# Integrated modeling of burning plasmas with the TRANSP code

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- TRANSP is widely used for self-consistent analysis of Tokamak experimental data
- TRANSP also is a valuable tool for predicting burning plasma performance

- Outline

1. Introduction to TRANSP
2. Simulations of ITER H-mode plasmas
3. Simulations of FIRE AT plasmas

# Introduction to TRANSP

- What is TRANSP?
  1. largest magnetic fusion code
  2. more than 100 man-years of development
  3. more than 200 man-years of application
  4. extensive verification and validation
  5. open source, used world wide
- What TRANSP does
  1. multiple plasma species n$_j$ with Maxwellian T$_j$
  2. arbitrary nested, toroidally-symmetric flux surfaces
  3. time evolving magnetic fields
  4. variety of heating and current drive packages
  5. distributions in energy and pitch angle for multiple gyrating fast ion species

# TRANSP applications

- measuring parameters
  1. thermal plasma transport: $\Gamma_j$, $D_j$, $q_j$, $\chi_j$
  2. fast ions: $\beta_{hot}$, $E_{prp}$ / $E_{par}$
- checking consistency of diagnostics
  1. $T_e^{TS} = T_e^{ece}$ ?
  2. $W_{dia} = W_{kinetic}$ ?
- simulating and analyzing diagnostics
  1. $B_{Pol}$ and q from Faraday rotation measurements
  2. $n_D$ and $n_T$ from DT neutron emission measurements
- bridge to theory
  1. inputs to MHD, TAE, microturbulence codes

# Integrated TRANSP modeling for burning plasmas

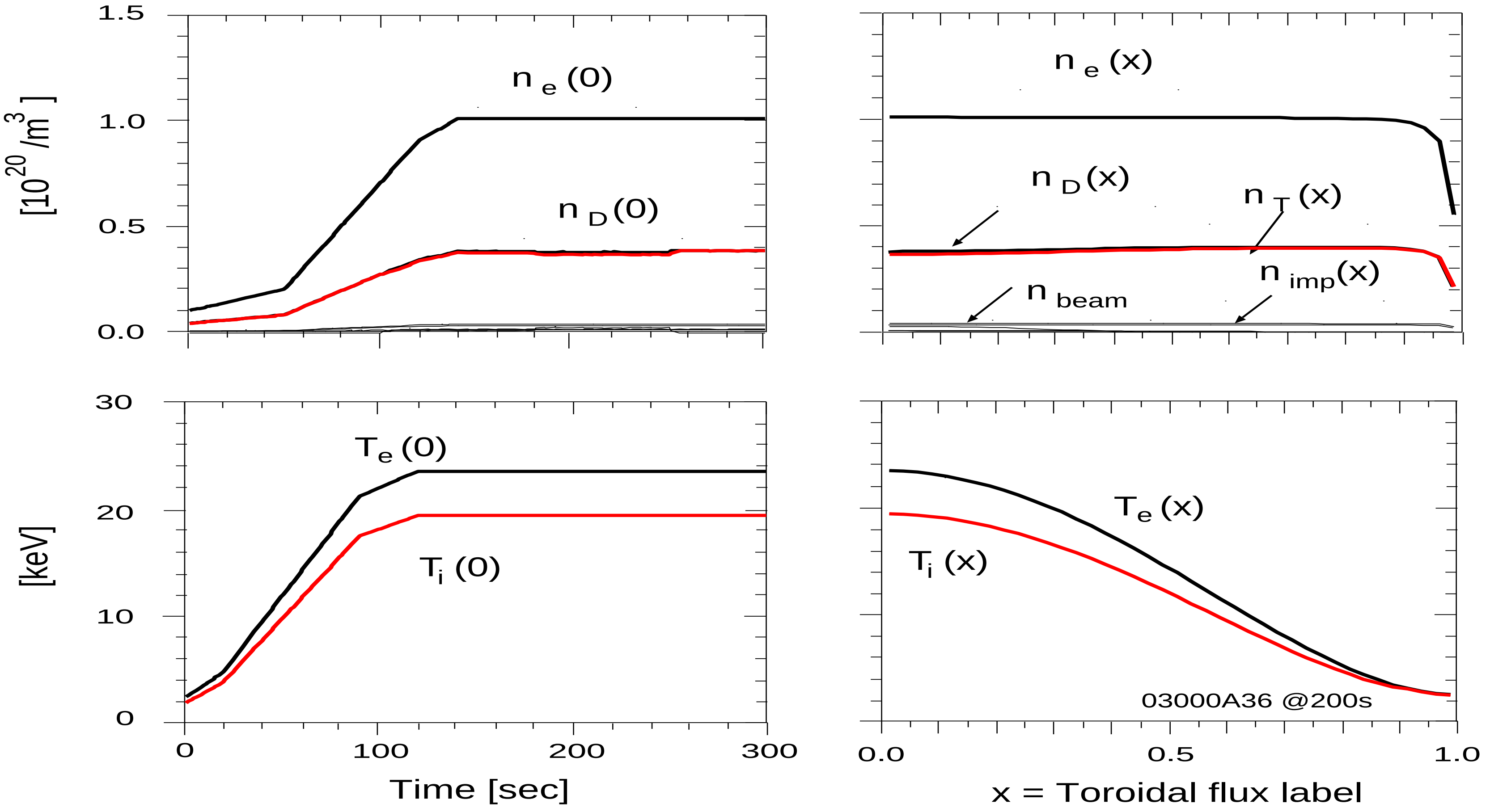
- Suite of equilibrium solvers
- Power deposition and current drive
  1. Monte Carlo for alpha heating and NNBI
  2. SPRUCE or TORIC for low harmonic ICRH
  3. CURAY for high harmonic RF
  4. TORAY for ECH/ECCD
  5. LSC for LHCD
- Need other codes to generate boundary and plasma profiles
  1. TSC
  2. PRETOR (and ASTRA)

# TRANSP outputs of interest for burning plasmas

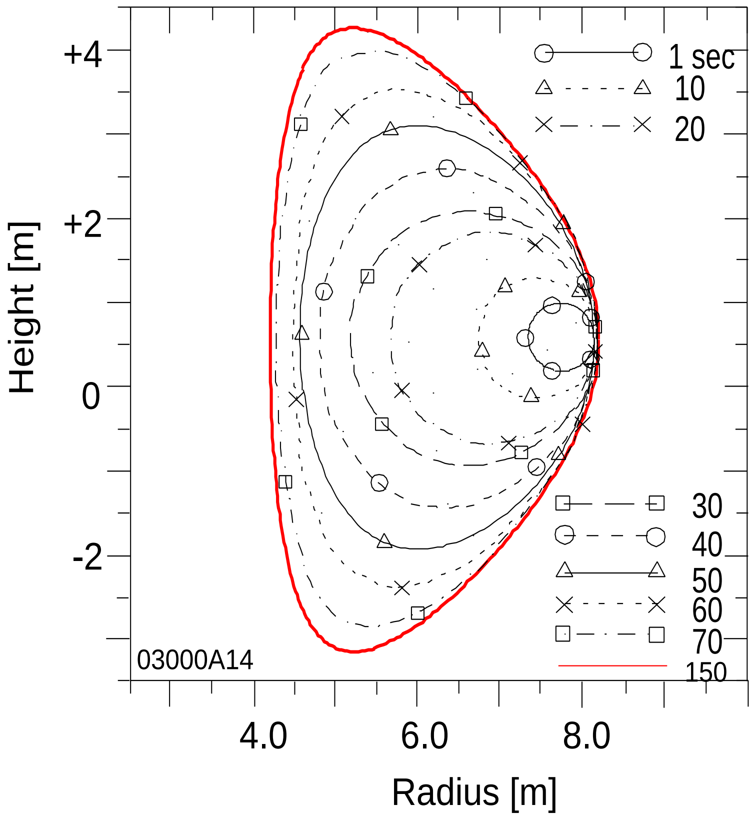
- Power densities such as $P_{ICRH}$(x,t)
- Current densities and q-profile
- $f_j$(x,t,E,pitch angle) for each fast ion species
- predictions of NNBI plasma rotation and current drive
- sawtooth mixing
- He ash accumulation
- ripple loss estimates

