Physics Analysis of FIRE

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PPPL

with input from

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Outline

- Systems code scans over Aspect Ratio
- FIRE* operating point and reference discharge
- GLF23 Analysis
- Analysis of LHCD in FIRE
- Long Pulse Capability and AT modes
- Physics R & D Needs

A Burning Plasma Systems Code (BPSC) has been developed for overall device optimization and evaluation

Confinement (Elmy H-mode) ITER98(y,2):

$$\tau_E = 0.144\ I^{0.93}\ R^{1.39}\ a^{0.58}\ n_{20}^{0.41}\ B^{0.15}\ A_i^{0.19}\ \kappa^{0.78}\ P_{heat}^{-0.69}\ H(y,2)$$

Density Limit: $n_{20} < 0.75\ n_{GW} = 0.75\ I_P/\pi a^2$

H-Mode Power Threshold: $P_{Loss} > (2.84/A_i)\ n_{20}^{0.58}\ B^{0.82}\ R\ a^{0.81}$

MHD Stability: $\beta_N = \beta\ /\ (I_P/aB) < 1.8$

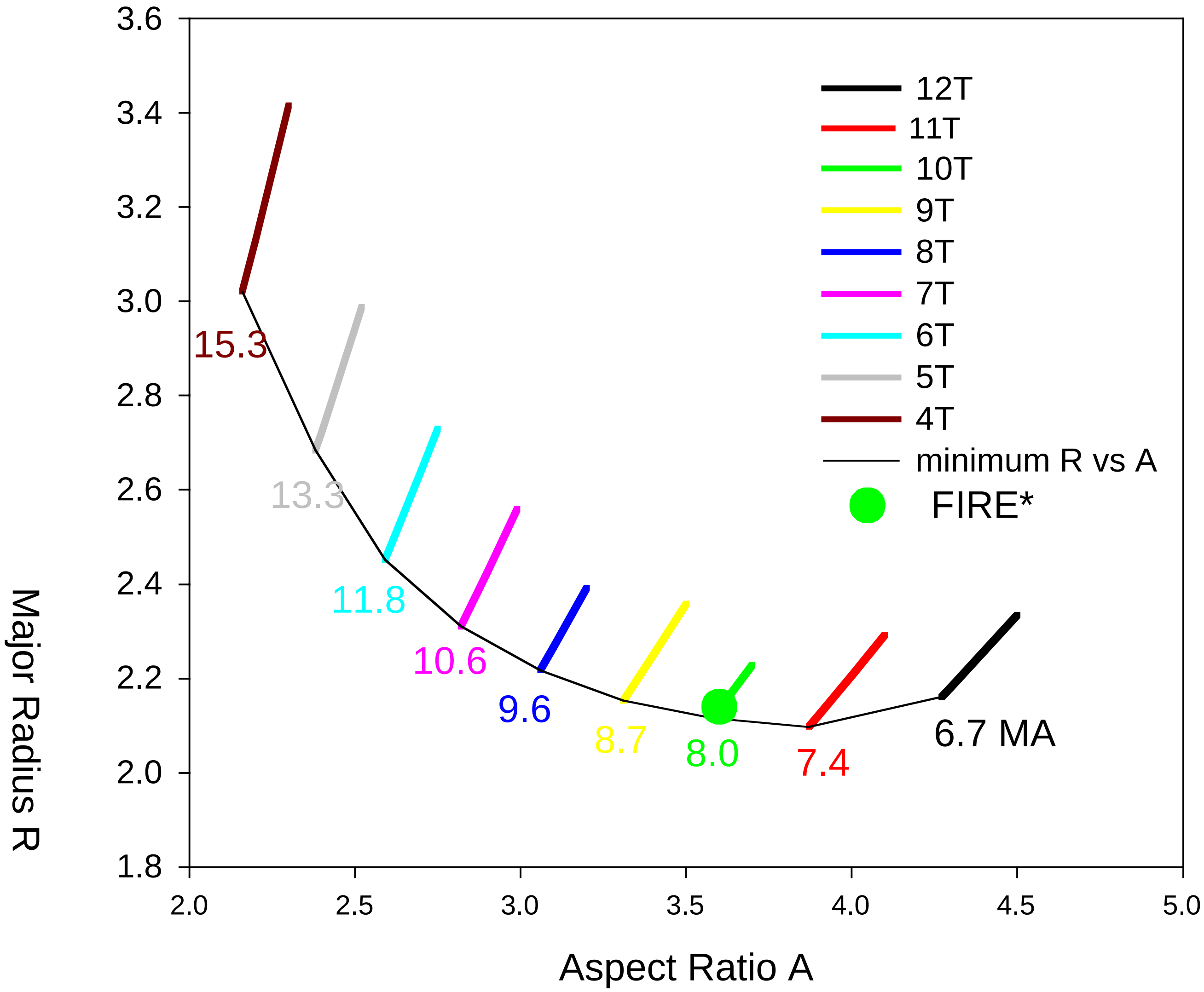
P_{AUX}, $Q = P_{FUSION}/P_{AUX}$, $q_{CYL} = \underline{\hspace{3cm}}$ or $q_{MHD,}$ Z_{EFF} all held fixed

