NP8.00004: Tokamak Simulation Code (TSC) Free-boundary Modeling for NSTX-U

C. E. Kessel, S. P. Gerhardt, F. M. Poli

Princeton Plasma Physics Laboratory

American Physical Society – Division of Plasma Physics

Denver CO, November 11-15, 2013

NSTX-U Will Significantly Extend Plasma Performance

NSTX-U

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

Ip → 2.0 MA for up to 5 s, 3 times larger flux swing OH Coil

B_T → 1.0 T for up to 6.5 s

P_{NB} → 10 MW for 5 s, with off-axis CD, higher CD efficiency

Divertor Coil Array → provides flexibility for conventional and snowflake geometries

The Tokamak Simulation Code (TSC) Can Provide Time-Dependent Free-Boundary Plasma Evolution Simulations

NSTX-U

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Rampup phase of discharge

- Examine current profile evolution, q-profile control
- Examine plasma shaping in early phases (divert time, rapid or slow elongation)
- H-mode timing
- Optimize inductive/non-inductive current contributions to control long time evolution

Non-Solenoidal startup/rampup discharge scenario

- CHI based early startup (Raman)
- Electron Cyclotron (EC) heating
- High Harmonic Fast Wave (HHFW) injection
- Neutral Beam injection
- Self-consistent ohm's law evolution including plasma shaping

Find ways to utilize NSTX-U's long pulse capability to optimize flattop phases of discharges

Examine coil protection algorithms

Examine plasma shape control algorithms

Extensive Equilibrium Scans Performed by S. P. Gerhardt

NSTX-U

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

NF, **52**, (2012) 083020

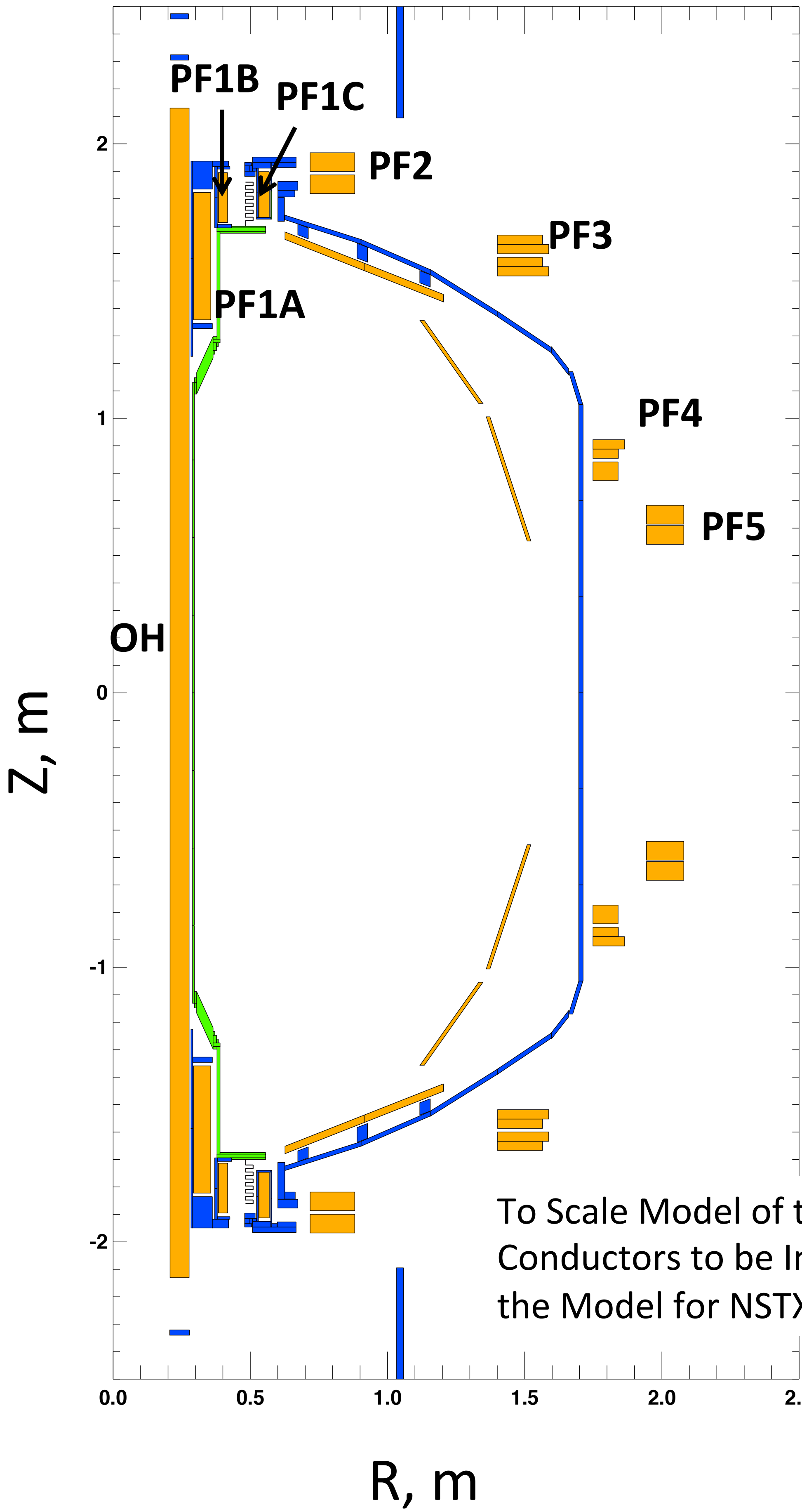
Examined relaxed flattop configurations under wide range of conditions with TRANSP

ISOLVER requested boundary equilibria for NB heated plasmas, using NSTX experimental T and n profiles scaled by ST and IPB98(y,2) scalings

Projections to NSTX-U parameters of $P_{NB,}$ Ip, B_T, and adding 2nd NB sources, varying outer gap, density, anomalous fast ion diffusivity, and H_{98}

Scenario exploration for 1) high current 100% non-inductive, 2) high current partial inductive, 3) partially inductive long pulse, and 4) sustained high β

NSTX Discharge based equilibria analysis with ISOLVER, scanning β_N, κ, δ, Z, and I_{OH} at Ip = 1.6 MA and B_T = 0.8 T



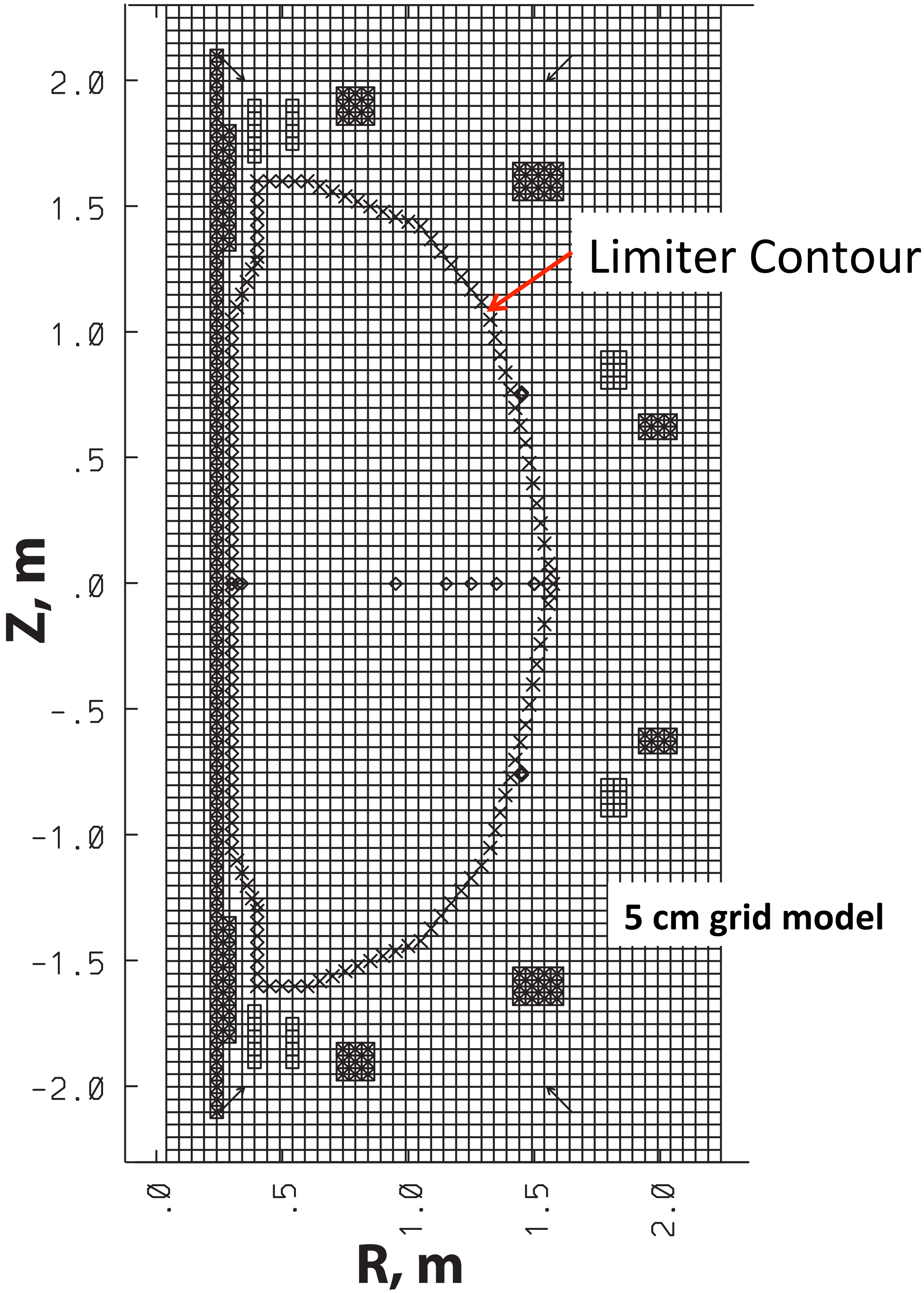
To Scale Model of the Various Conductors to be Included in the Model for NSTX-U