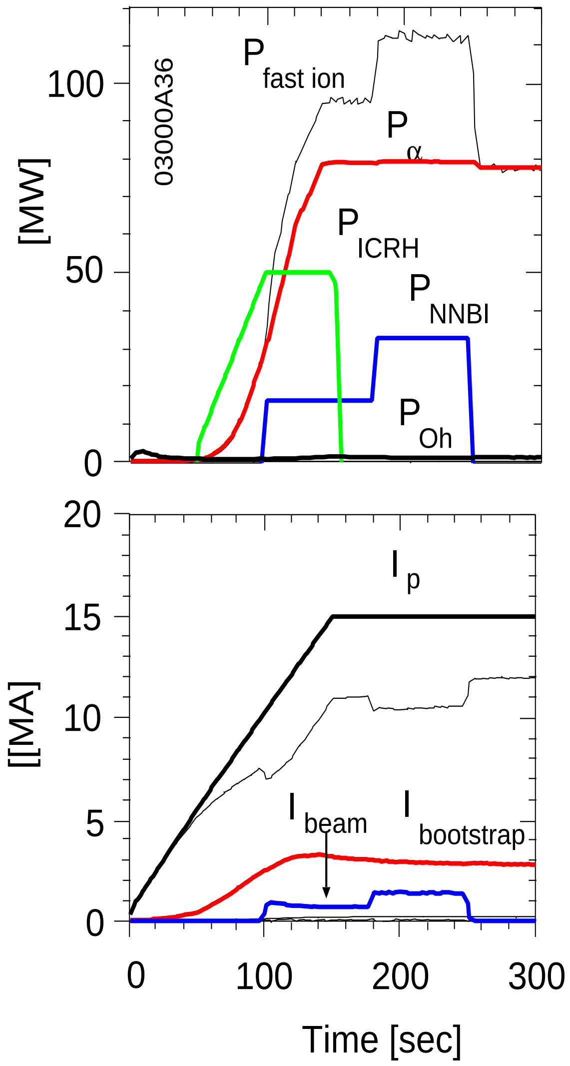
# ELMy H-mode plasma in ITER

Standard ITER ELMy plasma generating $P_{DT}$ = 400 MW [D.Campbell, PoP 2001]

