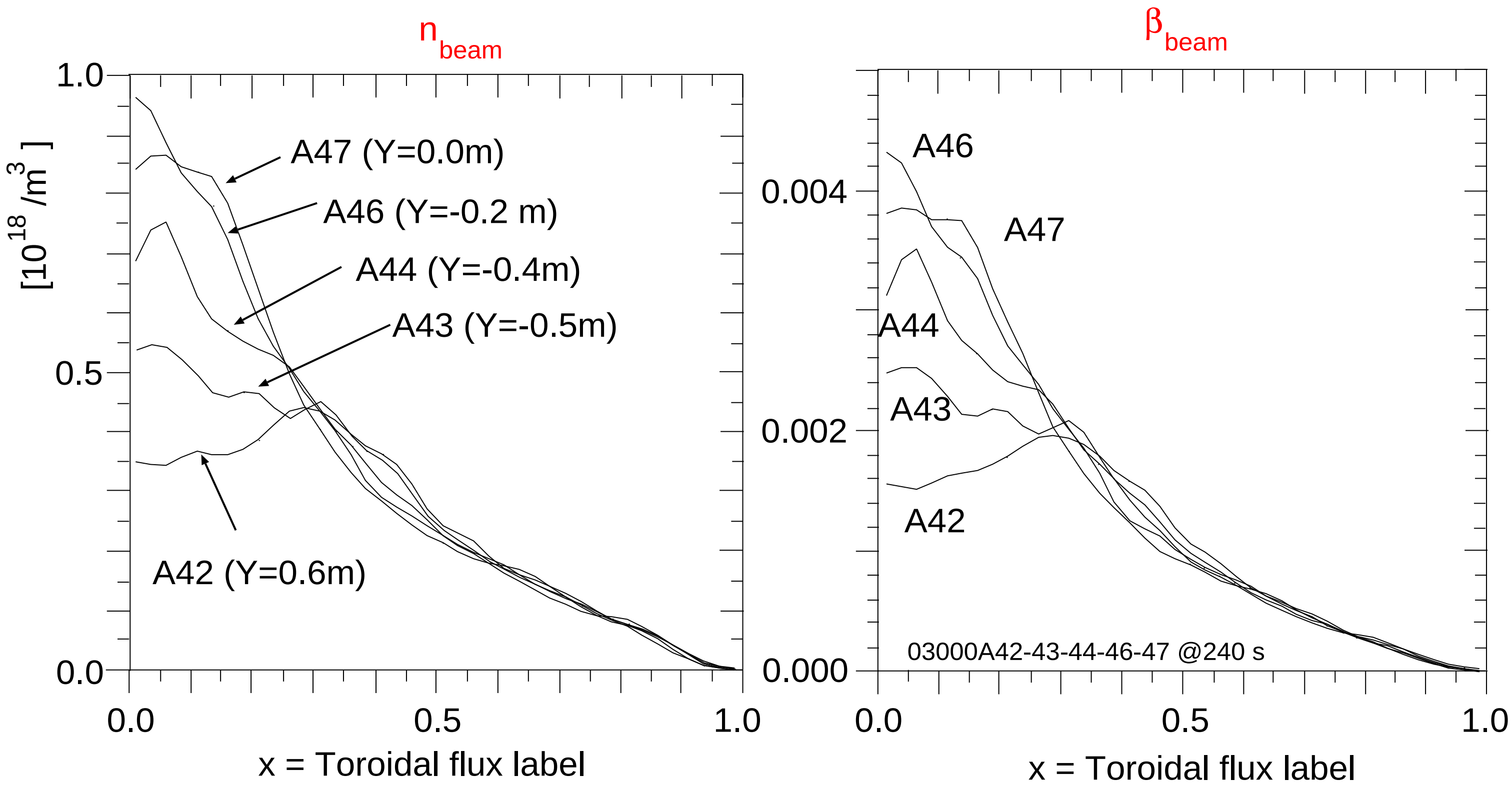
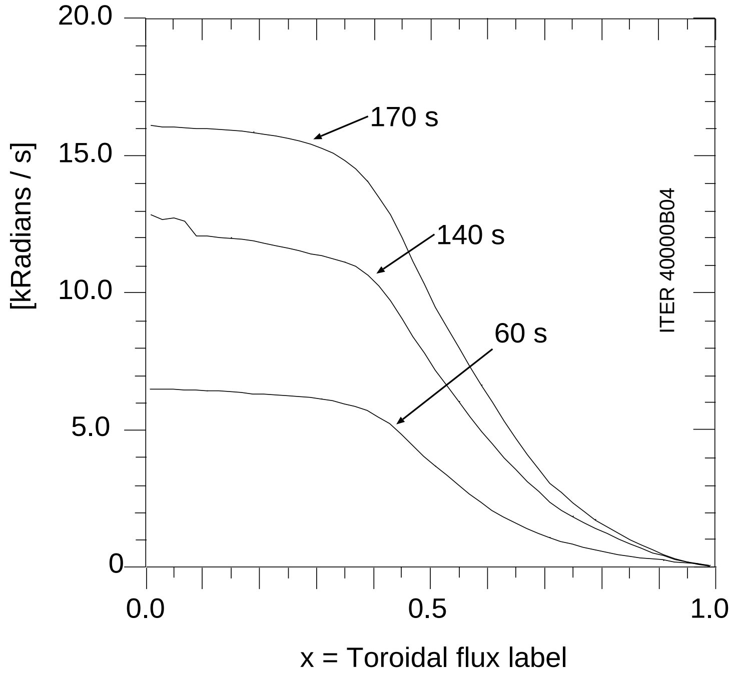
Variation of beam ion parameters with NNBI aiming



