Advanced Tokamak Modes in FIRE

Charles Kessel

for the FIRE Study Team

Overview
2002 Fusion Summer Study
Snowmass, CO

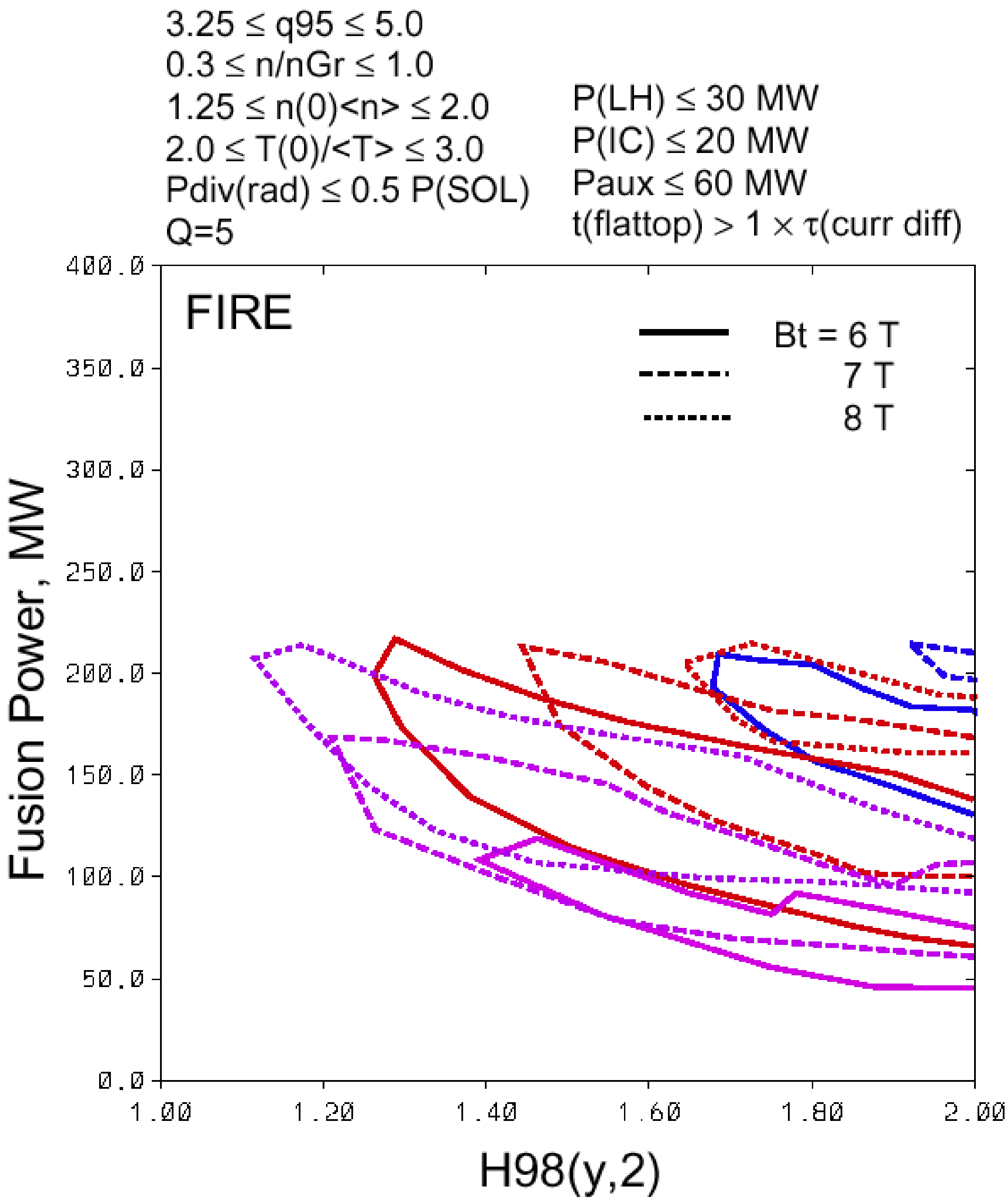
July 13, 2002

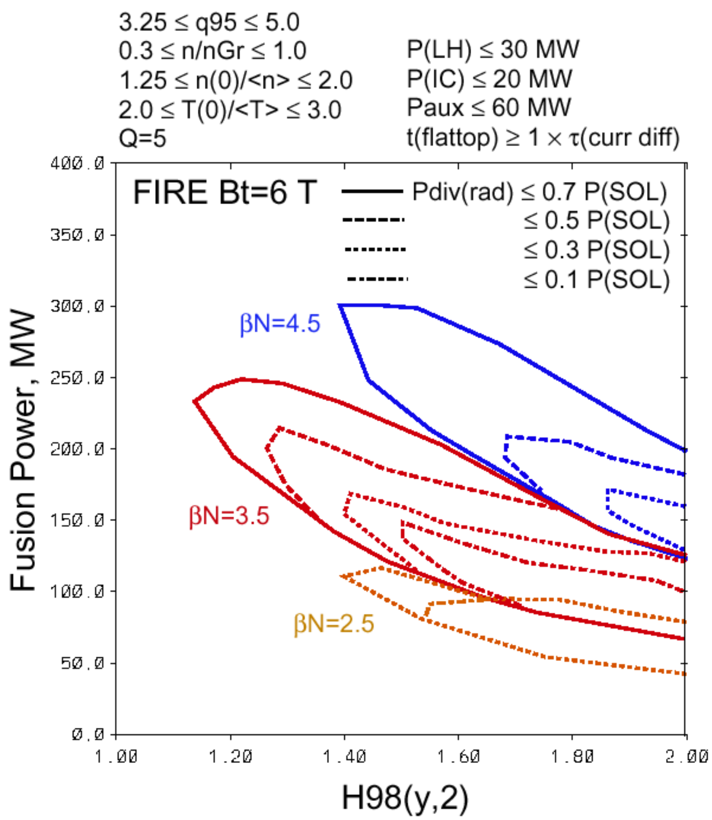
http://fire.pppl.gov

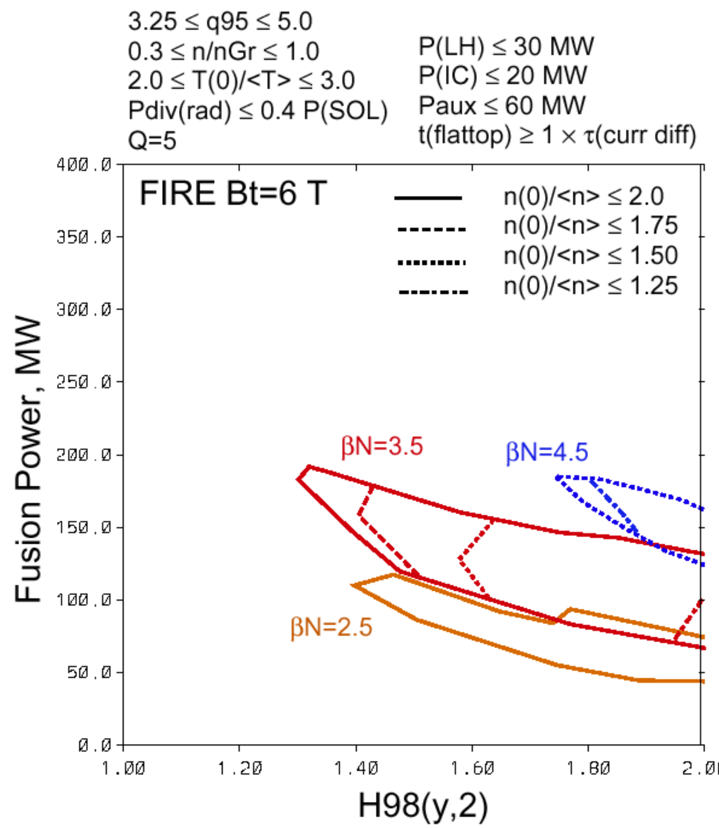
0D Operating Space Analysis for FIRE AT

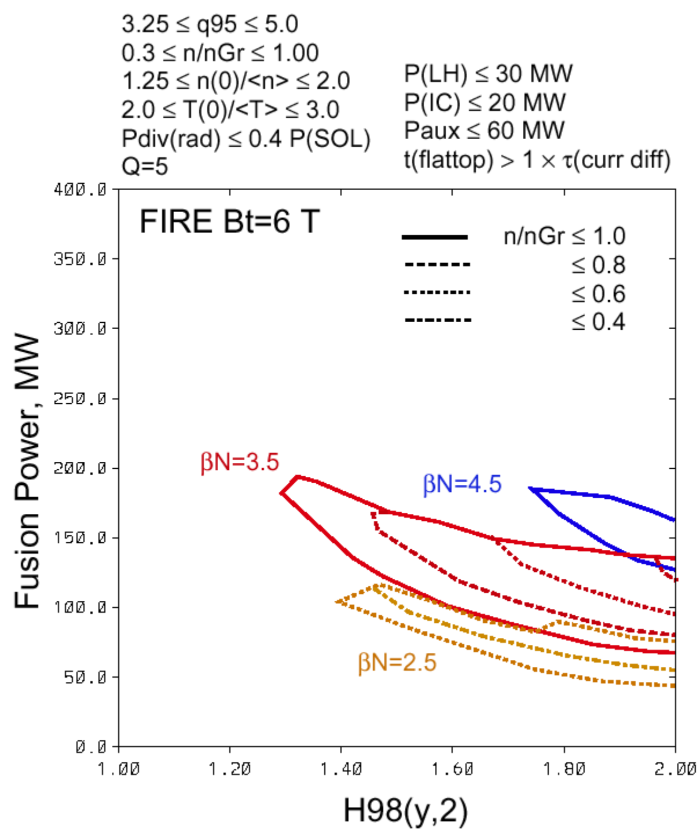
- 0D calculations described in E2 report
- Using FIRE 1.5D AT scenario
  - ICRF/FW, 30 MW
  - LHCD, 30 MW
- Using CD efficiencies determined by P2/T3 groups
  - η(FW)=0.25 A/W-m2
  - η(LH)=0.25 A/W-m2
- P(FW) and P(LH) determined at r/a=0 and r/a=0.75
- I(FW)=0.3 MA
- I(LH)=Ip(1-fbs)
- Scanning Bt, q95, n(0)/<n>, T(0)/<T>, n/nGr, βN, fBe, fAr

- Q=5
- Constraints:
- τ(flattop)/τ(CR) determined by VV nuclear heat or TF coil
- P(LH) and P(FW) $\leq$ max installed powers
- P(LH)+P(FW) $\leq$ Paux
- Ip < 5.5 MA, divertor coil heating for low li plasmas
- P(first wall) < 1.0 MW/m2 with peaking of 2.0
- P(SOL)-Pdiv(rad) < 28 MW
- Pdiv(rad) < 8 MW/m2