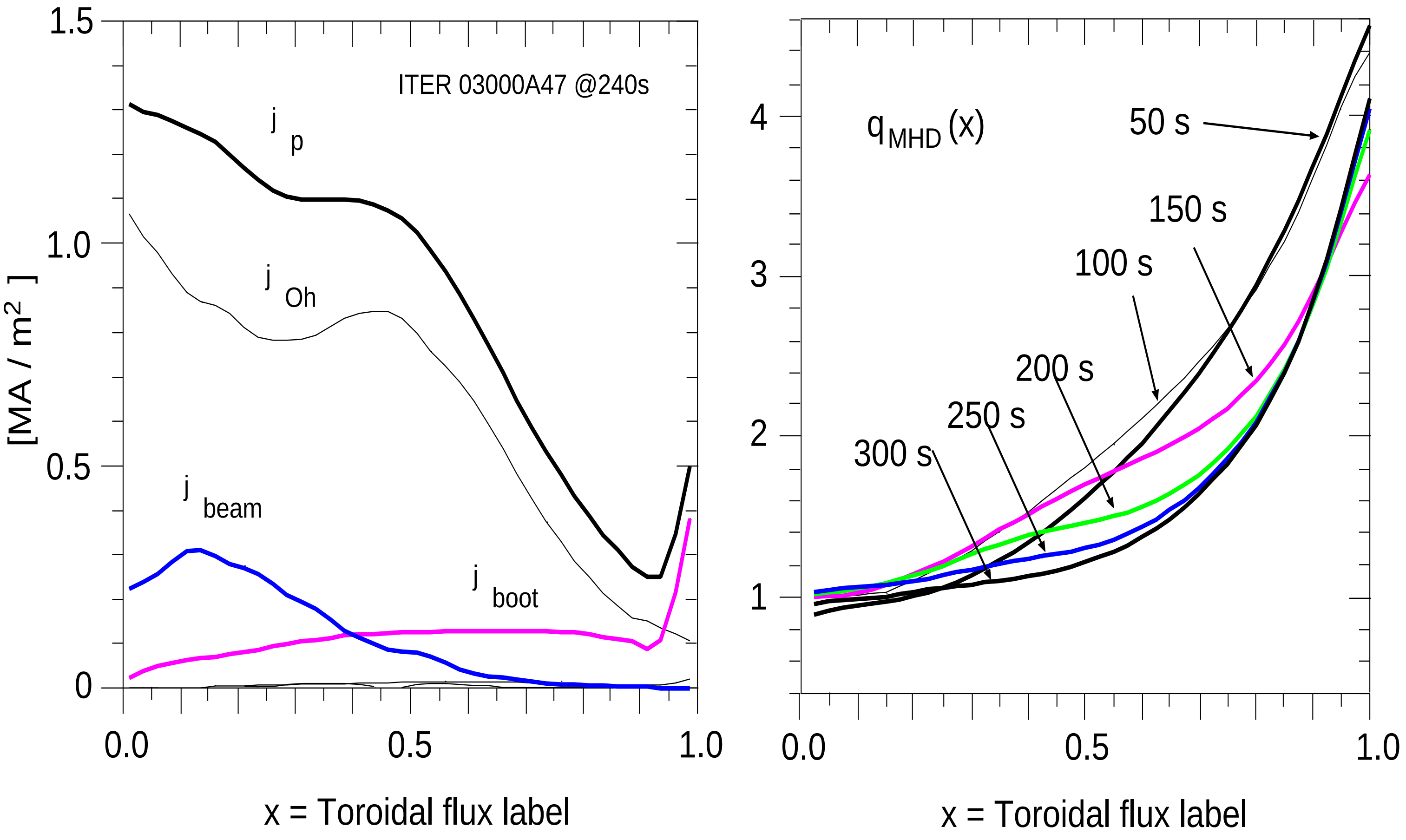


# Rampup plasma to steady state



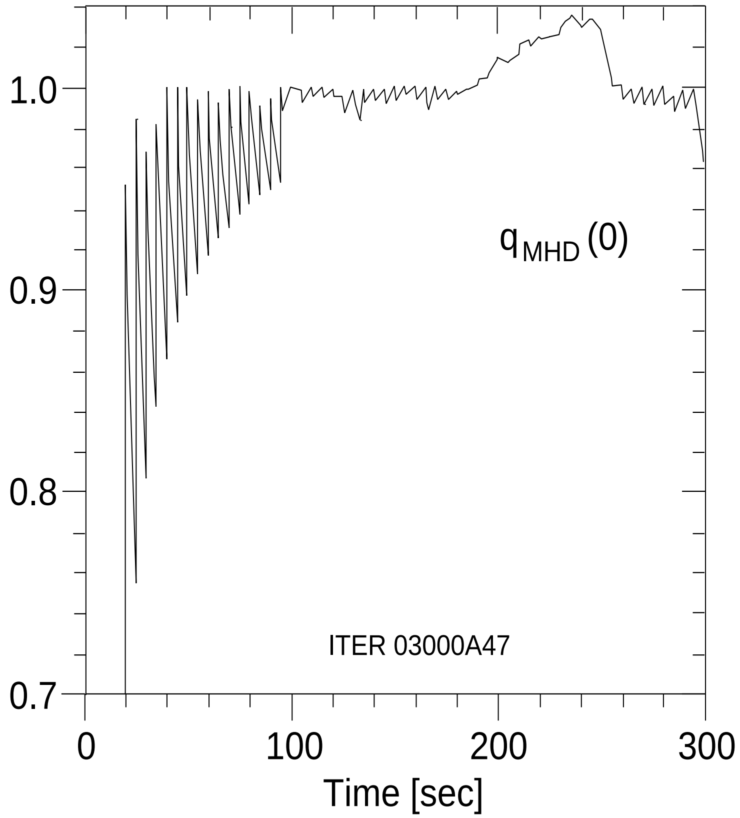


# Computed currents and $q_{MHD}$

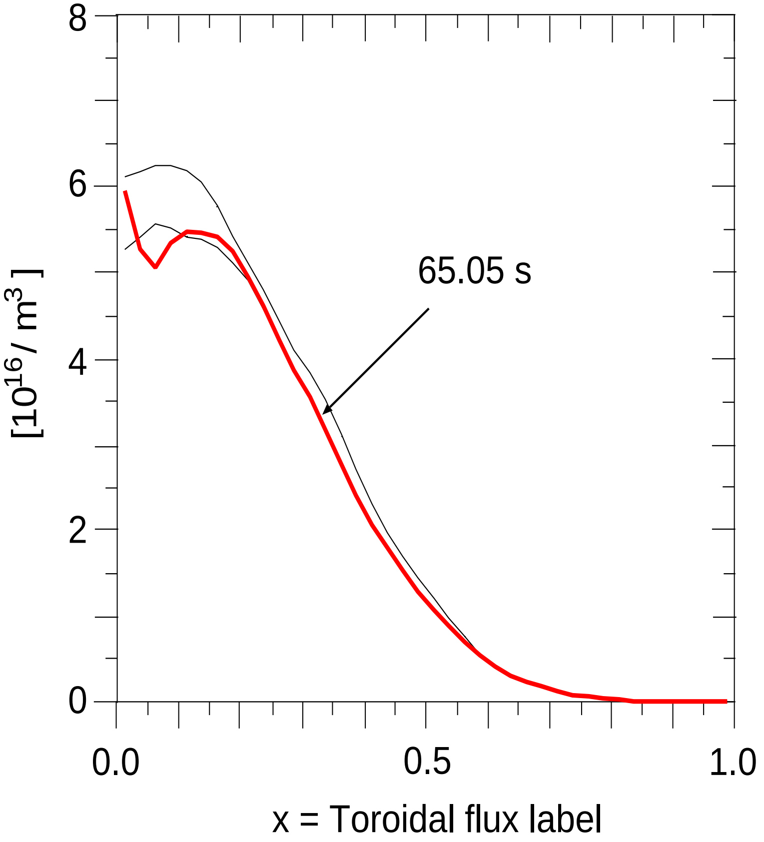


# Predict sawtooth effects on fast ions

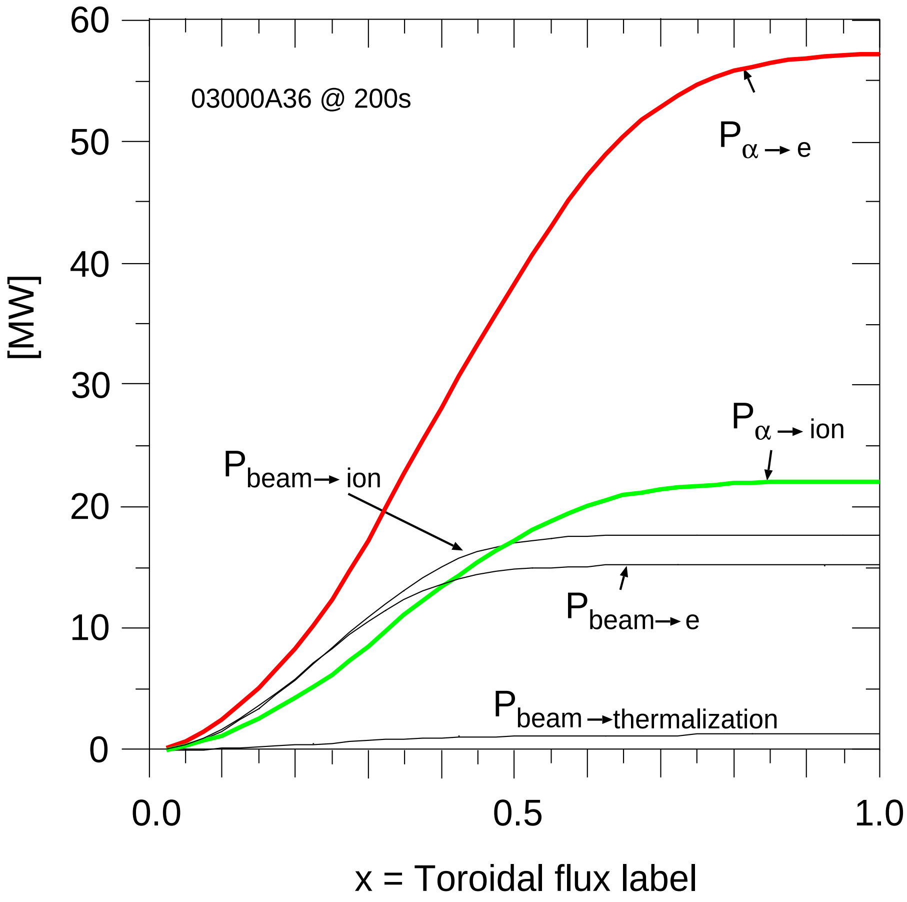
- Assume Kadomtsev mixing of helical flux and fast ions