TSC Models Free-Boundary Plasma Evolution including PF Coils and Conducting Structure

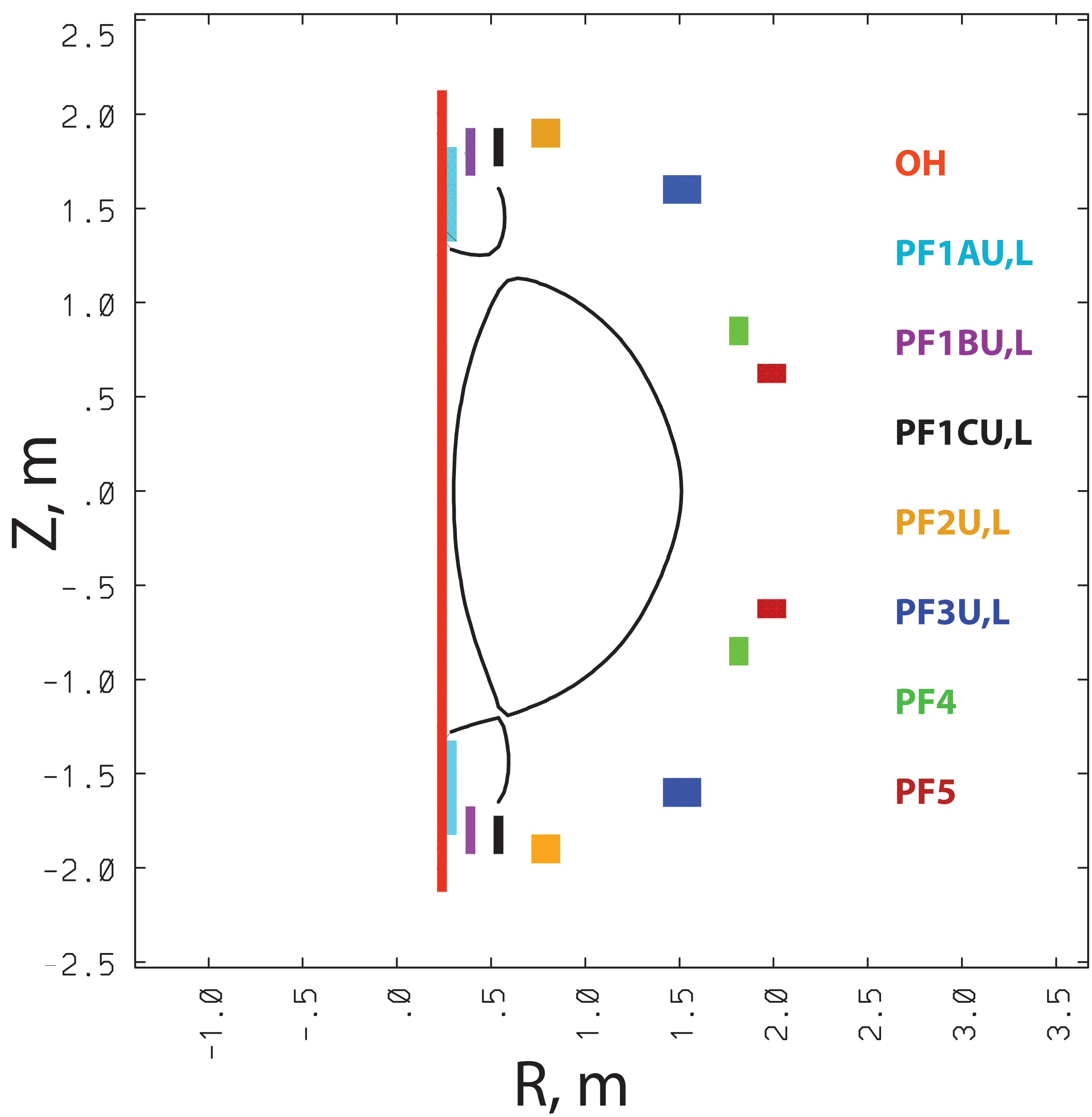
NSTX-U

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

R,Z Grid for TSC Simulations

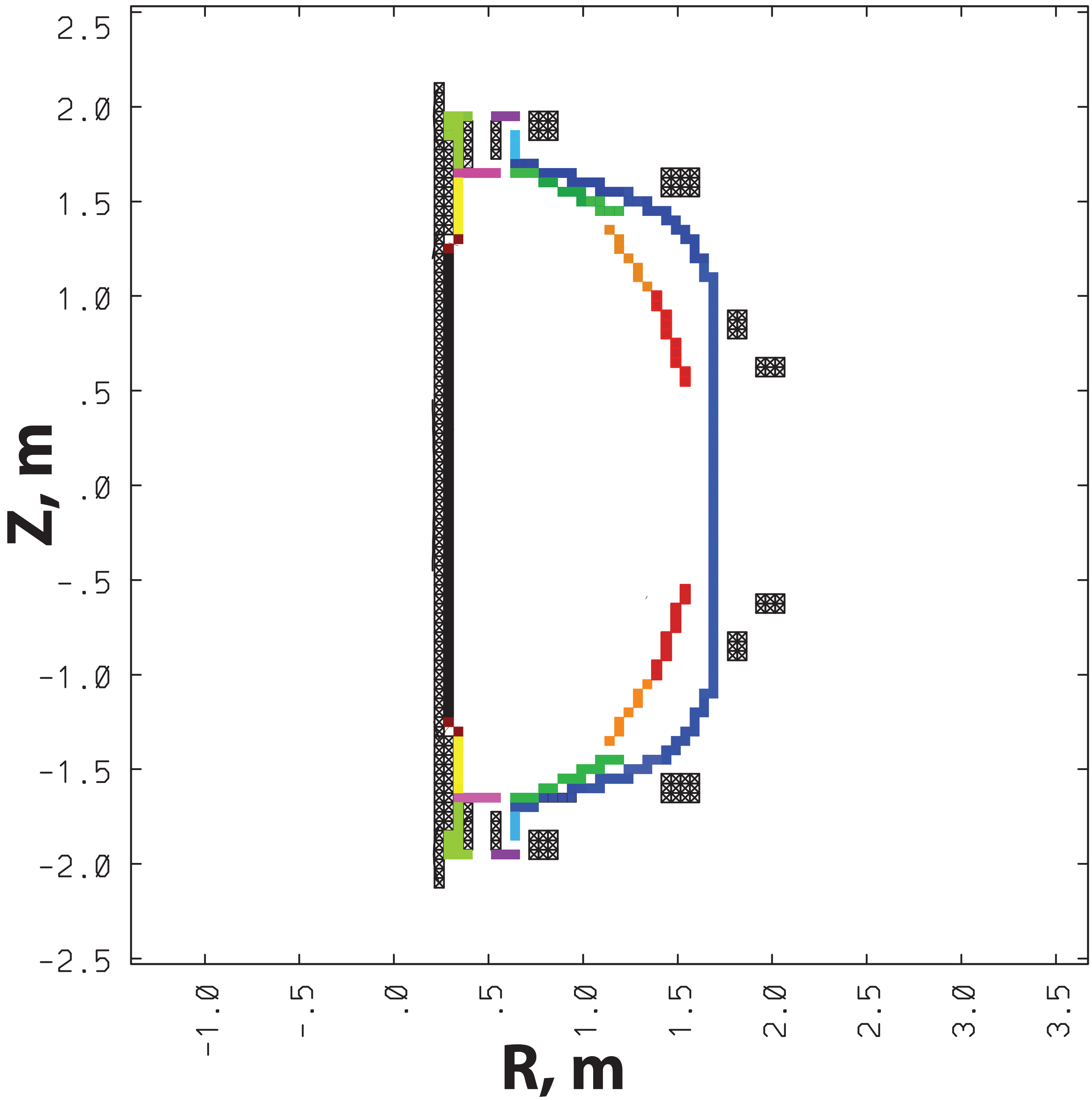


TSC Model of NSTX-U Coils



The OH and PF coils are modeled with their actual resistances, and connected to voltage/current sources. Feedback systems allow the coils to track their pre-programmed currents and to have feedback systems added to them for radial position, vertical position, plasma shape, and plasma current

Lumped Structure Zones Modeled in TSC



TSC structure elements are sized by the (R,Z) grid used. These elements are assigned a resistance that matches the actual resistance of the conducting structures. Most structures modeled are toroidally continuous, however zero-net current structures to approximate the discontinuous passive plates are used with measured gap resistances.

Some NSTX-U Plasma Equilibria Within the New OH and PF Coils

Primary Coils Functions:

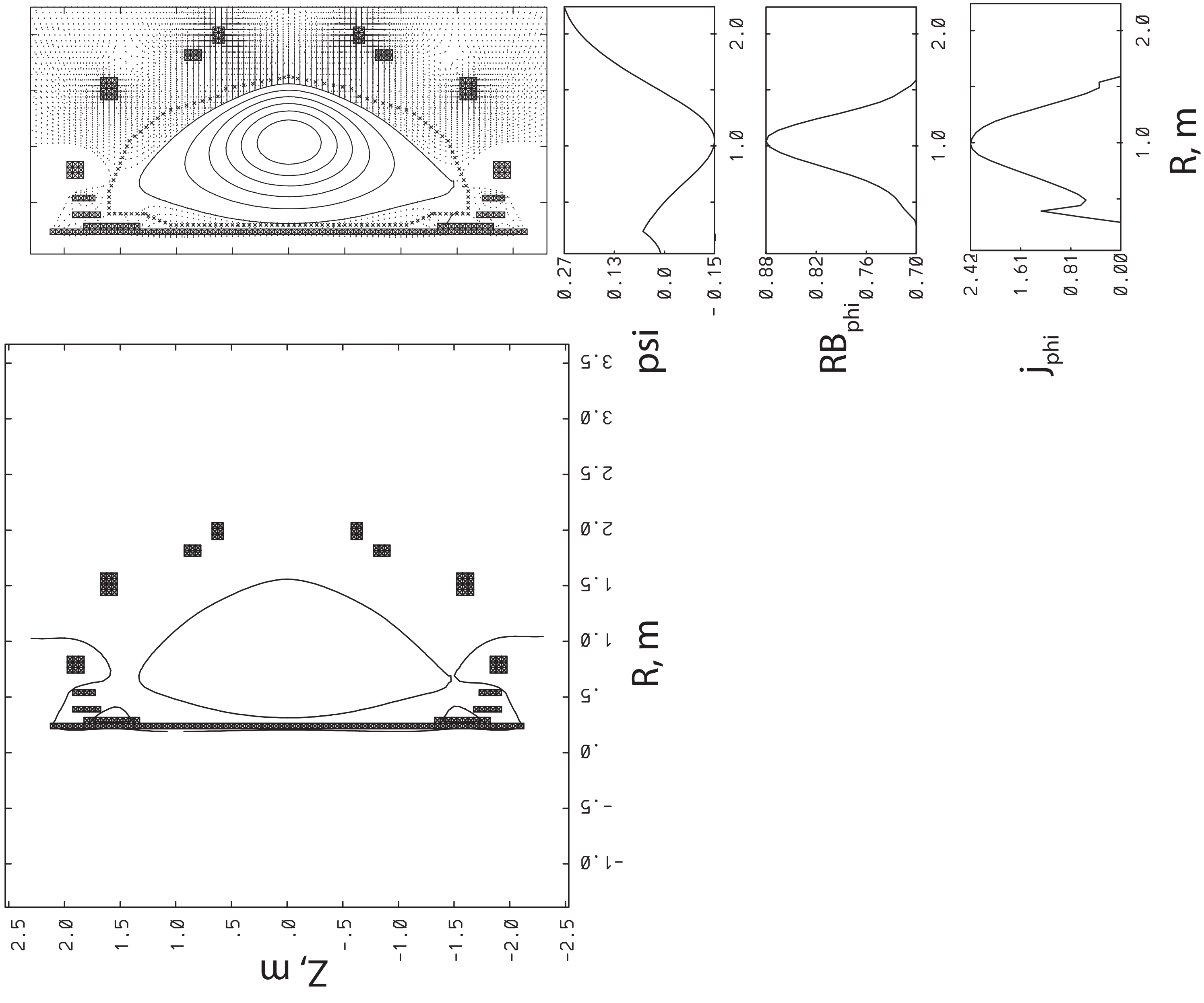
OH to provide inductive current drive, creates leakage field perturbation in plasma zone

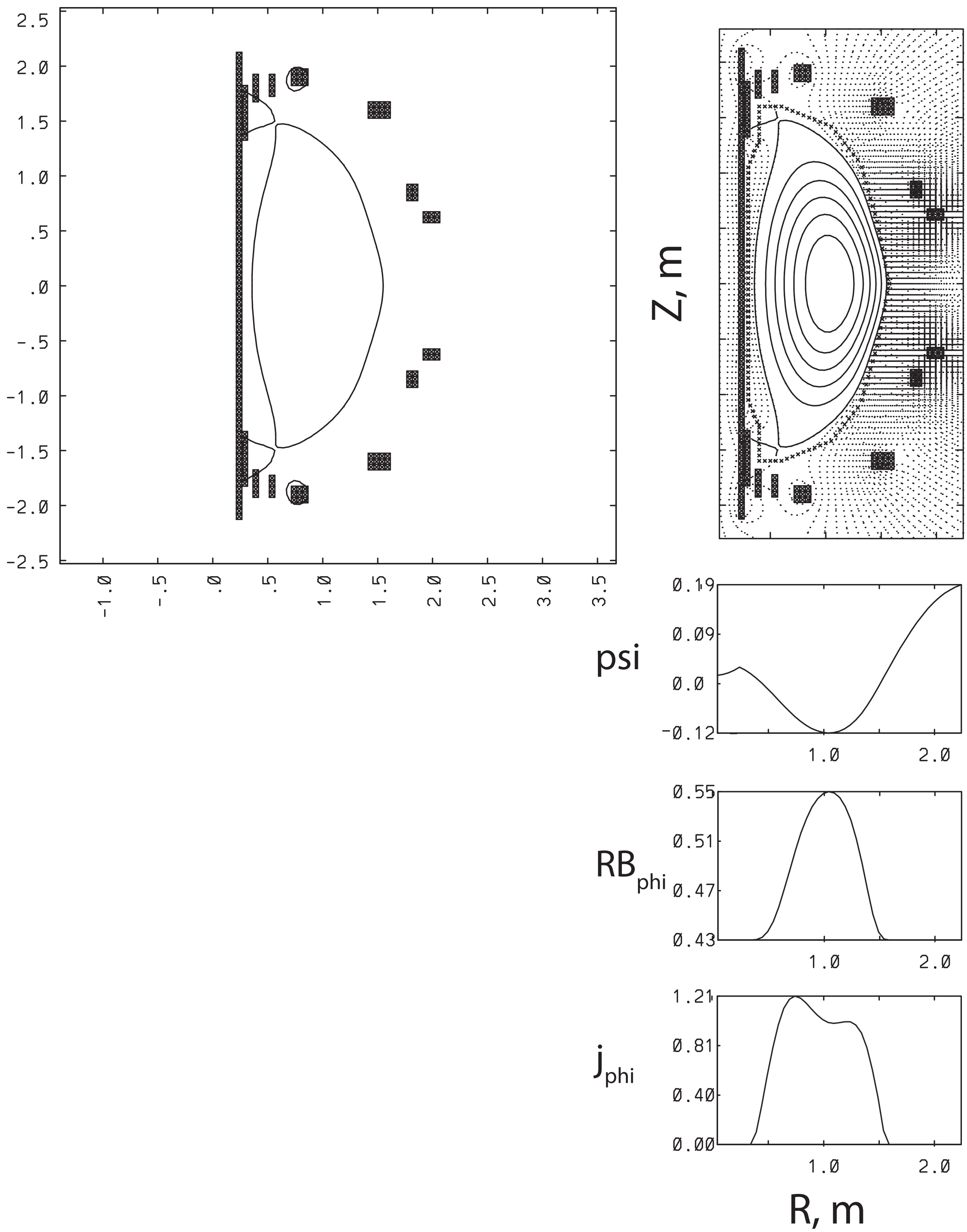
PF1A to provide X-pt location and high triangularity
PF1B, PF1C to provide detailed control of X-pt location and strike point

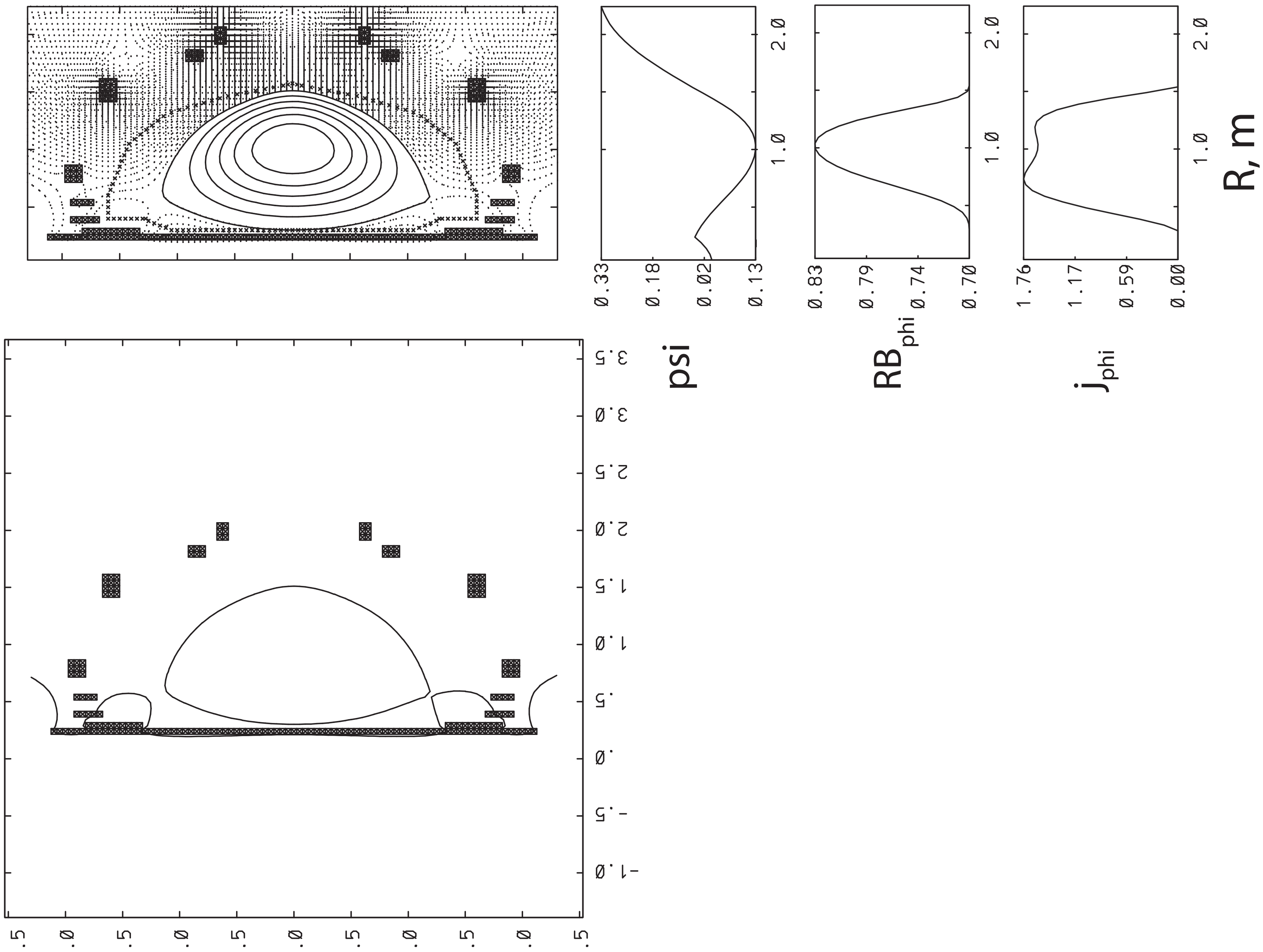
PF2 is primary divertor coil for pulling plasma elongation, works in conjunction with PF1A, PF1B, and PF1C to form X-pt and strike points