3.25 ≤ q95 ≤ 5.0
0.3 ≤ n/nGr ≤ 1.0
1.25 ≤ n(0)<n> ≤ 2.0
2.0 ≤ T(0)/<T> ≤ 3.0
Pdiv(rad) ≤ 0.5 P(SOL)
Q=5
P(LH) ≤ 30 MW
P(IC) ≤ 20 MW
Paux ≤ 60 MW
t(flattop) > 1 × τ(curr diff)
FIRE
Bt = 6 T
7 T
8 T
Fusion Power, MW
H98(y,2)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1.00
1.20
1.40
1.60
1.80
2.00


3.25 ≤ q95 ≤ 5.0
0.3 ≤ n/nGr ≤ 1.0
1.25 ≤ n(0)/<n> ≤ 2.0
2.0 ≤ T(0)/<T> ≤ 3.0
Q=5
P(LH) ≤ 30 MW
P(IC) ≤ 20 MW
Paux ≤ 60 MW
t(flattop) ≥ 1 × τ(curr diff)
FIRE Bt=6 T
Pdiv(rad) ≤ 0.7 P(SOL)
≤ 0.5 P(SOL)
≤ 0.3 P(SOL)
≤ 0.1 P(SOL)
βN=4.5
βN=3.5
βN=2.5
Fusion Power, MW
H98(y,2)


3.25 ≤ q95 ≤ 5.0
0.3 ≤ n/nGr ≤ 1.0
2.0 ≤ T(0)/<T> ≤ 3.0
Pdiv(rad) ≤ 0.4 P(SOL)
Q=5
P(LH) ≤ 30 MW
P(IC) ≤ 20 MW
Paux ≤ 60 MW
t(flattop) ≥ 1 × τ(curr diff)
FIRE Bt=6 T
n(0)/<n> ≤ 2.0
n(0)/<n> ≤ 1.75
n(0)/<n> ≤ 1.50
n(0)/<n> ≤ 1.25
βN=3.5
βN=4.5
βN=2.5
Fusion Power, MW
H98(y,2)


3.25 ≤ q95 ≤ 5.0
0.3 ≤ n/nGr ≤ 1.00
1.25 ≤ n(0)/<n> ≤ 2.0
2.0 ≤ T(0)/<T> ≤ 3.0
Pdiv(rad) ≤ 0.4 P(SOL)
Q=5
P(LH) ≤ 30 MW
P(IC) ≤ 20 MW
Paux ≤ 60 MW
t(flattop) > 1 × τ(curr diff)
FIRE Bt=6 T
n/nGr ≤ 1.0
≤ 0.8
≤ 0.6
≤ 0.4
βN=3.5
βN=4.5
βN=2.5
Fusion Power, MW
H98(y,2)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1.00
1.20
1.40
1.60
1.80
2.00