Example of sawtooth mixing of $n_\alpha$

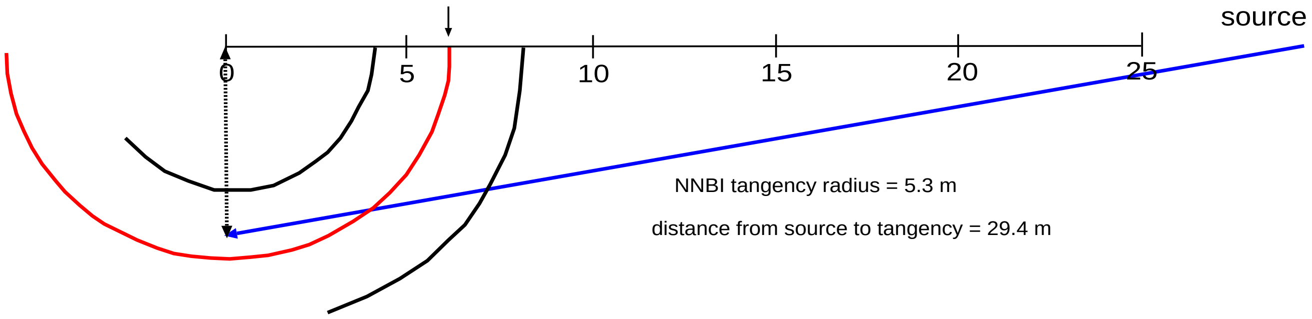


# Alpha parameters



# NNBI geometry in ITER

Plan view

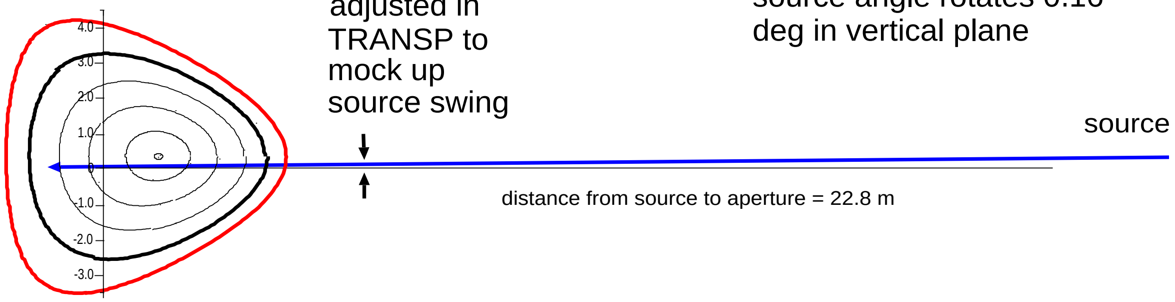


Major radius of plasma axis = 6.1 m

NNBI tangency radius = 5.3 m

distance from source to tangency = 29.4 m

Vertical view along beam

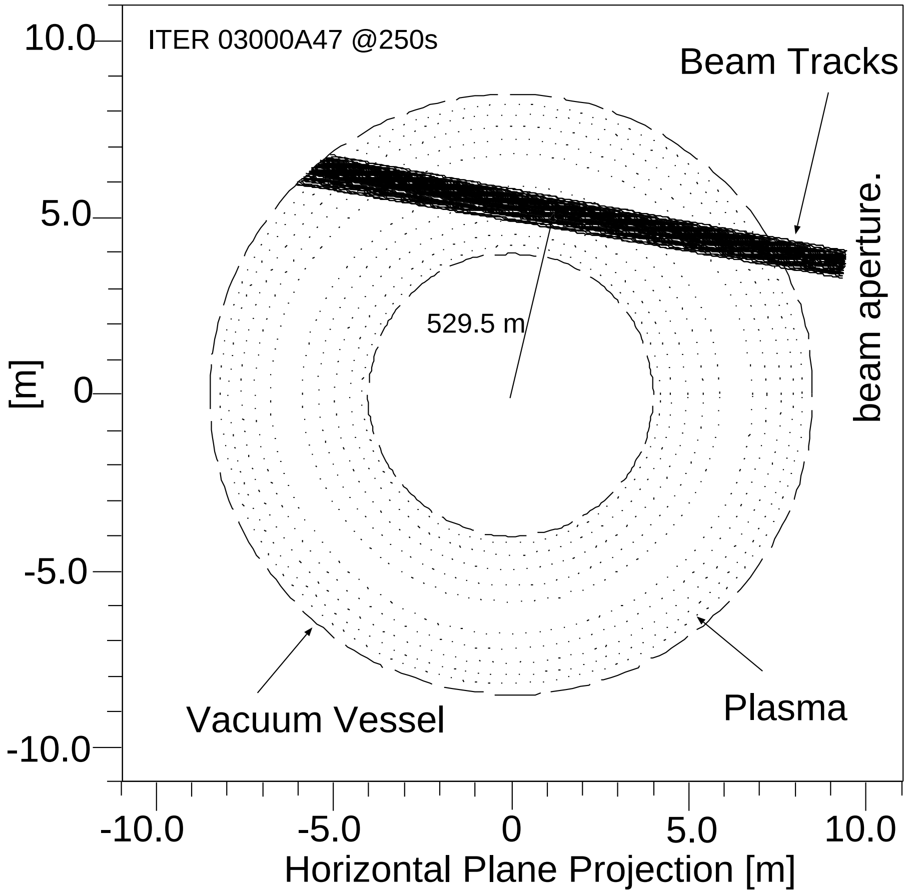


Aperture height adjusted in TRANSP to mock up source swing

source angle rotates 0.16 deg in vertical plane

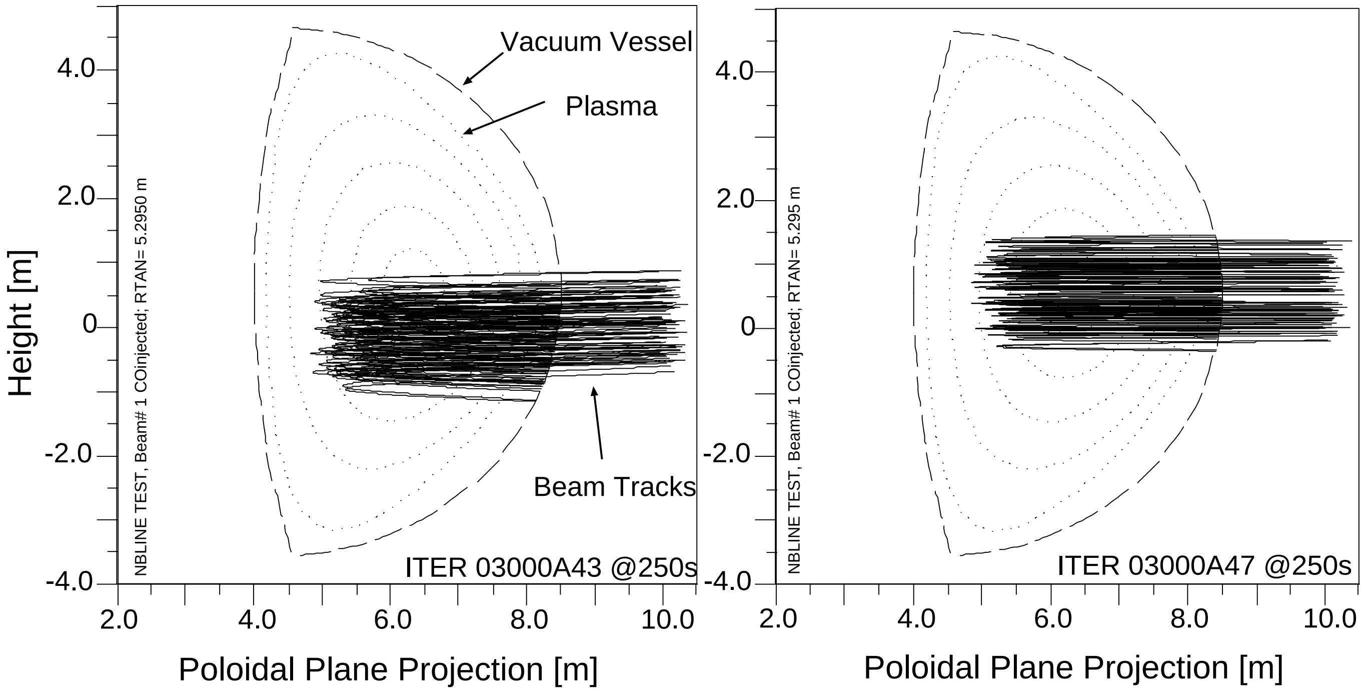
distance from source to aperture = 22.8 m