Engineering Constraints:
1. Flux swing requirements in OH coil (V-S)
2. Coil temperature not exceed 373° K
3. Coil stresses remain within allowables

Configuration Concept:
1. OH coils interior to TF coils, or
2. OH coils exterior to TF coils*
3. ST

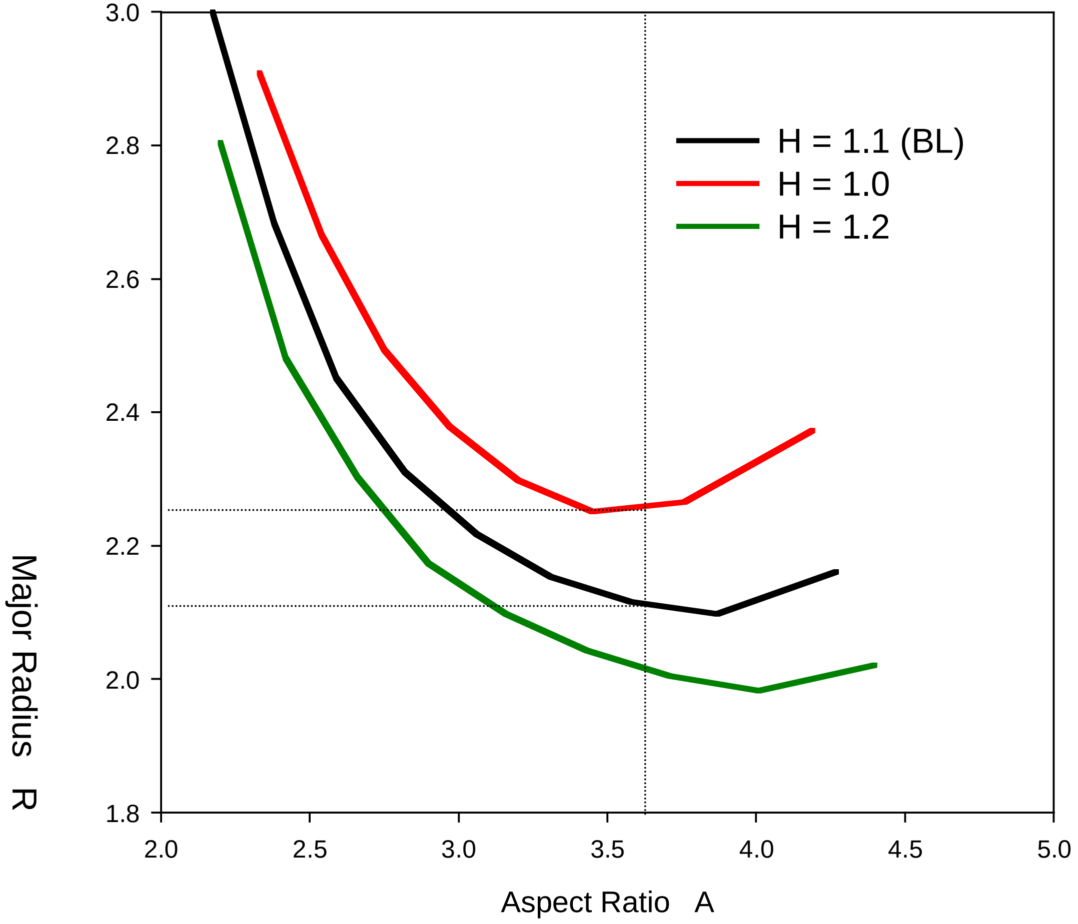
Scan over A, B, I shows FIRE* near optimum