PF3 contributes to outer plasma boundary location/shape, and are primary vertical position feedback coils

PF5 (and PF4 if used) is to control the radial position of the plasma and the outermost plasma boundary location


Z, m
R, m
2.5
2.0
1.5
1.0
.5
.0
-.5
-1.0
-1.5
-2.0
-2.5
-1.0
-.5
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
psi
0.27
0.13
0.0
- 0.15
RB_phi
0.88
0.82
0.76
0.70
j_phi
2.42
1.61
0.81
0.00
1.0
2.0
R, m


Z, m
psi
RB_phi
j_phi
R, m



psi
RBphi
jphi
R, m

A Trial Time-Dependent Free Boundary H-mode Simulations

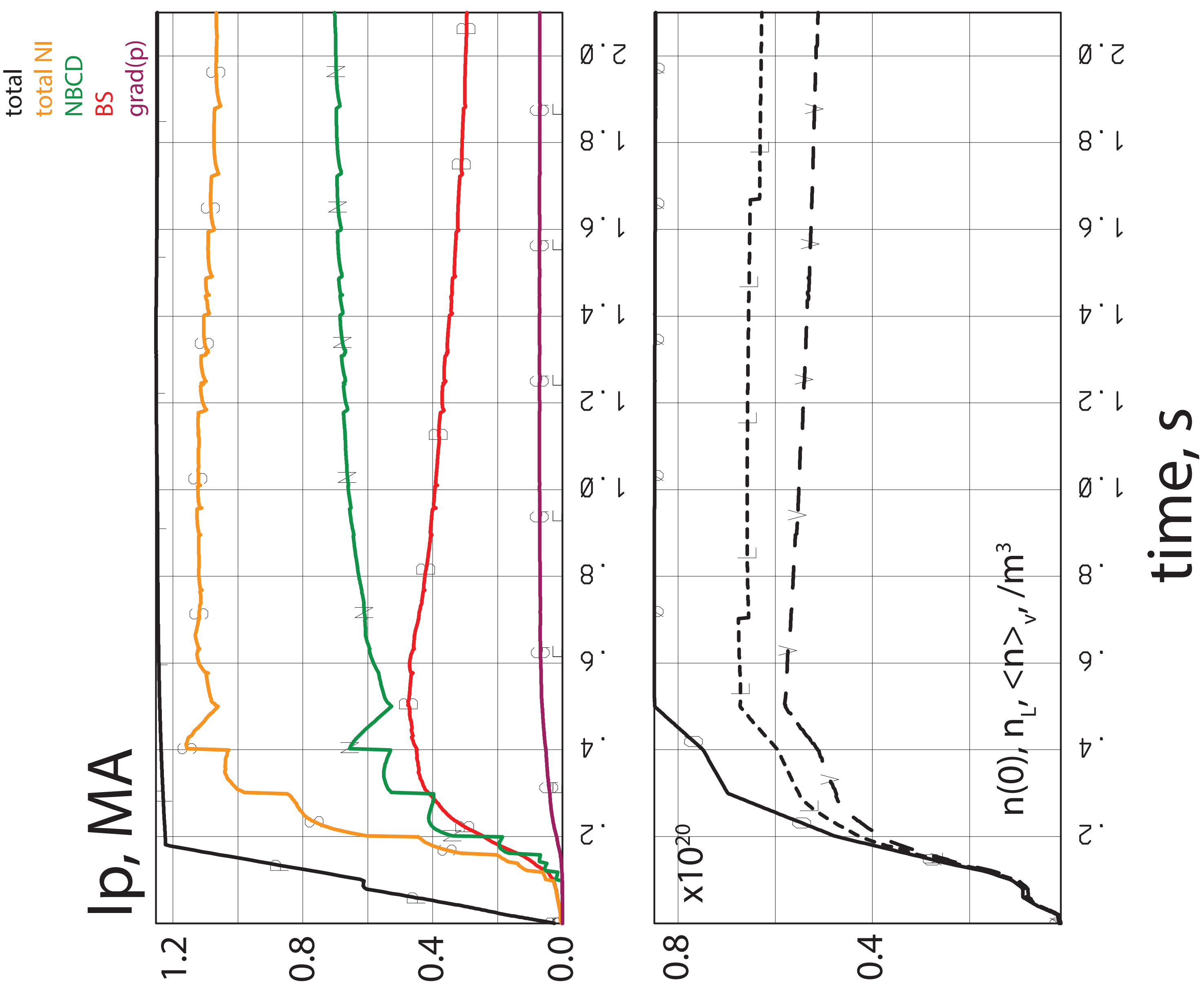
High Non-inductive fraction H-mode plasma