# Diagnostics of NNBI into ITER



# Diagnostics of NNBI into ITER - cont

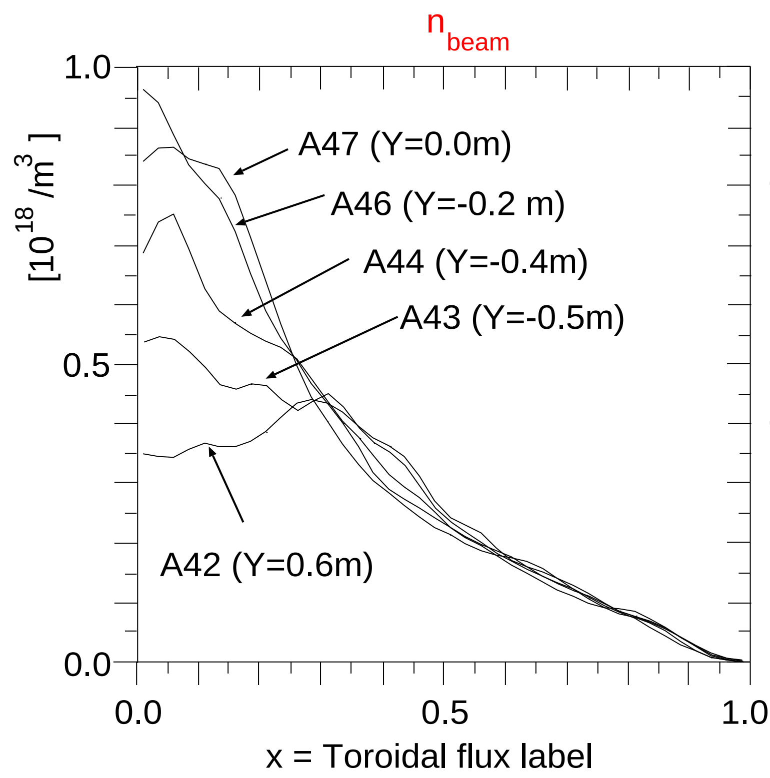
Effects of changing NNBI aiming

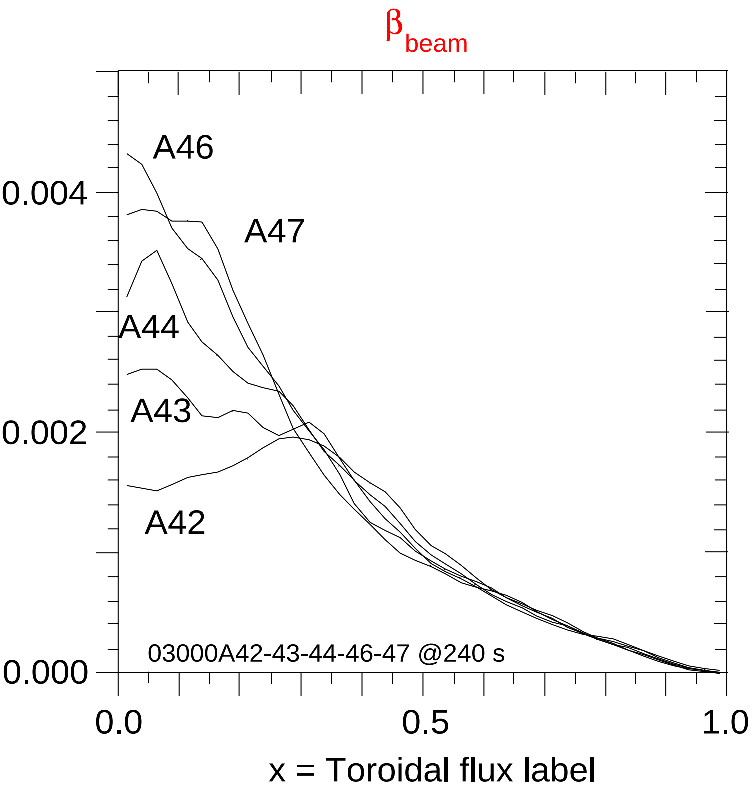


0.5 m below magnetic axis midplane

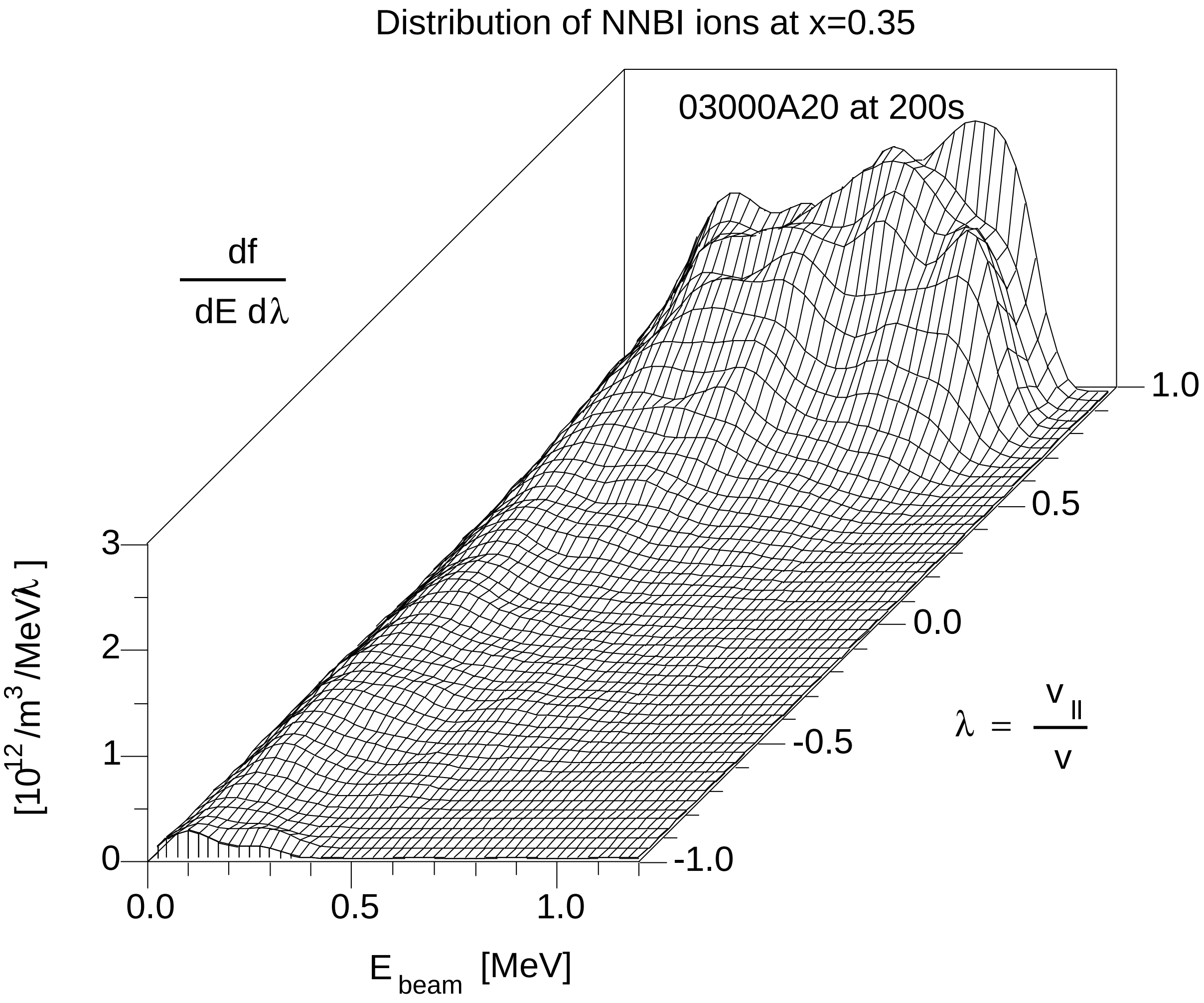
along magnetic axis midpland