Q=10, T = 20 s, H = 1.1, q_{cyl} = 2.2, κ > 1.8, q_{AUX} =15 MW

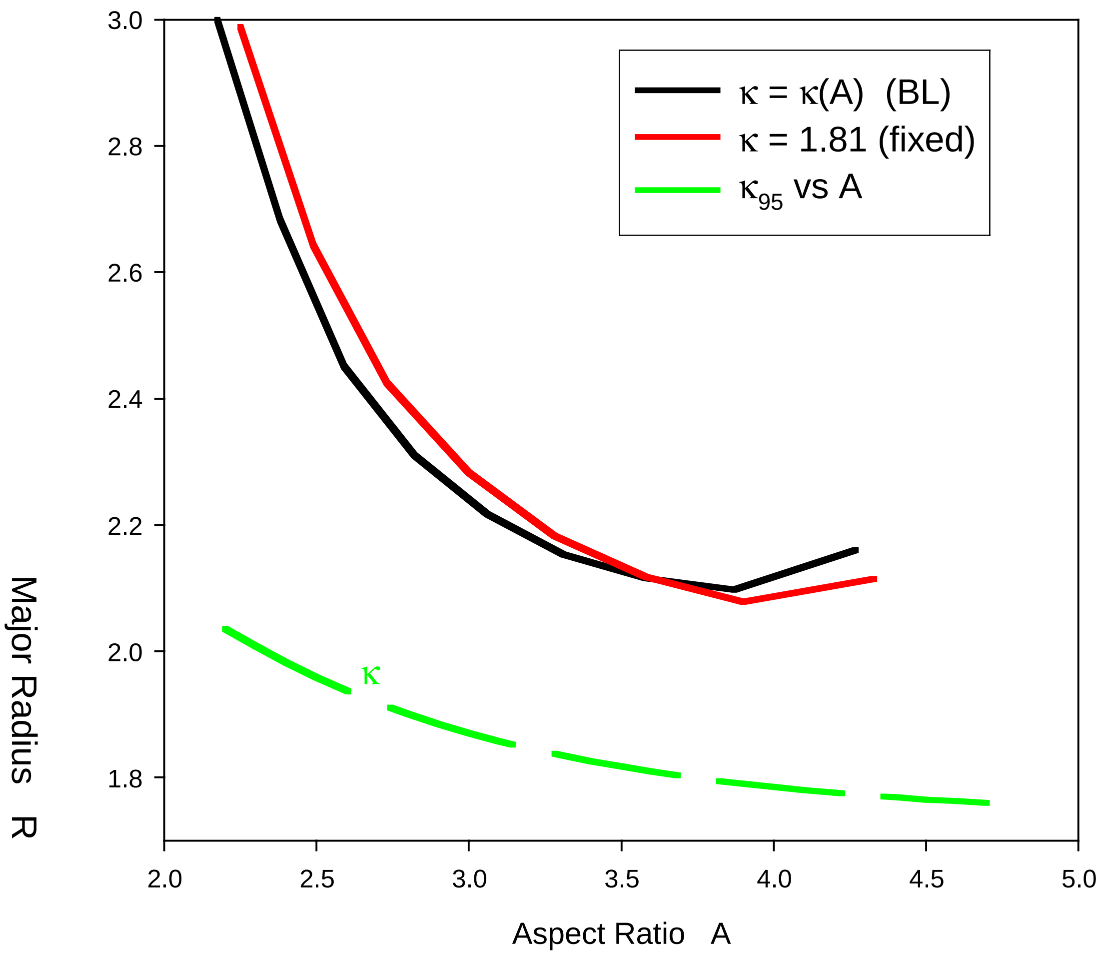


Dependence of Minimum R(A) on Confinement Factor H(y,2)