Equilibrium, Ideal MHD Stability and Current Drive Identify AT Target Plasmas

q(min) = 2.1-2.2

r/a(qmin) = 0.8

$n(0)/\langle n \rangle = 1.5$

Ip = 5.4 MA

Bt = 8.5 T

No wall stabilization

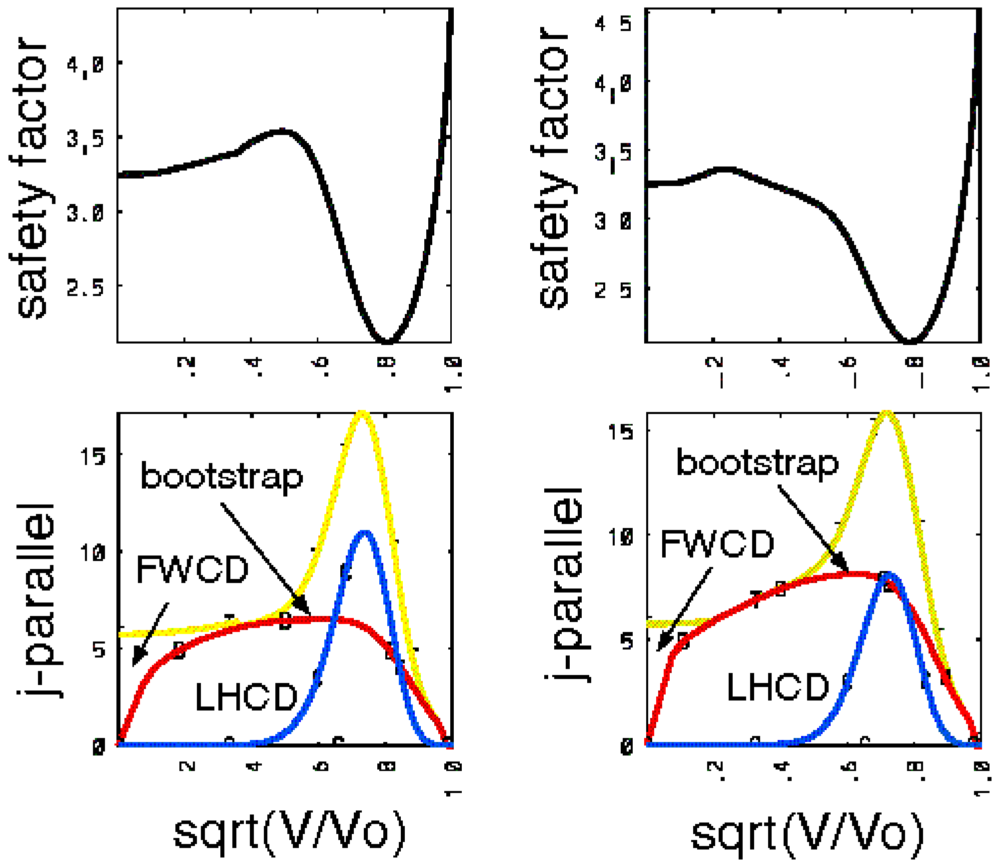
$\beta_N = 2.5$

n=1 RWM stabilized

$\beta_N = 3.65$

$\beta_N = 2.5$, $f_{bs} < 0.55$,
I(LH)=2.1 MA,
I(FW)=0.25 MA

$\beta_N = 3.65$, $f_{bs} < 0.75$,
I(LH)=1.5MA,
I(FW)=0.2 MA



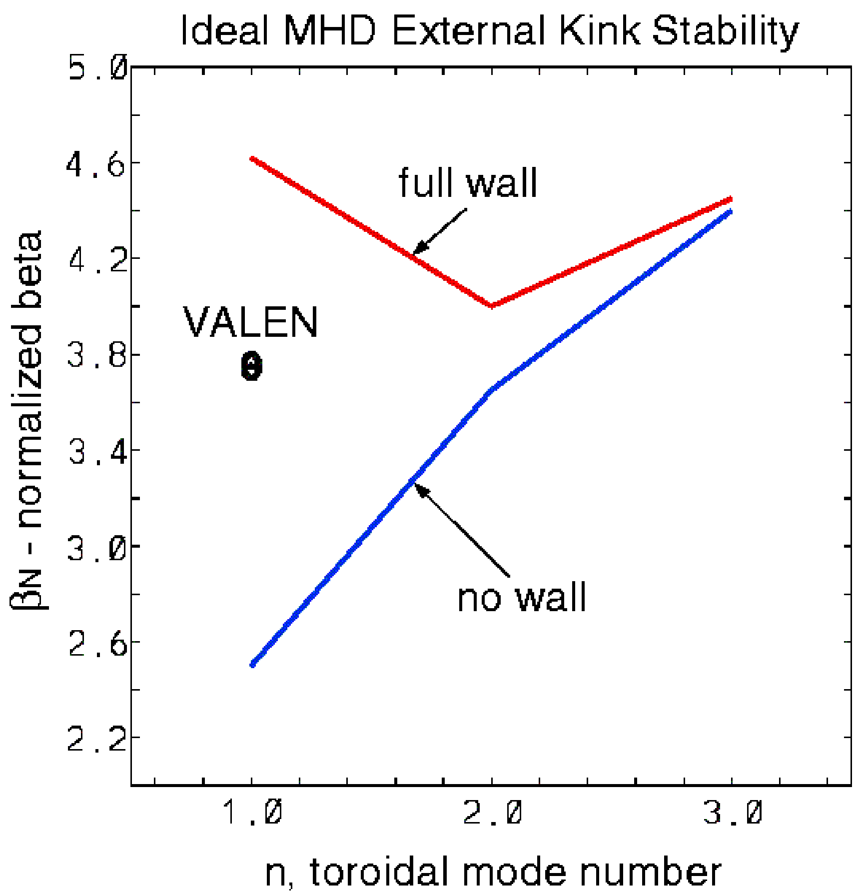
NTM Control for AT Plasmas

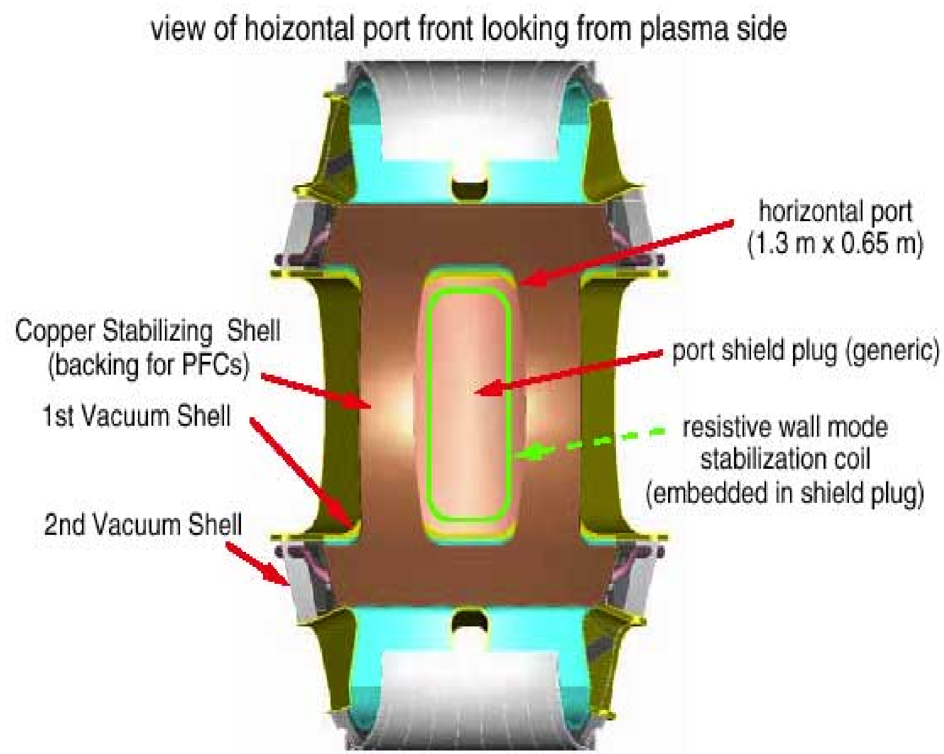
- AT plasmas operated at lower field, 6-8.5 T
- Safety factor > 2.0 everywhere
- (5,2) and (3,1) are primary NTM surfaces
- Location of (5,2) and (3,1) depends on detailed q profile
- The βN = 2.5 / 3.5 without/with n=1 stabilization