# Variation of beam ion parameters with NNBI aiming in ITER

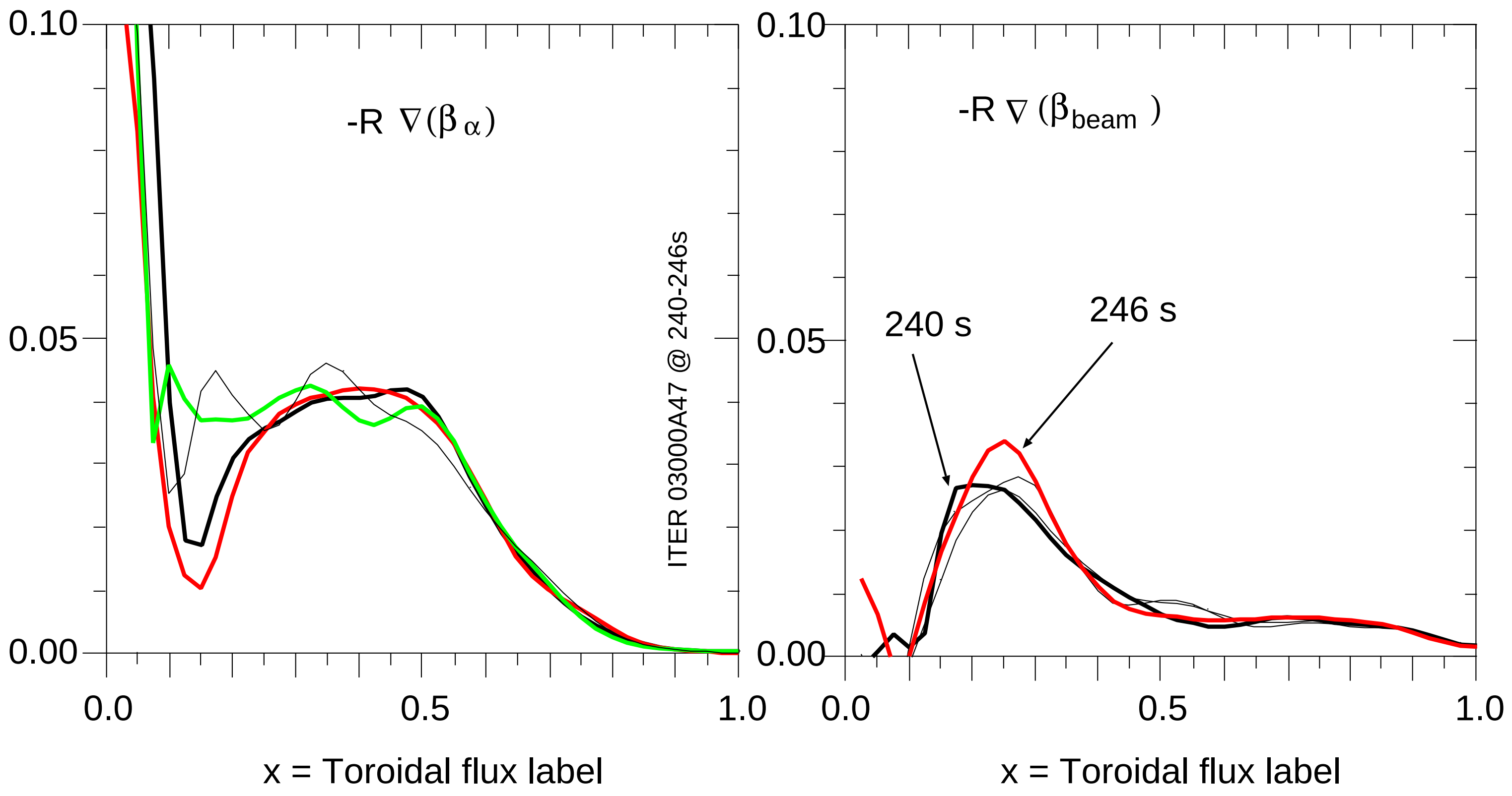




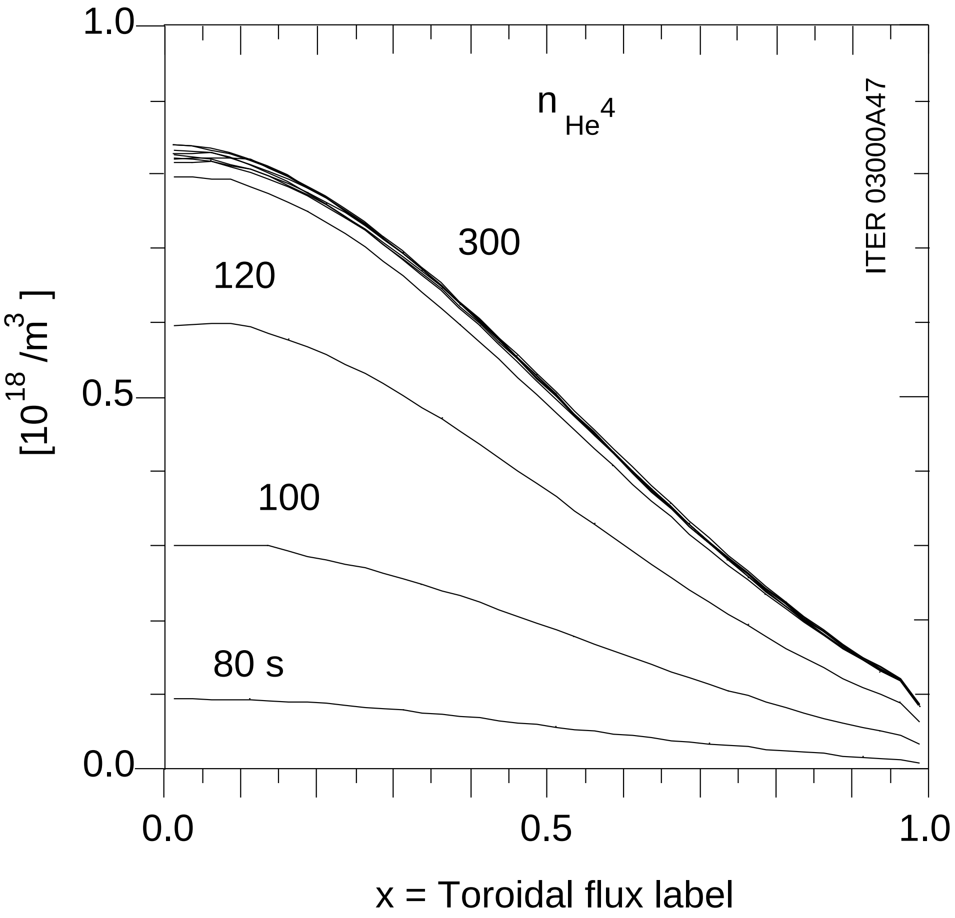
# Phase space distribution of NNBI ions in ITER



# compare alpha and beam TAE drive in ITER



# model ash accumulation in ITER



Sources:

$He^4$ thermalization

Recycling = 0.4

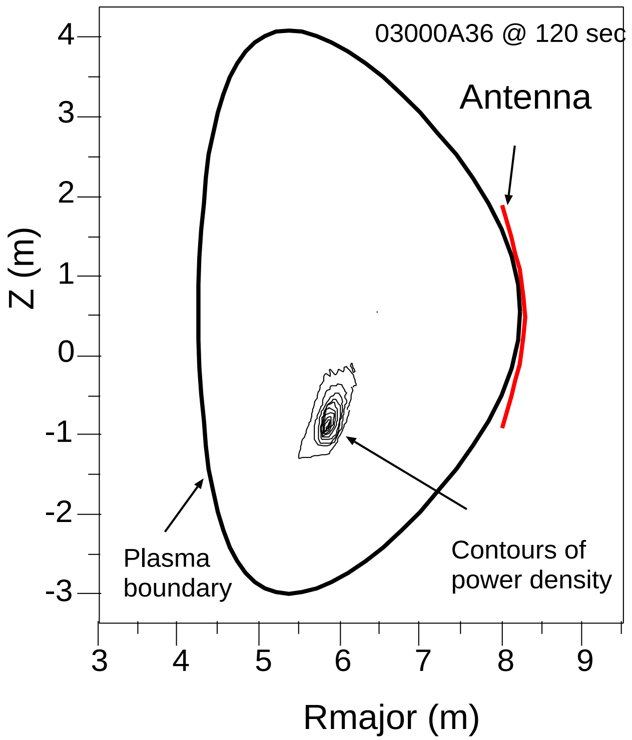
Transport

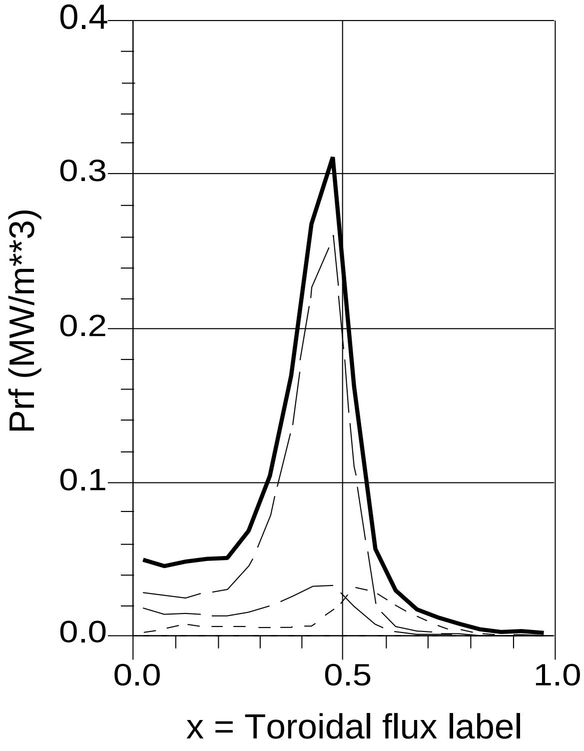
$\Gamma = -D \nabla n_{He^4} + V n_{He^4}$

$D = 1 \ m^2 /s$

$V = -1 \ m /s$

# He$^3$ minority ICRH



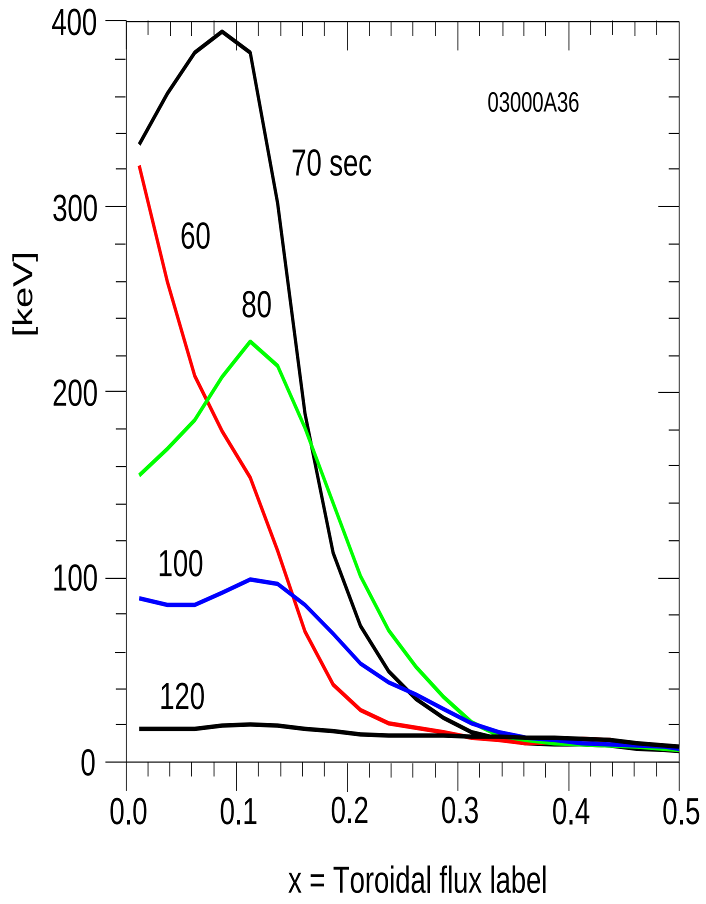


total Prf= 50 MW
minorities: 35.56 MW
other ions: 6.876 MW
electrons: 7.56 MW
mode conv.: 0.000 MW

T : 5.06 %
D : 1.29 %
He4 : 0.03 %
Be8_4 : 0.52 %
D_MCfi : 1.60 %
He3_mino : 71.13 %
He4_MCfi : 5.25 %
electrons : 15.12 %

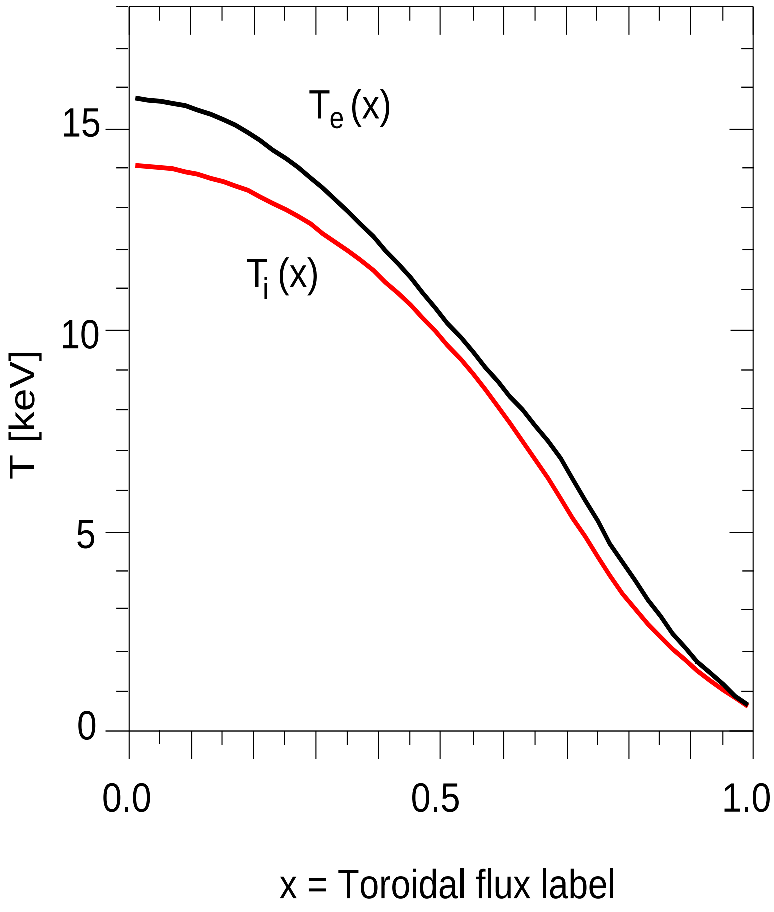
# RF tail temperature decreases as density increases