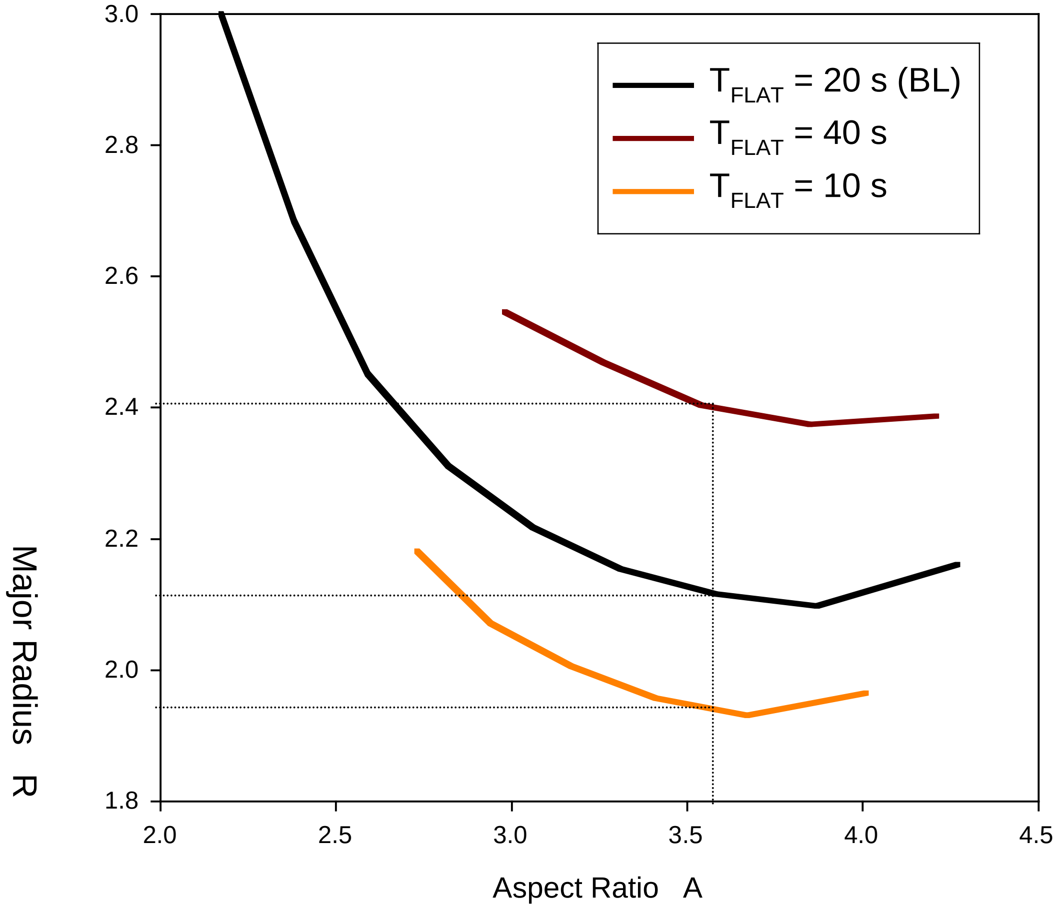
Q=10, T = 20 s, H = 1.1, q_{cyl}= 2.2, κ > 1.8, q_{AUX} =15 MW