- ECCD: at the outboard half-radius
  - Bt = 6 T, fce = 147 GHz
  - Bt = 7 T, fce = 172 GHz
  - Bt = 8 T, fce = 197 GHz
- Compared to FIRE reference H-mode
  - Bt = 10 T, fce(r=a/2) = 215 GHz
  - Bt = 10 T, fce(r=0) = 245 GHz
- Use of LHCD would require two spectrum to create "notch" in j||, compromising total P(LH)

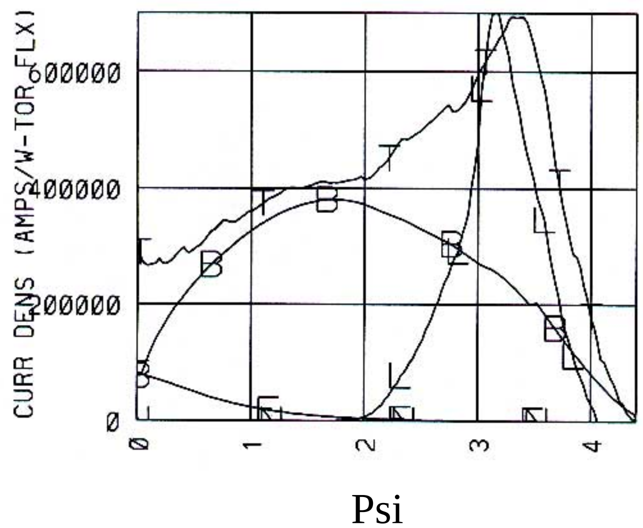
Stabilization of the n=1 RWM on FIRE

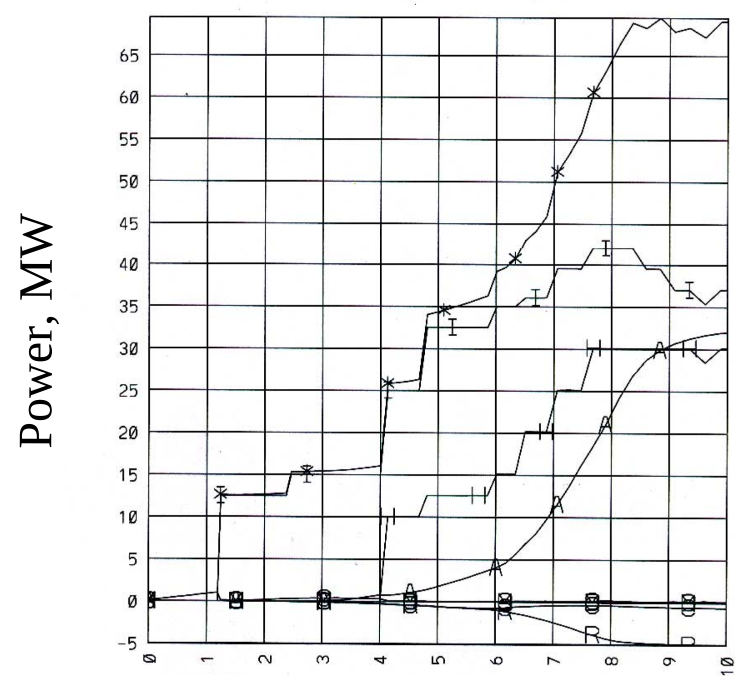
PEST2 and VALEN analysis used to determine possible strategies for raising β by feedback stabilization based on DIII-D experience