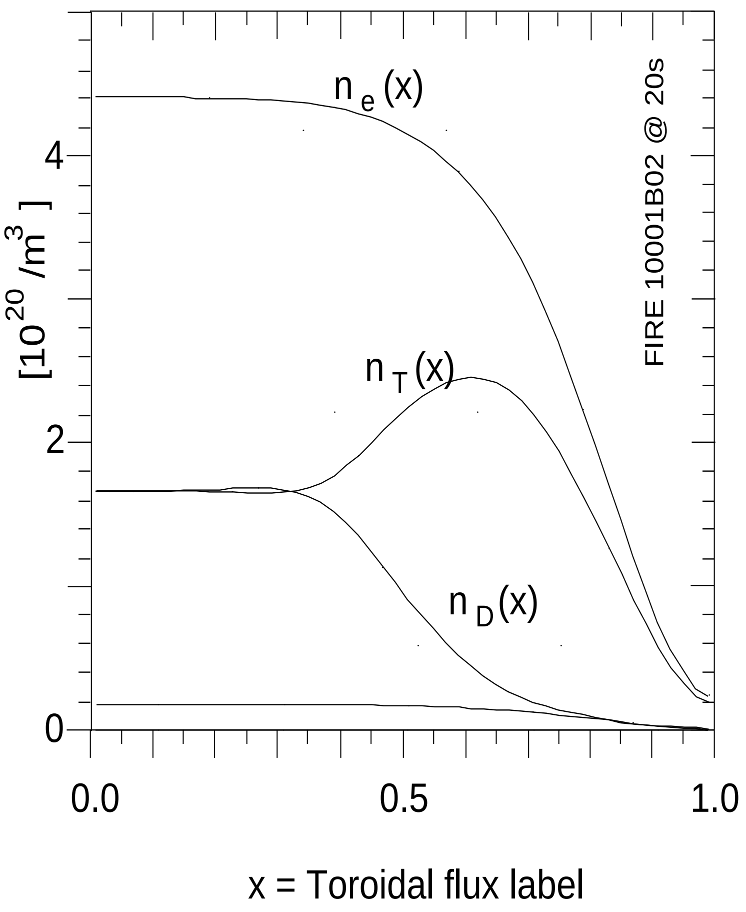
- Assume $n_{He} / n_e = 0.03$



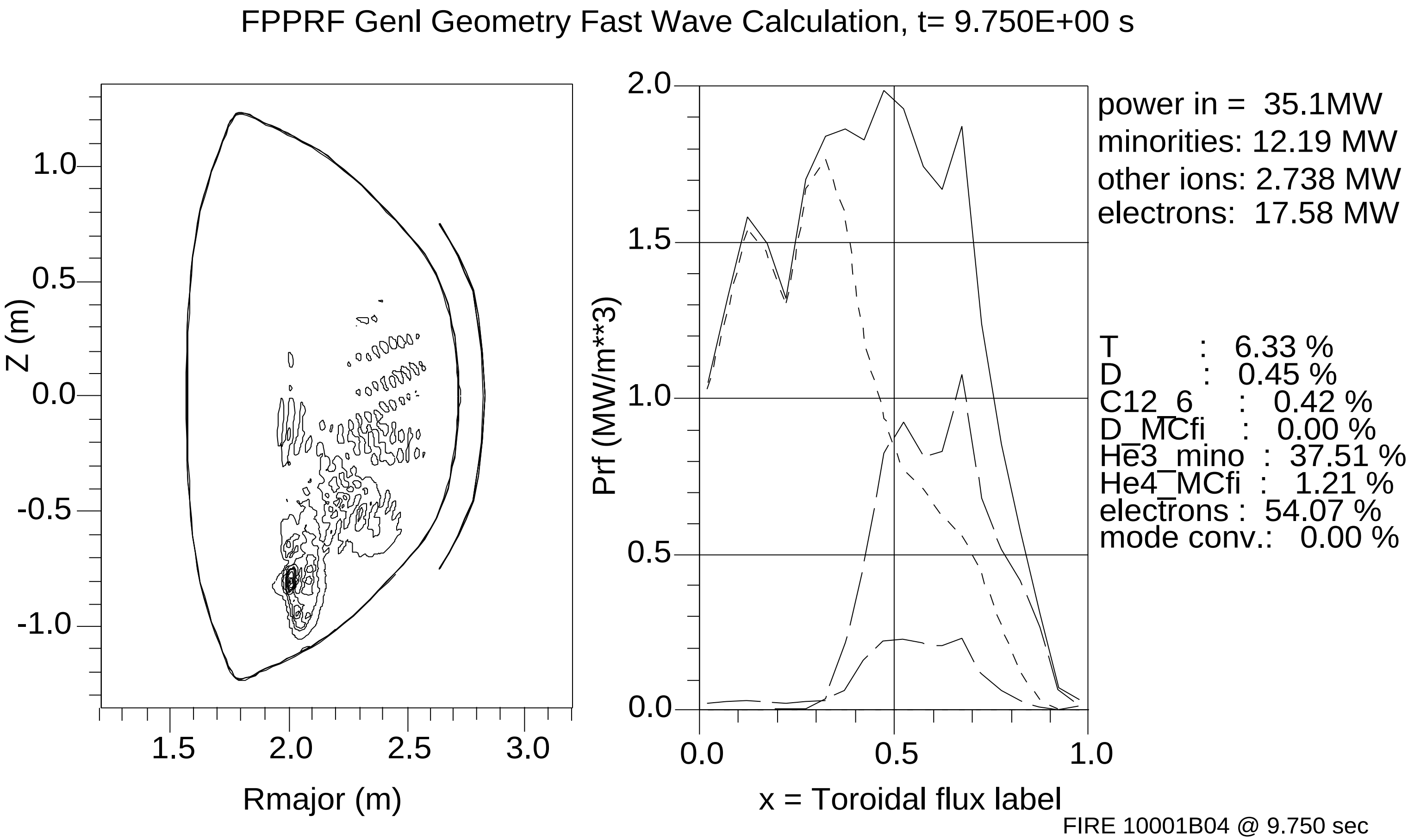
$$T_{RF} = \frac{2\,W_{\perp}}{3\,n_{He\,3}}$$

# FIRE-AT plasma (from TSC)





# ICRH in FIRE-AT



FPPRF Genl Geometry Fast Wave Calculation, t= 9.750E+00 s

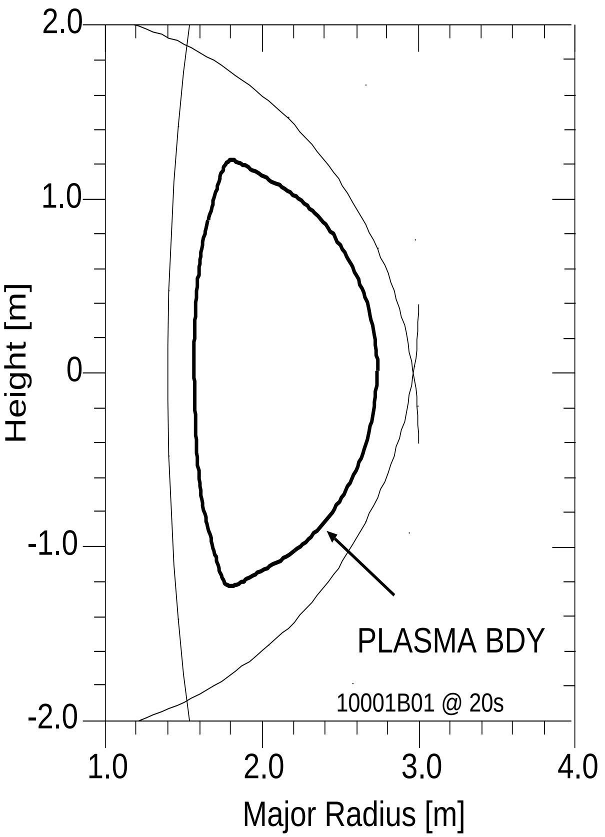
power in = 35.1MW
minorities: 12.19 MW
other ions: 2.738 MW
electrons: 17.58 MW

T : 6.33 %
D : 0.45 %
C12_6 : 0.42 %
D_MCfi : 0.00 %
He3_mino : 37.51 %
He4_MCfi : 1.21 %
electrons : 54.07 %
mode conv.: 0.00 %

FIRE 10001B04 @ 9.750 sec

# TRANSP includes orbit losses to first walls

Plasma boundary and first wall for FIRE-AT



$P_{\alpha}$ = 20 MW

$P_{\text{orbit-loss}}$ = 0.3 MW

# Other applications of TRANSP to burning plamsas

- predicting plasma rotation

  1. Combine calculated torques with assumptions of $\chi_{phi}$

- Estimates of ripple loss

# Conclusions

- Powerful TRANSP capabilities for predicting burning plasma performance

  1. Accurate equilibrium solvers
  2. Variety of heating and current drive
  3. Monte Carlo fast ion calculations
  4. phase space distributions