Effect of Plasma Elongation varying with A

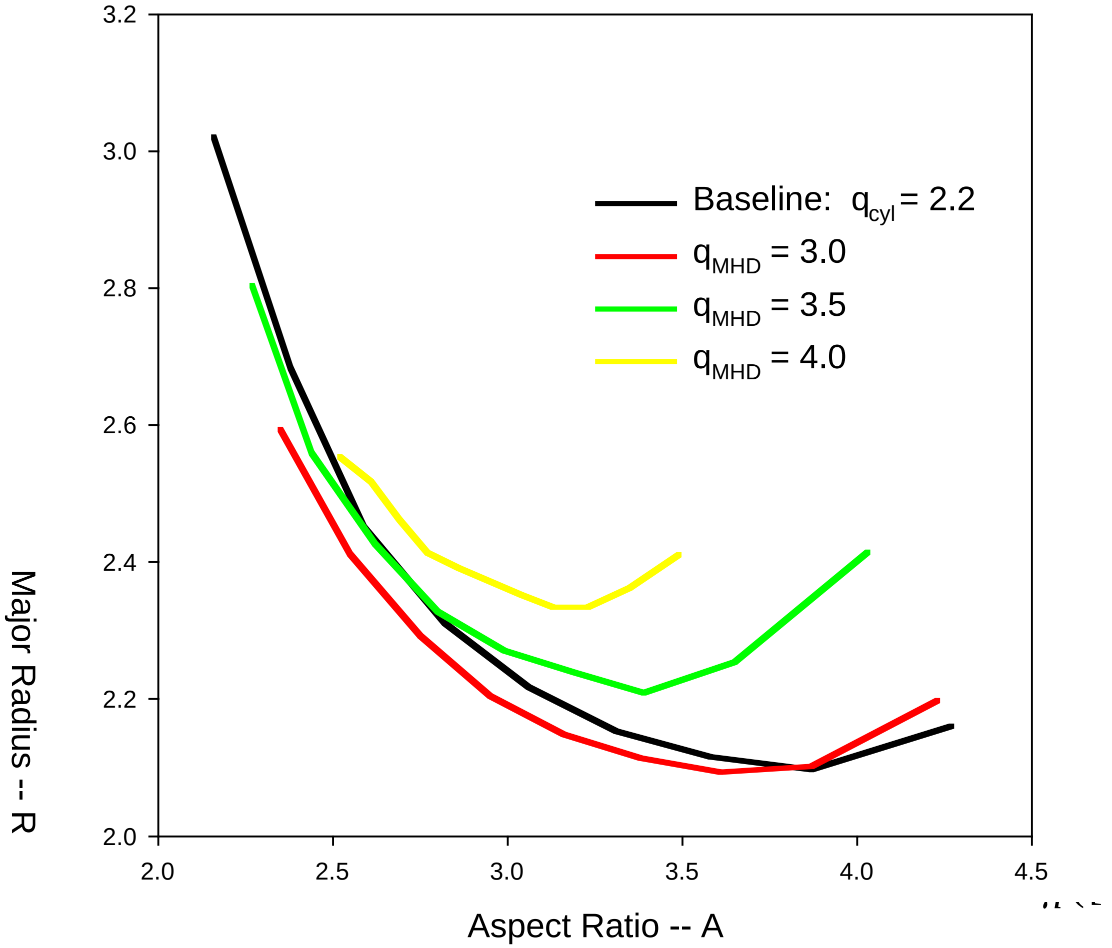


Dependence of Device Size