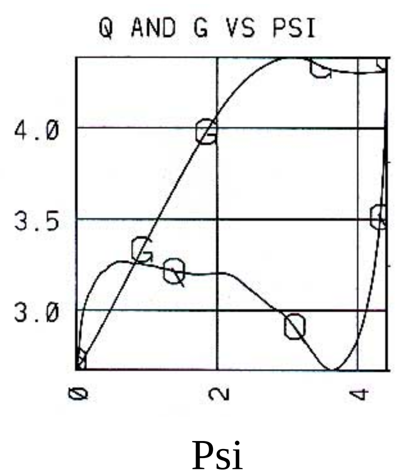


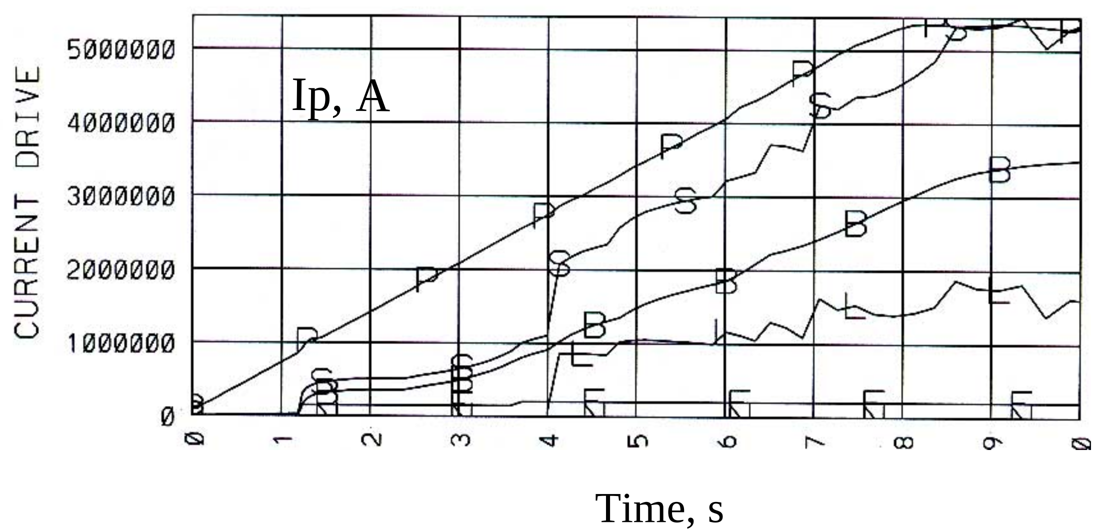


Bt=6.5 T, Ip=5.3 (5.0) MA, q95=3.35 (3.5)
n/nGr=0.65, n(0)=3.6x10^20, betaN=3.75,
H98=1.6, n(0)/<n>=1.4, Q=4.4 (5.0),
fbs=0.67, I(LH)=1.6 MA, P(LH)=30 MW