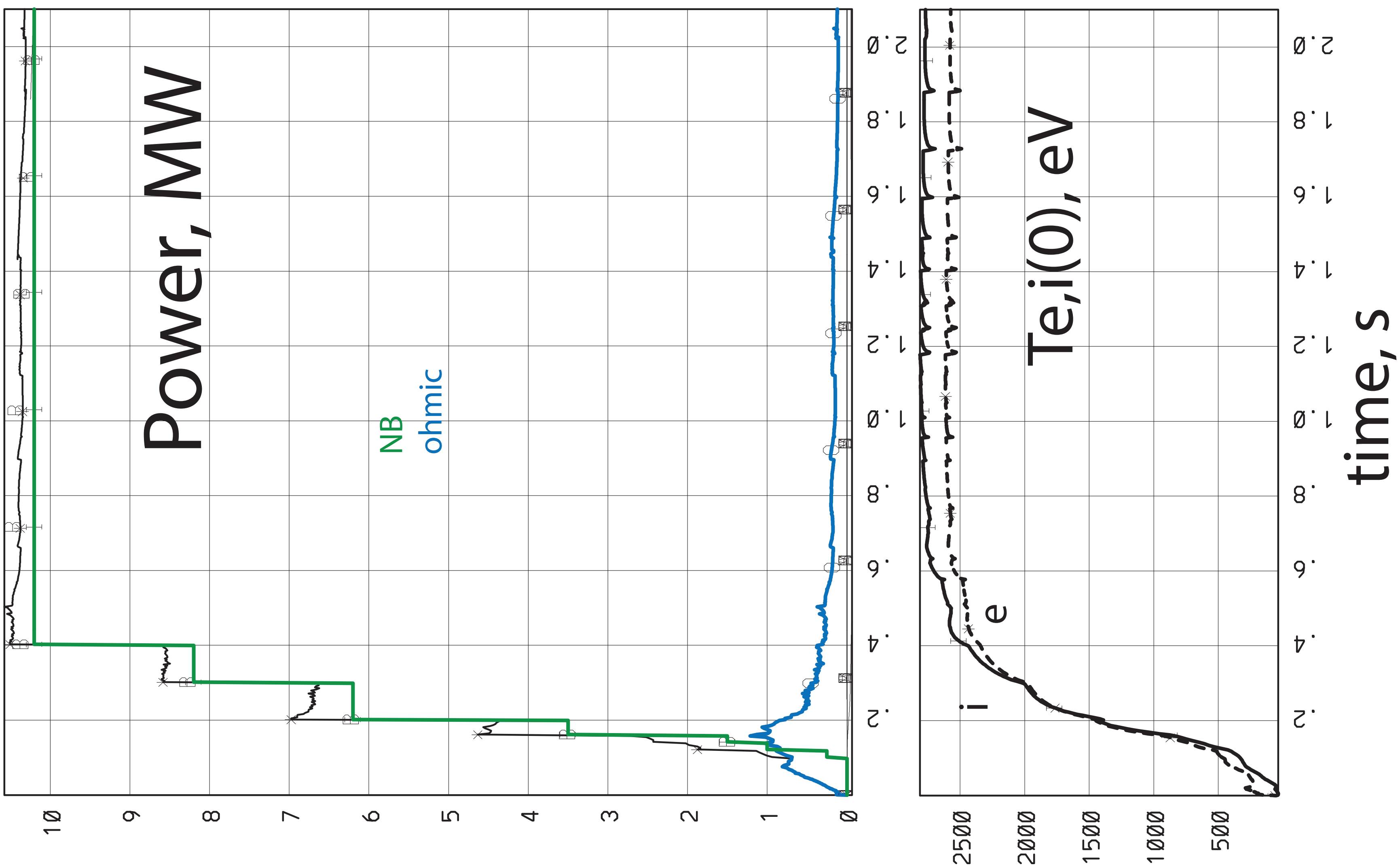
Ip = 1.25 MA

10.5 MW of NB Power

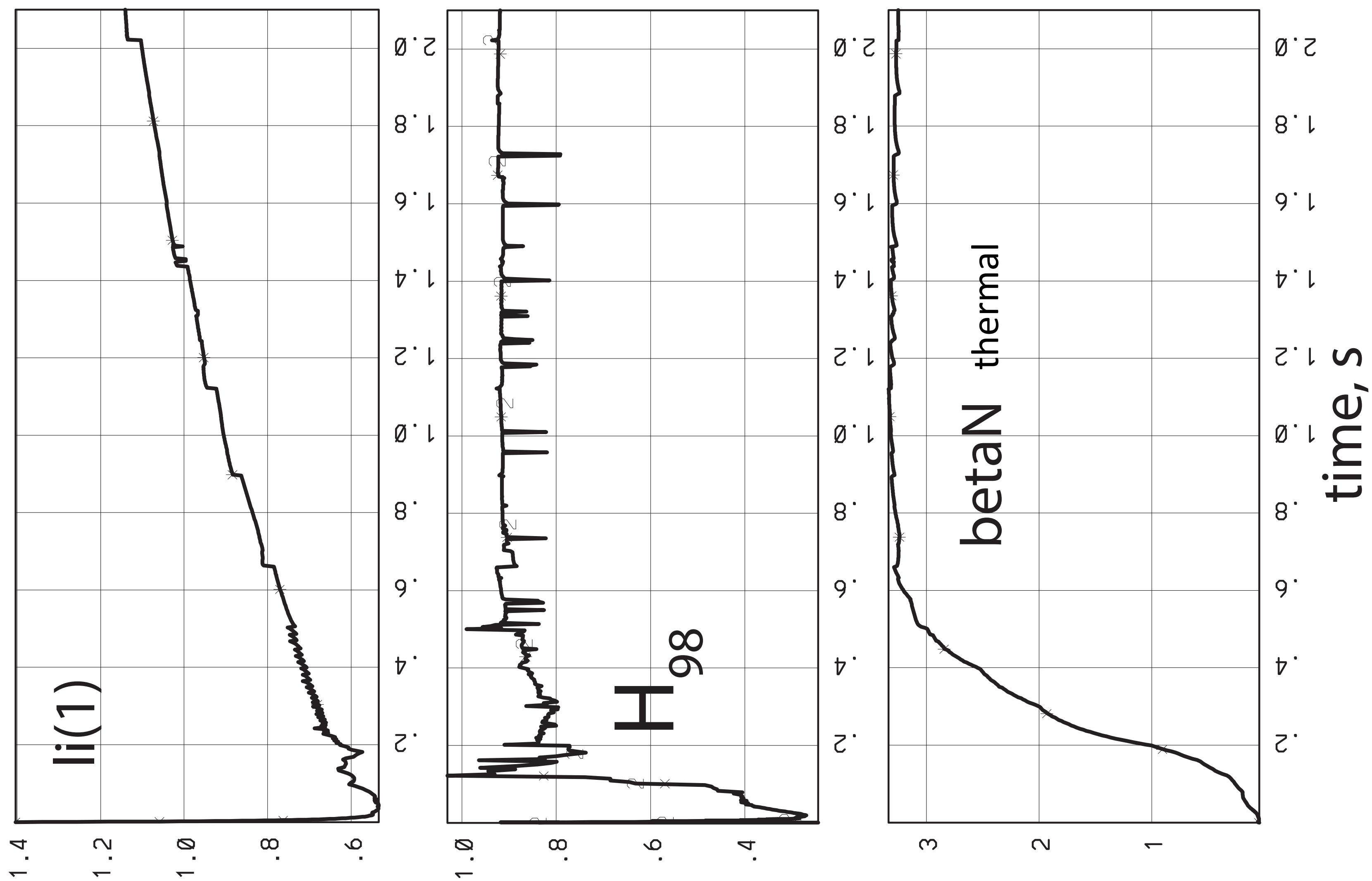
Used Coppi-Tang thermal diffusivity model scaled to give H_{98}~ 1