on Flattop Time



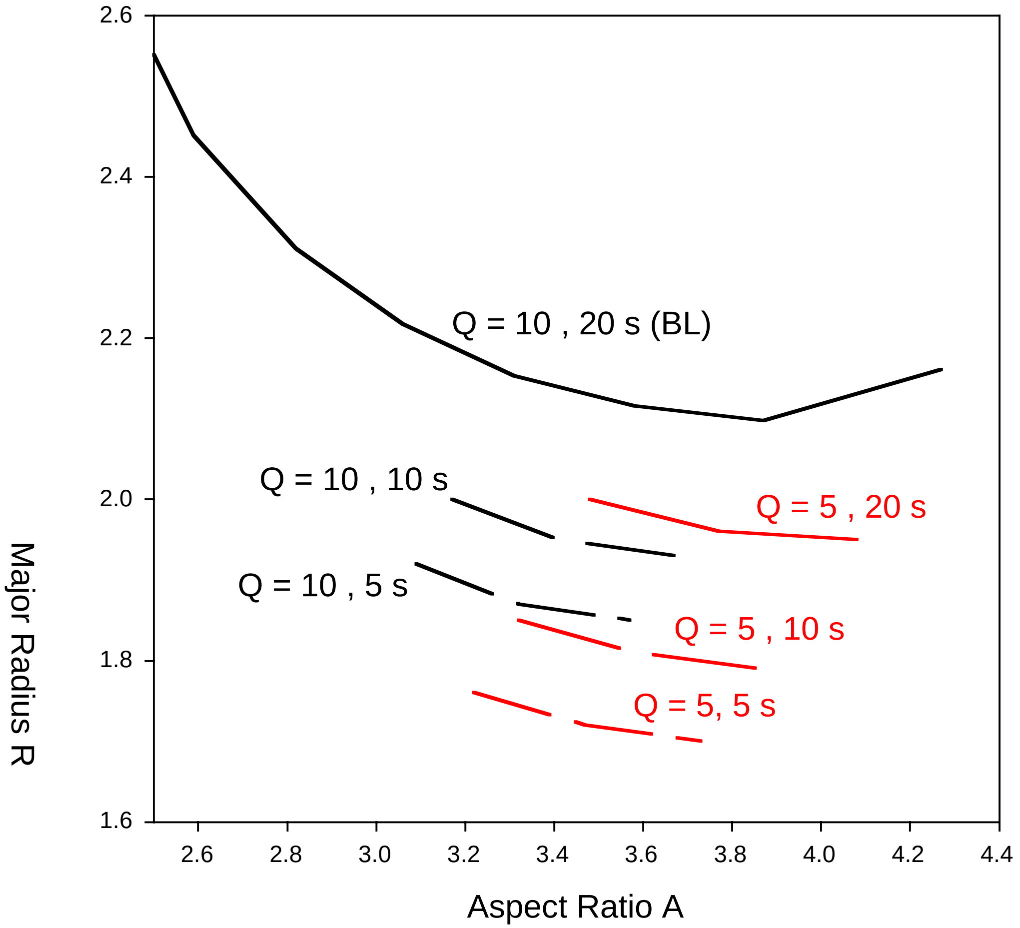
Dependence of device size on plasma safety factor q