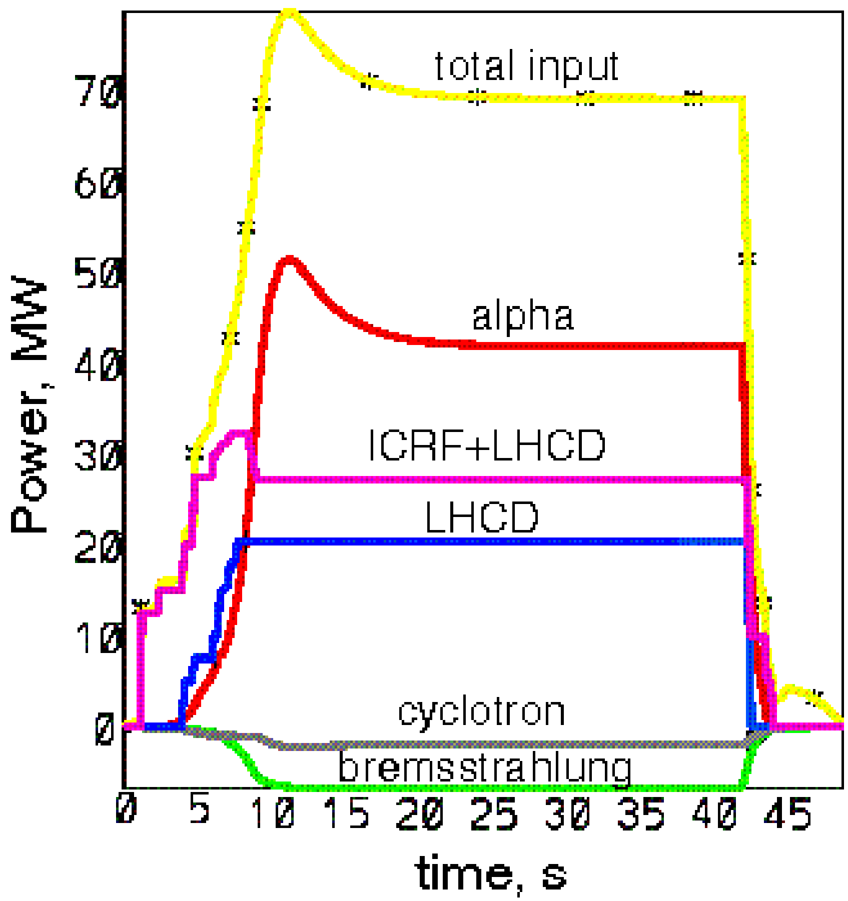


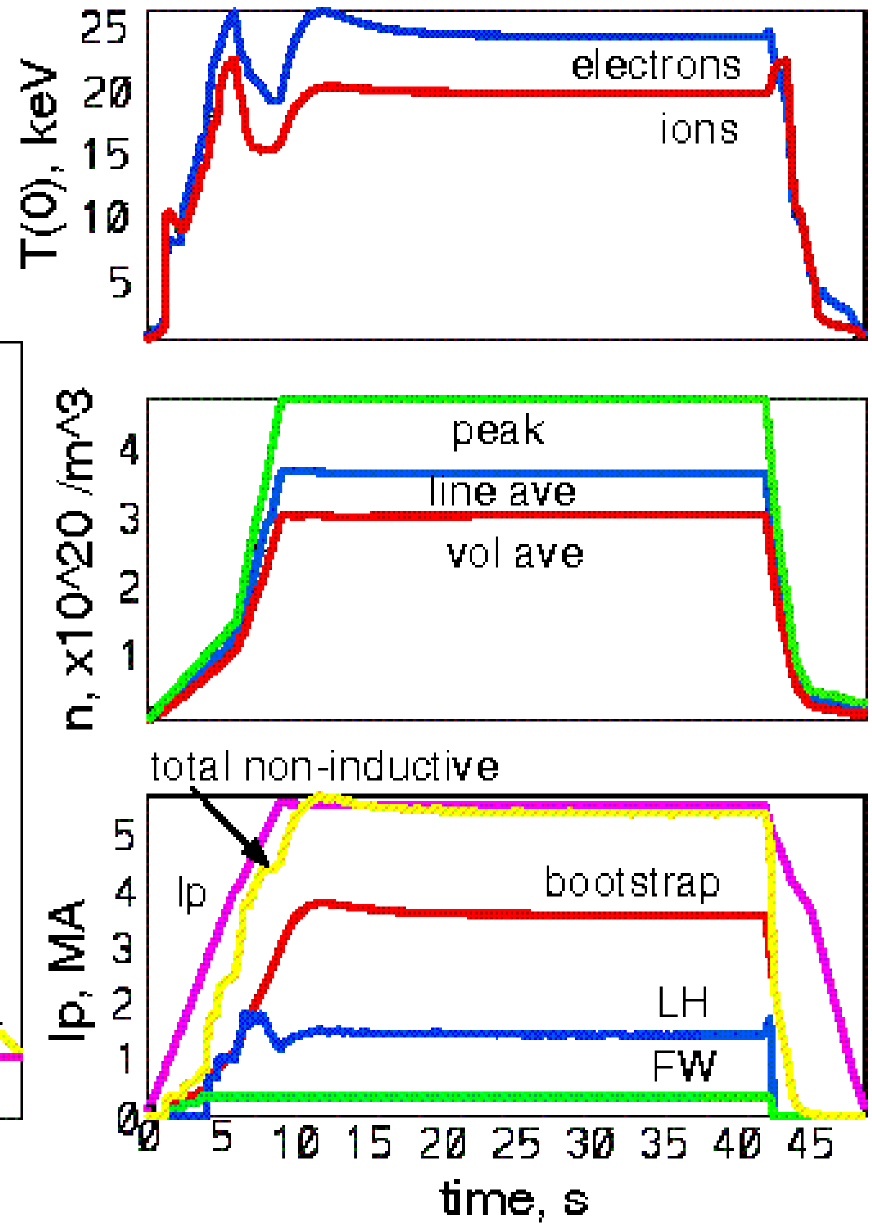




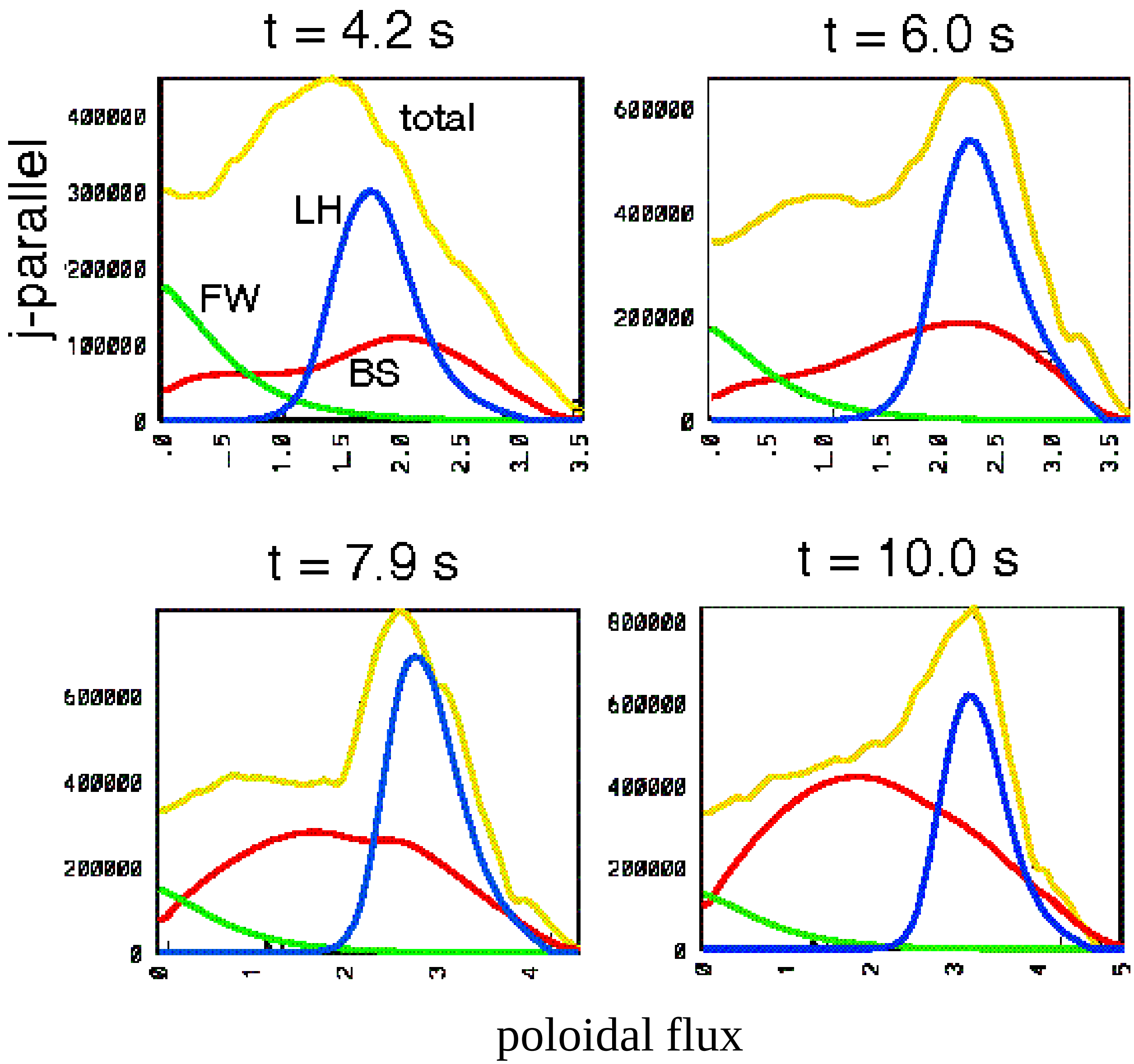
TSC-LSC Simulation of Q=7.8 Burning AT Plasma