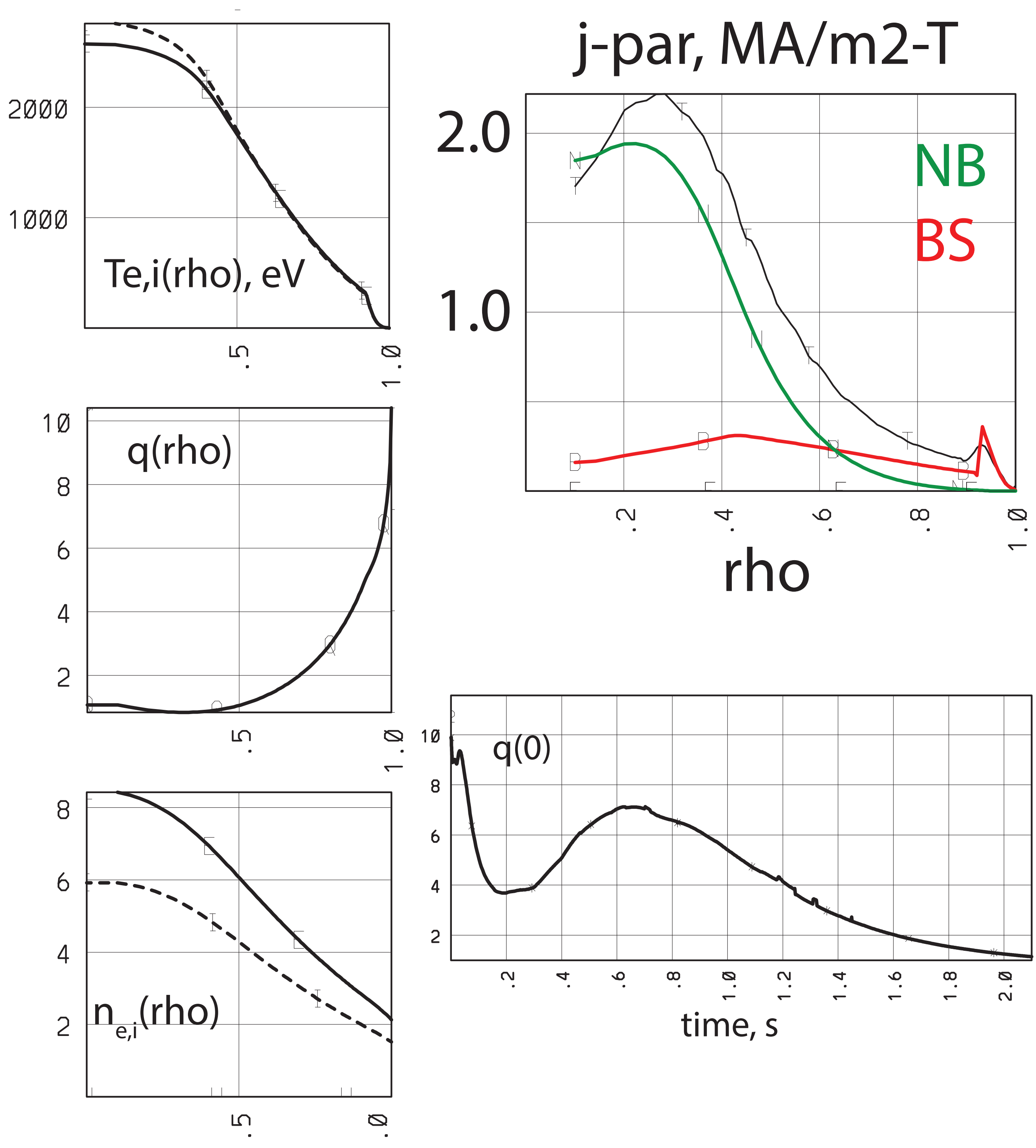
B_T = 0.8 T

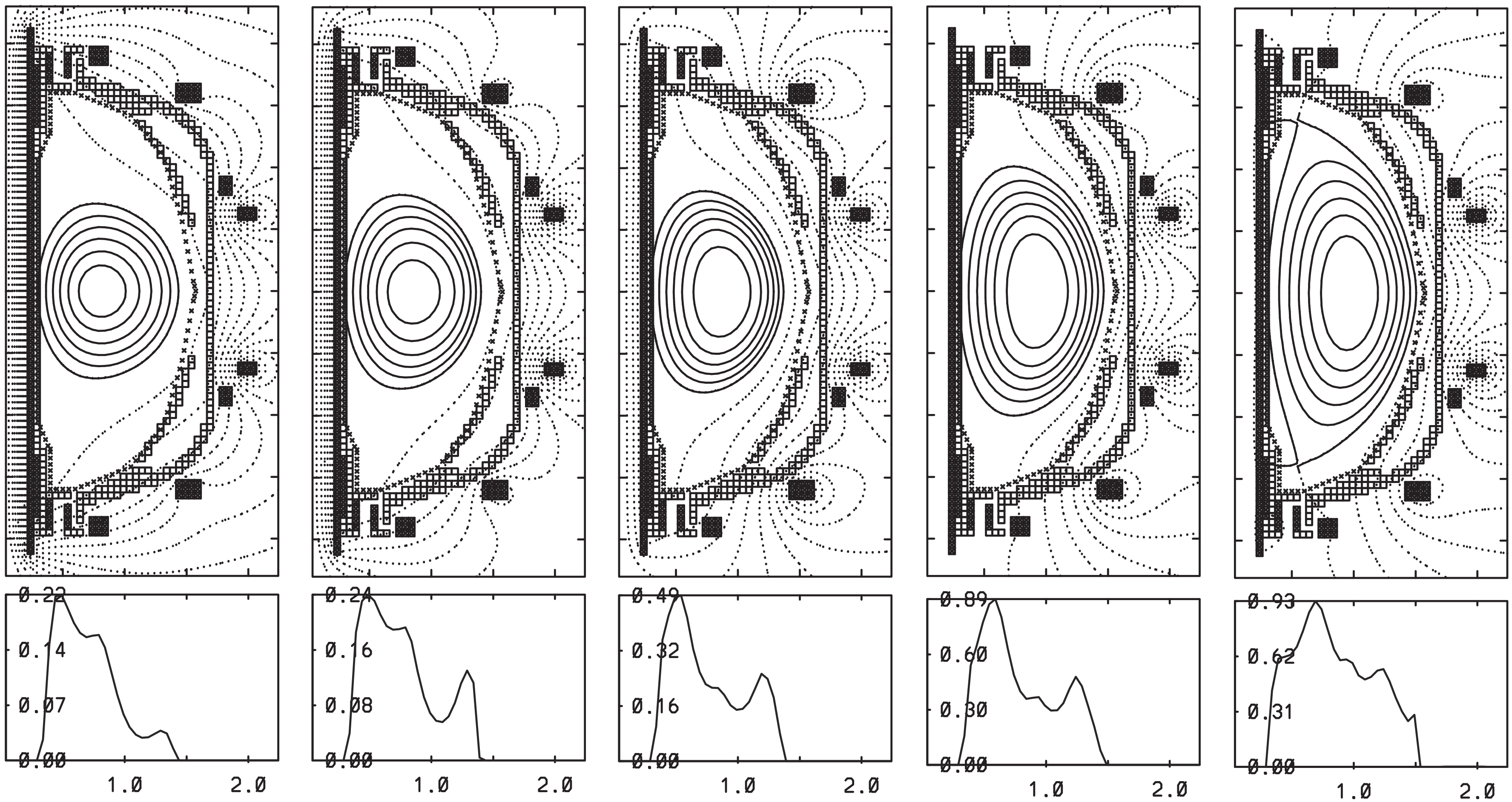

Ip, MA
total
total NI
NBCD
BS
grad(p)
n(0), n_L, <n>_v, /m^3
x10^20
time, s



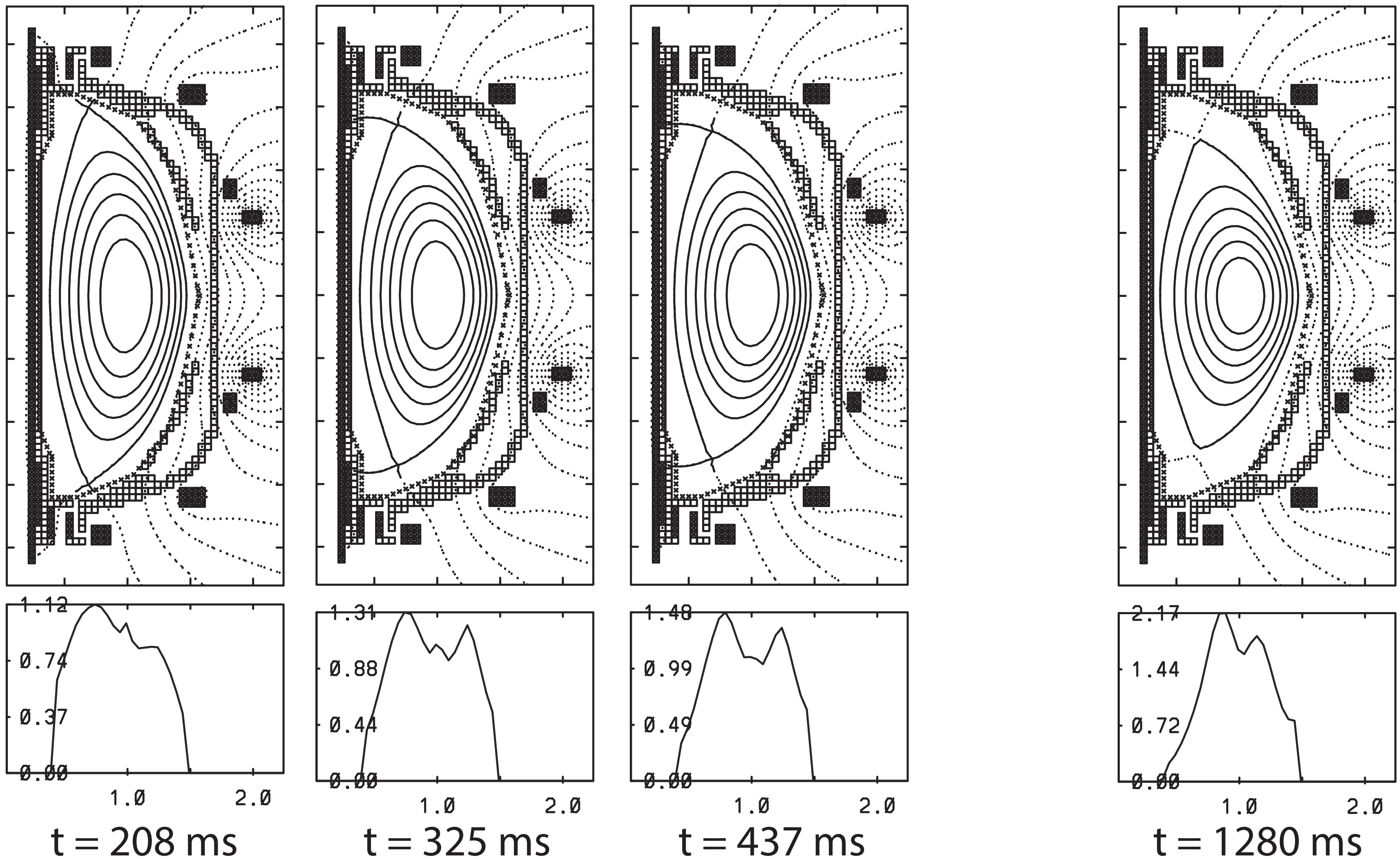
Power, MW
NB
ohmic
Te,i(0), eV
e
i
time, s


li(1)
H98
betaN thermal
time, s

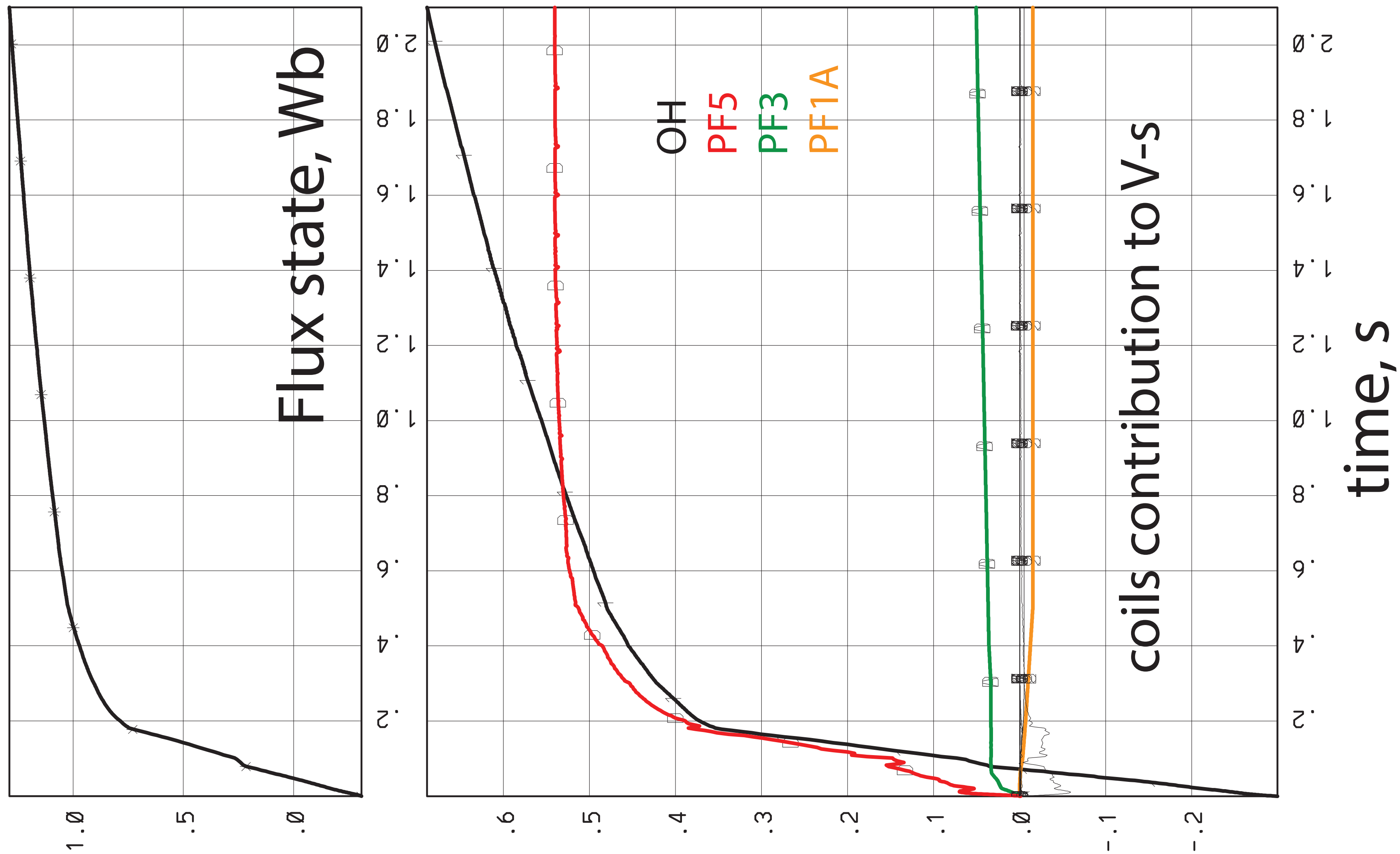

Te,i(rho), eV
2000
1000
.5
1.0
q(rho)
10
8
6
4
2
$n_{e,i}$(rho)
j-par, MA/m2-T
2.0
1.0
NB
BS
.2
.4
.6
.8
rho
q(0)
time, s
1.2
1.4
1.6
1.8
2.0



t = 5.2 ms t = 10.9 ms t = 32 ms t = 78 ms t = 135 ms



1.12
0.74
0.37
0.00
1.0
2.0
t = 208 ms
1.31
0.88
0.44
0.00
1.0
2.0
t = 325 ms
1.48
0.99
0.49
0.00
1.0
2.0
t = 437 ms
2.17
1.44
0.72
0.00
1.0
2.0
t = 1280 ms



Flux state, Wb
1.0
.5
0
OH
PF5
PF3
PF1A
coils contribution to V-s
.6
.5
.4
.3
.2
.1
0
-.1
-.2
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
time, s