Predict toroidal rotation in the Hybrid plasma

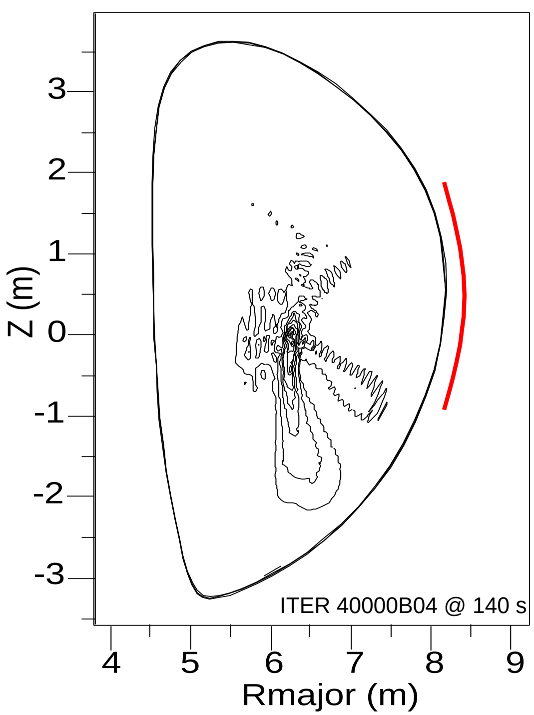


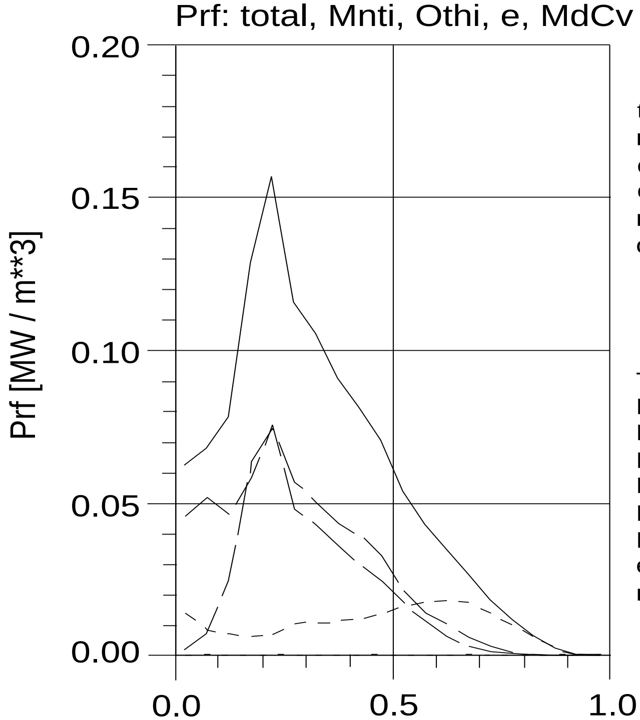
Assume:

$\chi_{mom} = \chi_i$

Torques from NNBI

He³ minority ICRH in the Hybrid plasma

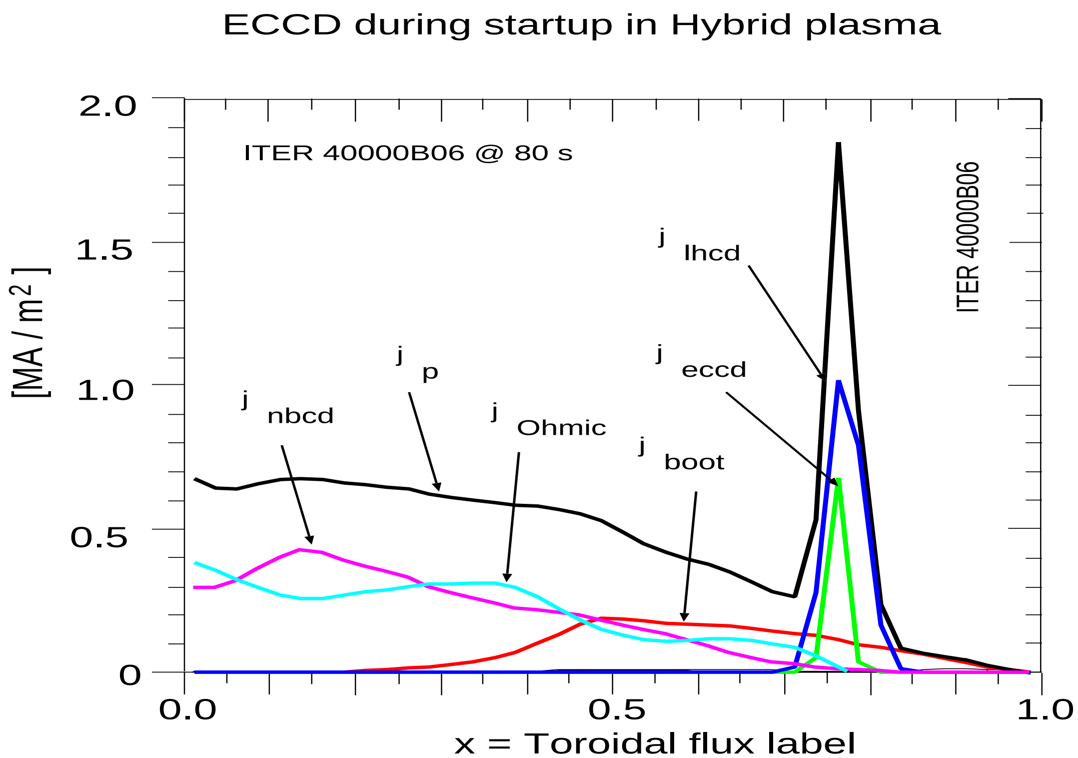




total Prf= 30.0 MW
minorities: 12.14 MW
other ions: 10.64 MW
electrons: 7.223 MW
mode conv.: 0.00 MW
outside LCFS: 0.00 MW

T : 5.50 %
D : 4.23 %
He4 : 0.65 %
Be9_4 : 0.86 %
D_MCfi : 7.89 %
He3_mino : 40.47 %
He4_MCfi : 16.32 %
electrons : 24.08 %
mode conv.: 0.00 %

First attempt at ECCD in the Hybrid plasma



ECCD parameters

5 MW

170 GHz

Z = 4.1m

R = 6.4 m

Theta = 145

Phi = 135

Future Plans

- Closer coupling between TSC and TRANSP
- Further attempts to improve AT solutions
- Improve, Validate, Verify Heating / CD and predictive codes

Conclusions

- The TSC-TRANSP codes have been used together for time-dependent integrated modeling of burning plasmas
  1. AT, Hybrid, and ELMy H-mode ITER plasmas
  2. AT and H-mode FIRE plasmas
- moderate toroidal rotation predicted from NNBI
- LHCD effective at altering q around x=0.8
- TAE activity in predicted for ITER
- GLF model in TSC generated only H-mode plasmas
- ash accumulation modeled for various transport assumptions
- sawtooth mixing of fast alphas and ash