I_p=5.4 MA, B_t=8.5T, β_N=3.5, β=4.4%, n/n_{Gr}=0.5, $n(0)/\langle n \rangle$=1.6, $n_{20}(0)$=4.7, $T_i(0)$=20 keV, $T_e(0)$=24 keV, I_{LH}=1.5 MA, I_{FW}=0.35 MA, I_{BS}=3.6 MA, τ_E=0.6 s, H98=1.6

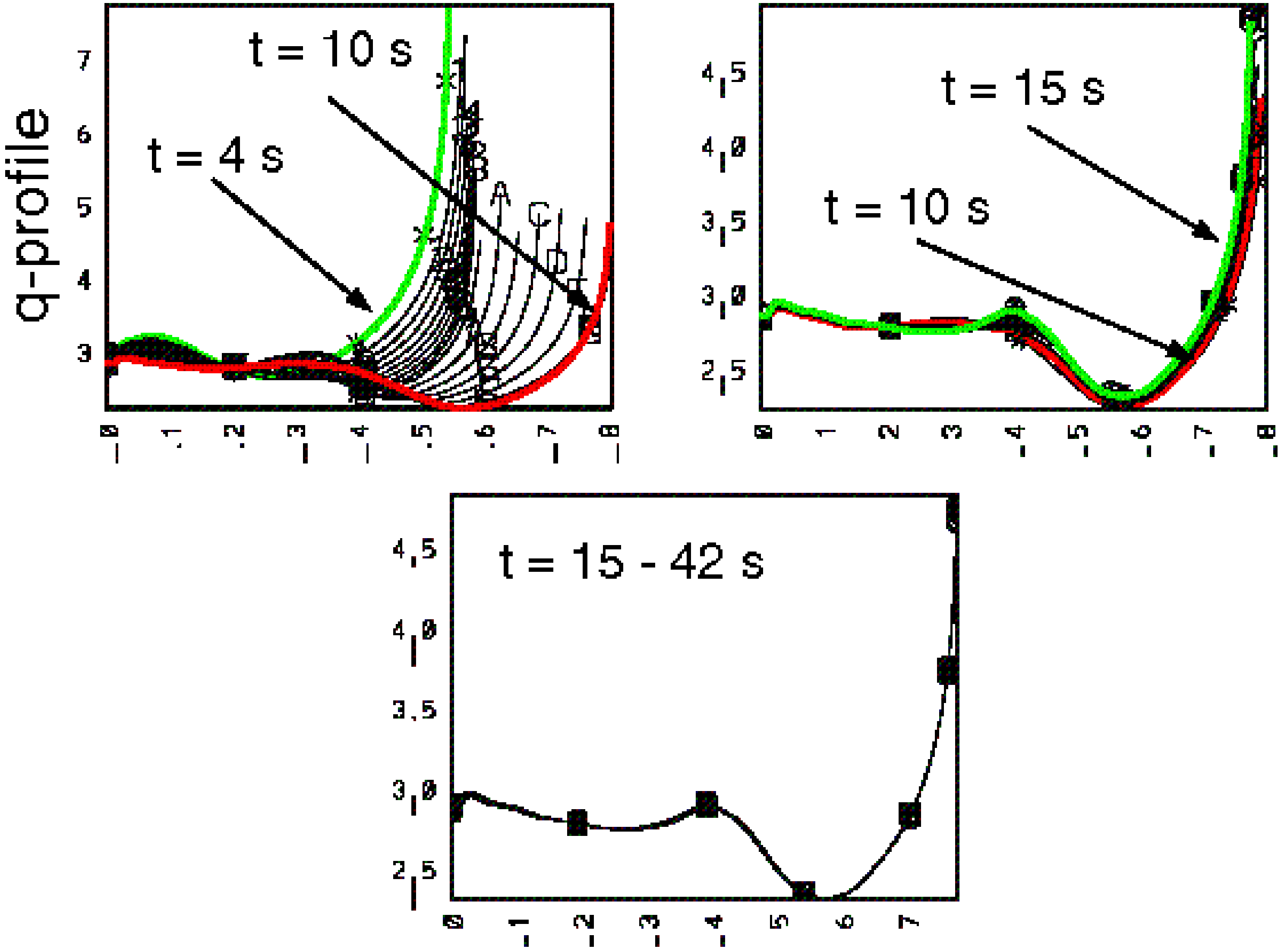




TSC-LSC Simulation of Q=7.8 Burning AT Plasma



TSC-LSC Simulation of Q=7.8 Burning AT Plasma



poloidal flux