Baseline parameters: Q=10, T = 20 s, H = 1.1 , κ > 1.8, q_{AUX} =15 MW



Reduced size and cost options with T = 10, 5 s and/or Q = 5

$H = 1.1$, $\kappa > 1.8$, $P_{AUX} = 15$ MW, $Z_{EFF} = 1.4$



$A = 3.6$

$\kappa_{95} = 1.81$

$P_{AUX} = 15$ MW

$q_{CYL} = 2.2$

$q_{MHD} = 3.05$

$\tau_E = 1.06$ s

$\tau_P = 5.3$ s

$T_{FLATTOP} = 20$ s

$\tau_J = 8.7$ s

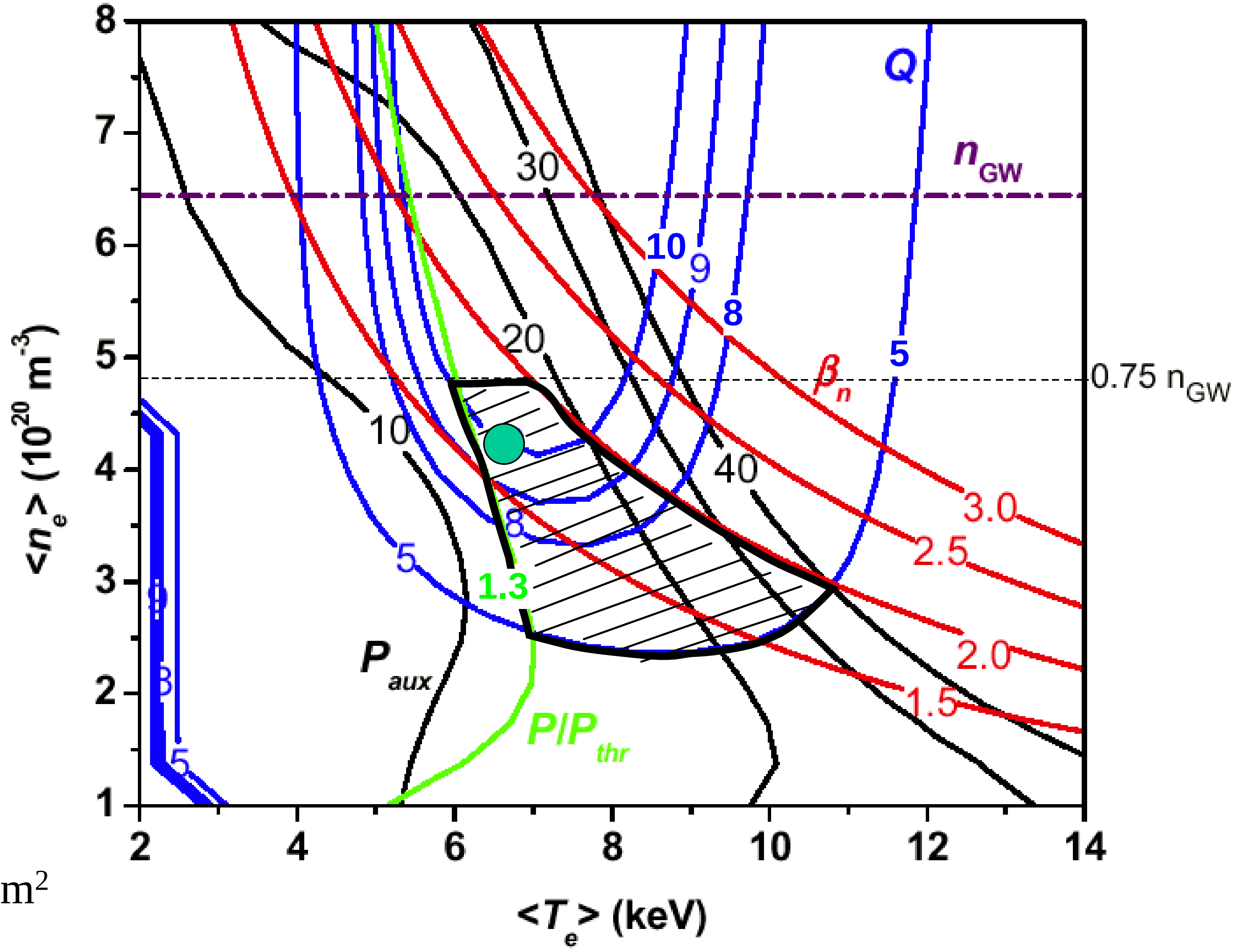
$f_{BS} = 0.2$

$f_{RAD} = .41$

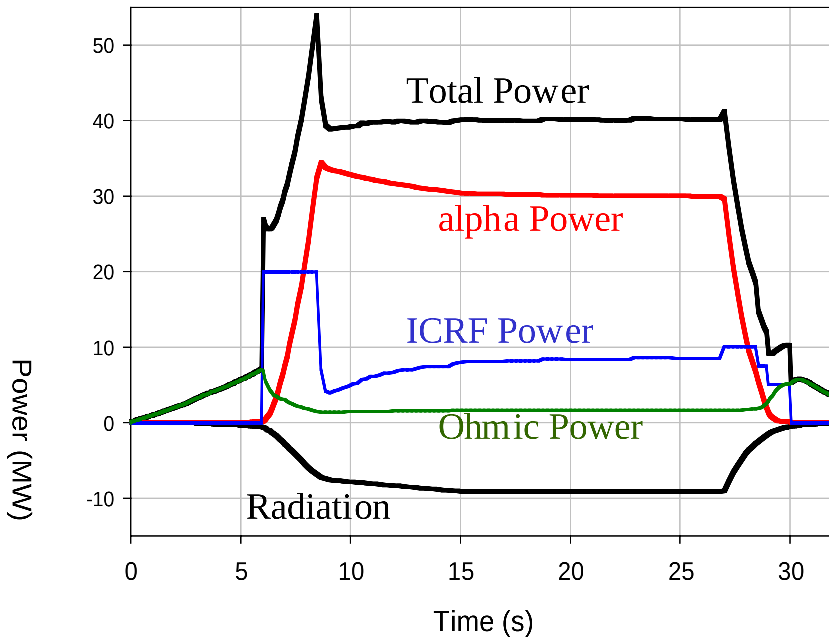
$Z_{EFF} = 1.4$