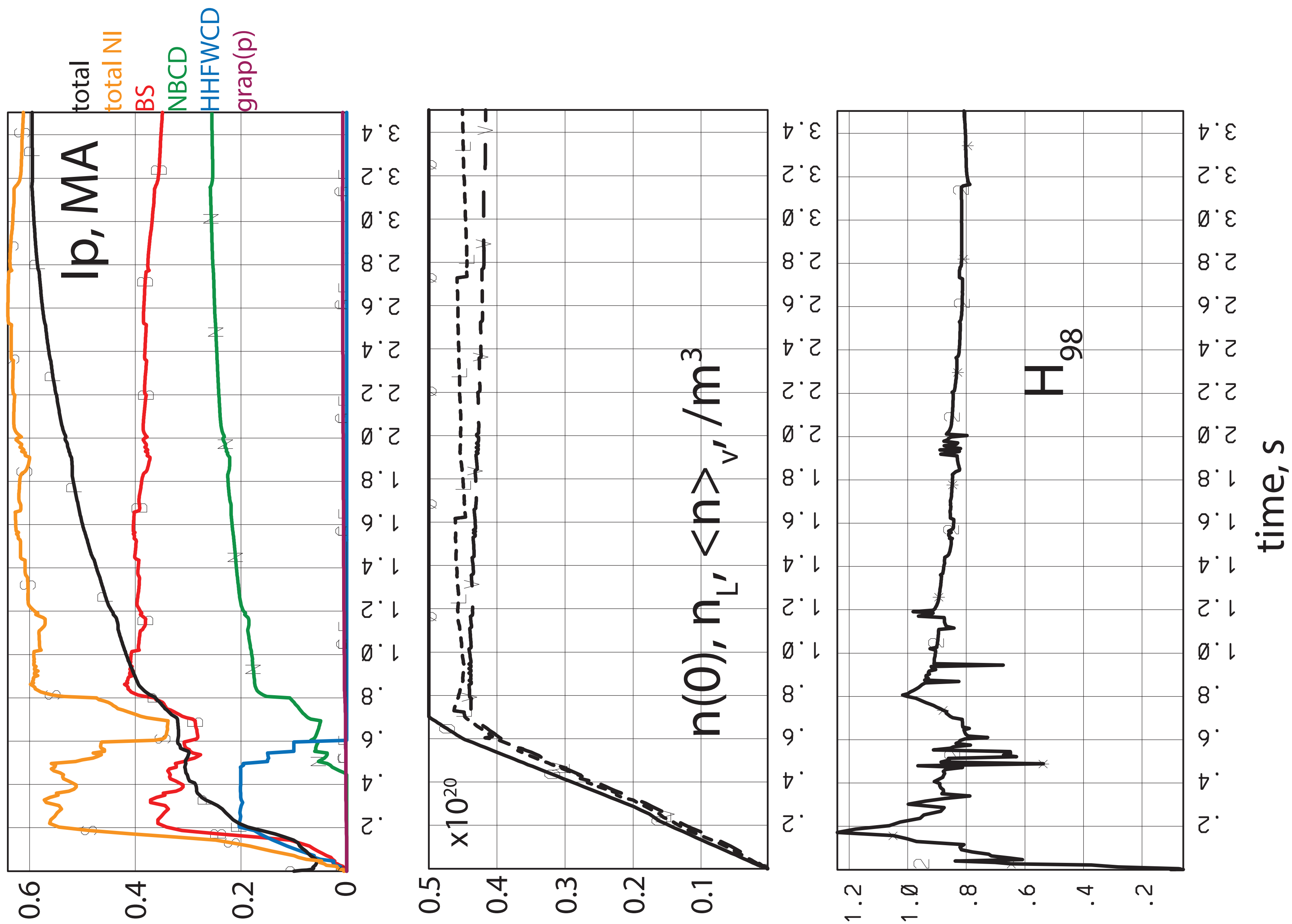
A Trial Non-Solenoidal Time Dependent Rampup Simulation

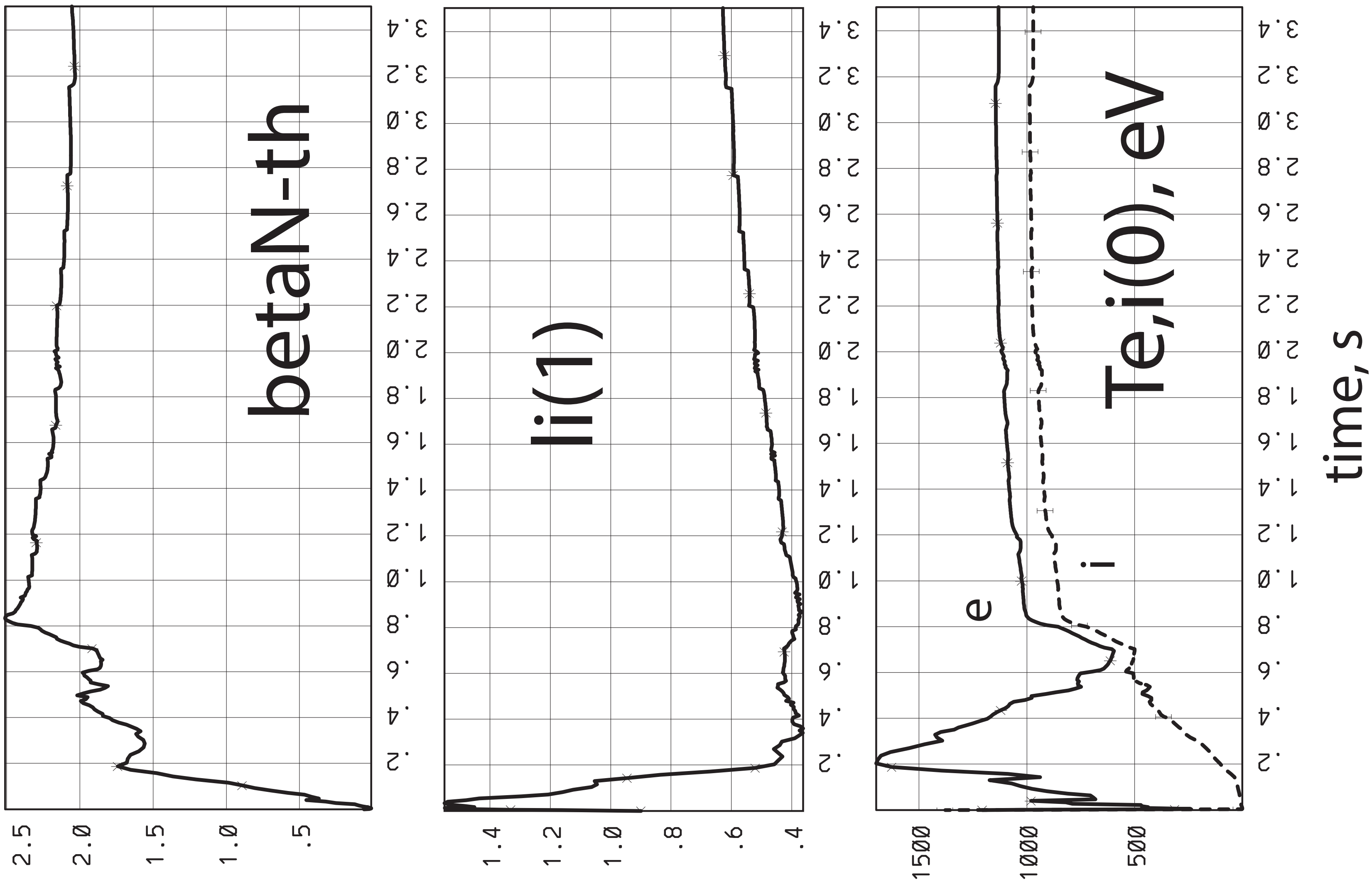
Non-Solenoidal Rampup H-mode Plasma Simulation

Ip^{start} = 100 kA (inductive current)

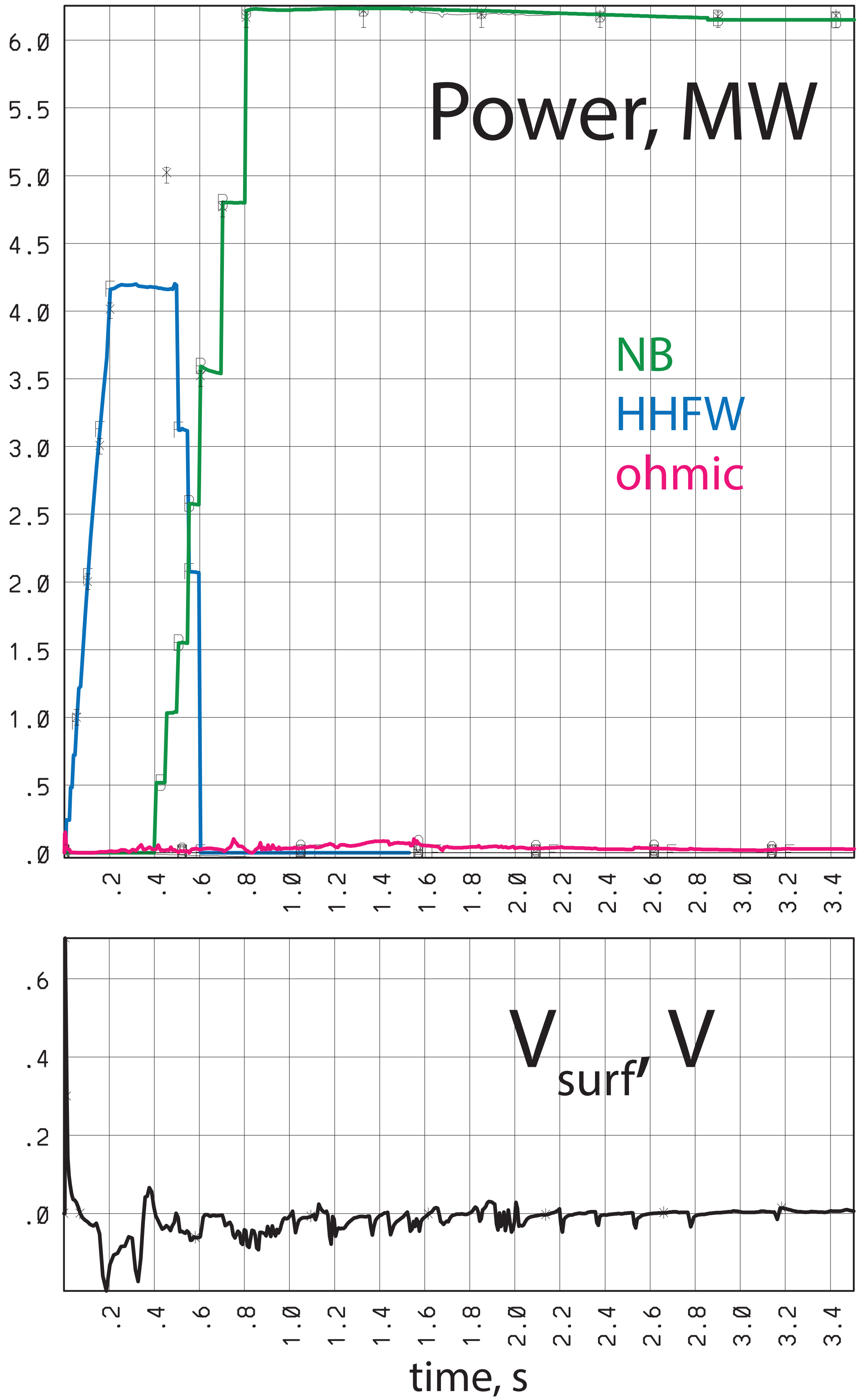
B_T = 0.8 T

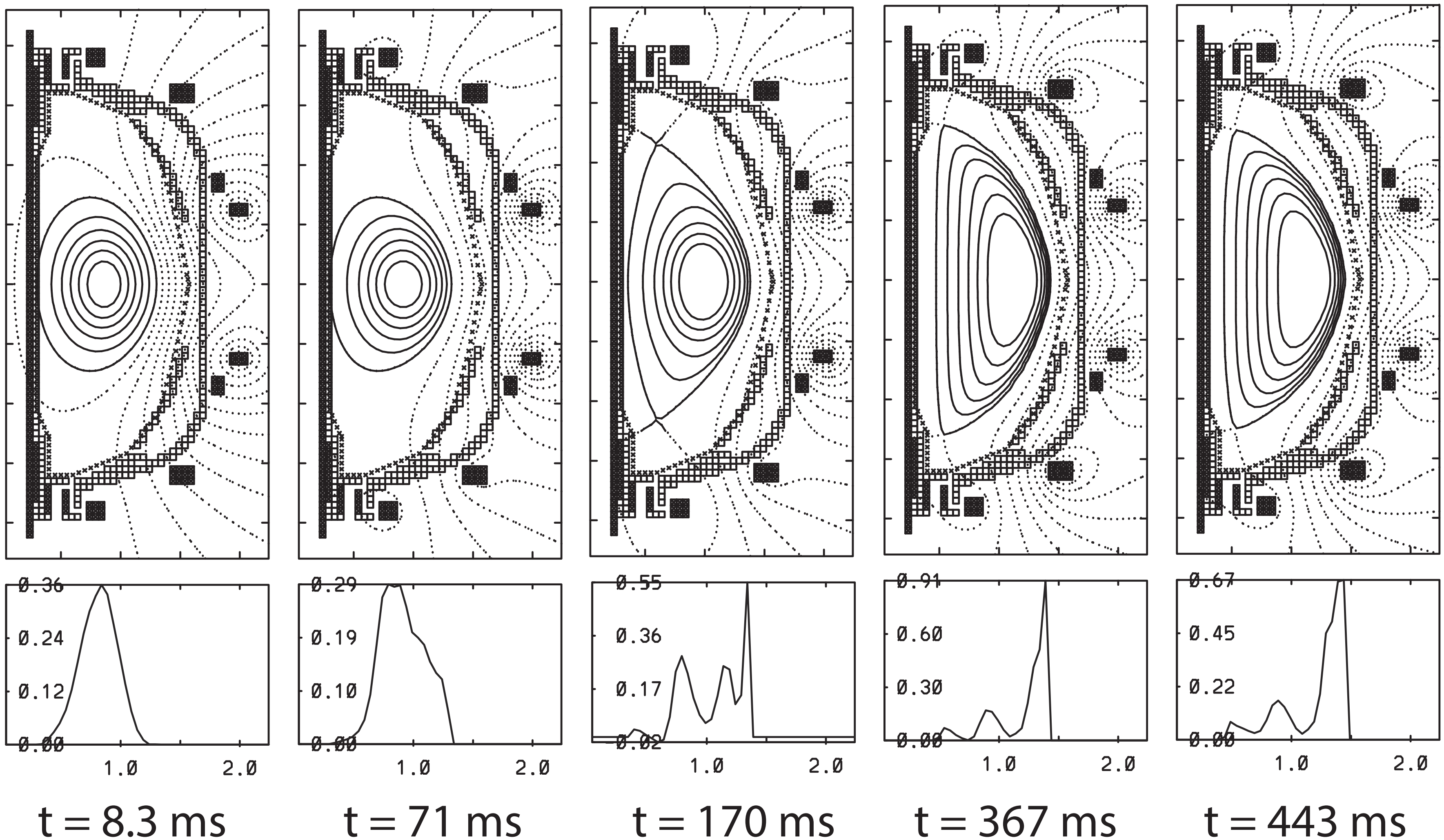
P_{HHFW}^{max} = 4.0 MW to plasma
P_{NB}^{max} = 6.2 MW to plasma


Ip, MA
total
total NI
BS
NBCD
HHFWCD
grap(p)
n(0), n_L', <n>_v', /m^3
x10^20
H_98
time, s

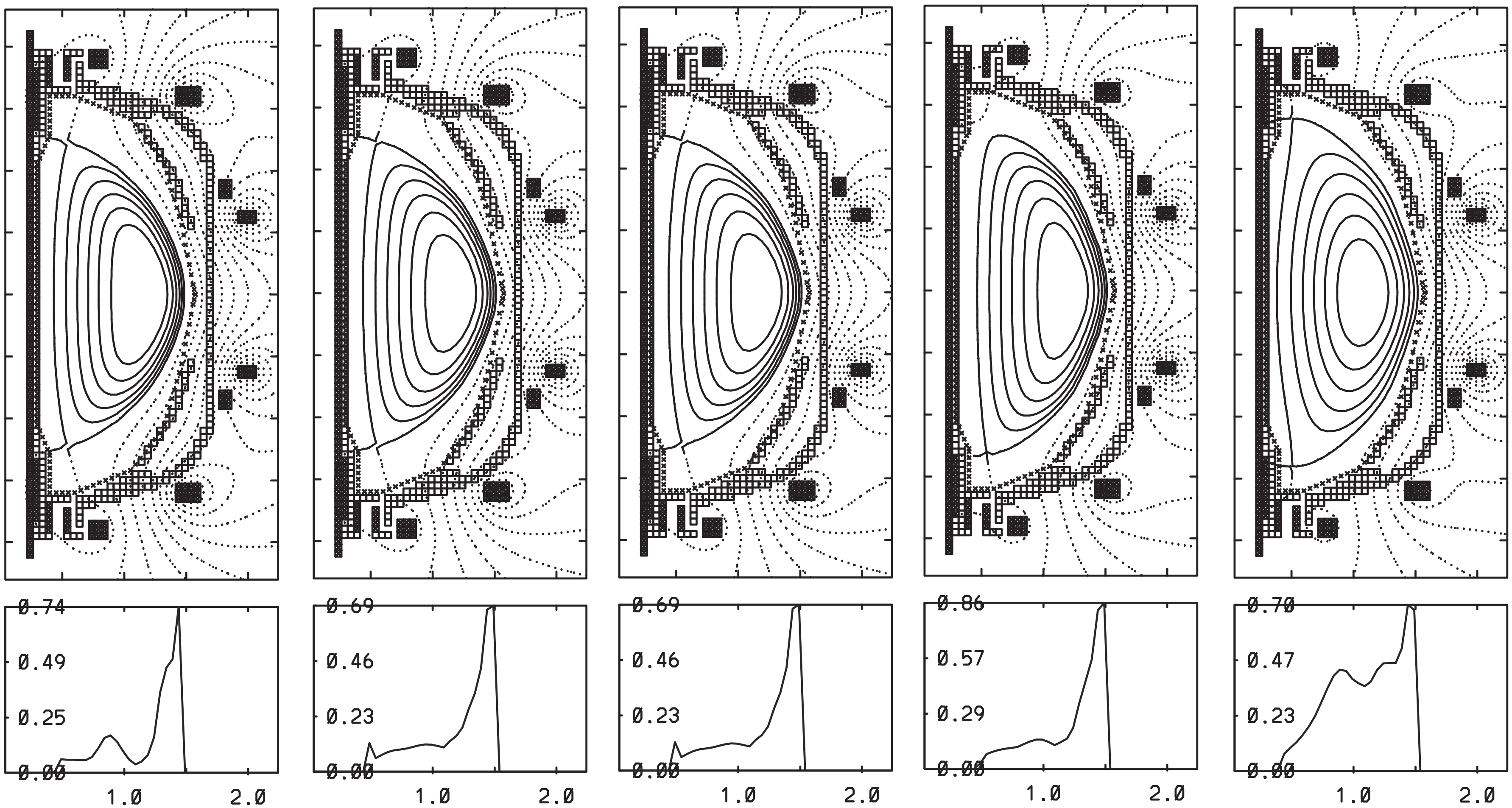


betaN-th
li(1)
Te,i(0), eV
e
i
time, s


Power, MW
NB
HHFW
ohmic
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
V_{surf}, V
.6
.4
.2
.0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
time, s



Ø.36
Ø.24
Ø.12
Ø.ØØ
1.Ø
2.Ø
Ø.29
Ø.19
Ø.1Ø
Ø.ØØ
Ø.55
Ø.36
Ø.17
Ø.Ø2
Ø.91
Ø.6Ø
Ø.3Ø
Ø.67
Ø.45
Ø.22
t = 8.3 ms
t = 71 ms
t = 170 ms
t = 367 ms
t = 443 ms



t = 543 ms   t = 713 ms   t = 879 ms   t = 1126 ms   t = 3463 ms

Future Activities for TSC Modeling of NSTX-U

Utilize most recent L-mode and H-mode profile data for T(r,t) and n(r,t) for projections to NSTX-U

Utilize TRANSP NB deposition directly rather than fits, and fast ion departures from classical deposition

Work with TRANSP free-boundary development efforts

Target specific NSTX discharges for simulation comparisons

Examine for NSTX-U

- V-s consumption and pulse length
- Rampup optimization for preserve V-s
- Shape control algorithms to maximize volume, shaping, or to control divertor flux geometry
- q-profile control in rampup with ramp rate and heating
- Non-solenoidal current rampup