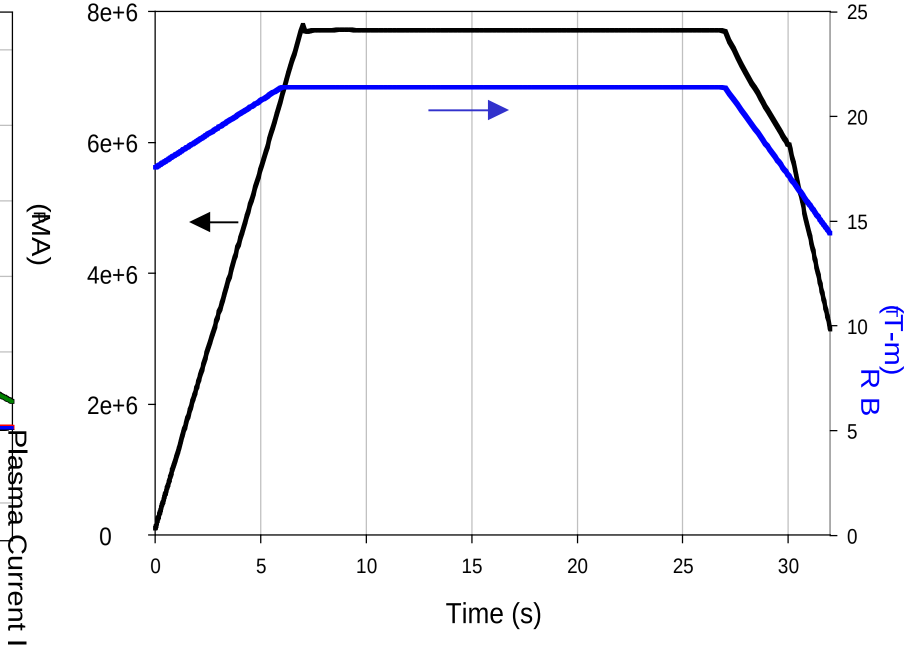
$N_{WALL} = 2$ MW/m^2

FIRE* 10T, 2.14m, 7.7 MA, H(y,2) = 1.14, α_n = 0.2



TSC Simulation of Reference FIRE* Discharge with Burn Control





$\beta_P = 0.70$ $n_e = 5 \times 10^{20}$ $\tau_E = W/P =$ 800 ms $= 0.8\ H_{98(y,2)}$ $n_\alpha = 10^{19}$

$\beta_T = 2.1\%$ $T_{e0} = 11$ keV $= W/(P-P_{RAD}) =$ 1100 ms $= 1.1\ H_{98(y,2)}$ $\beta_\alpha = 0.2\%$

$\beta_N = 1.6\ \%$ W = 32 MJ $\ell_i\ (1) = 1.08$ $\ell_i\ (3) = 0.9$

Why a 20 sec discharge ?

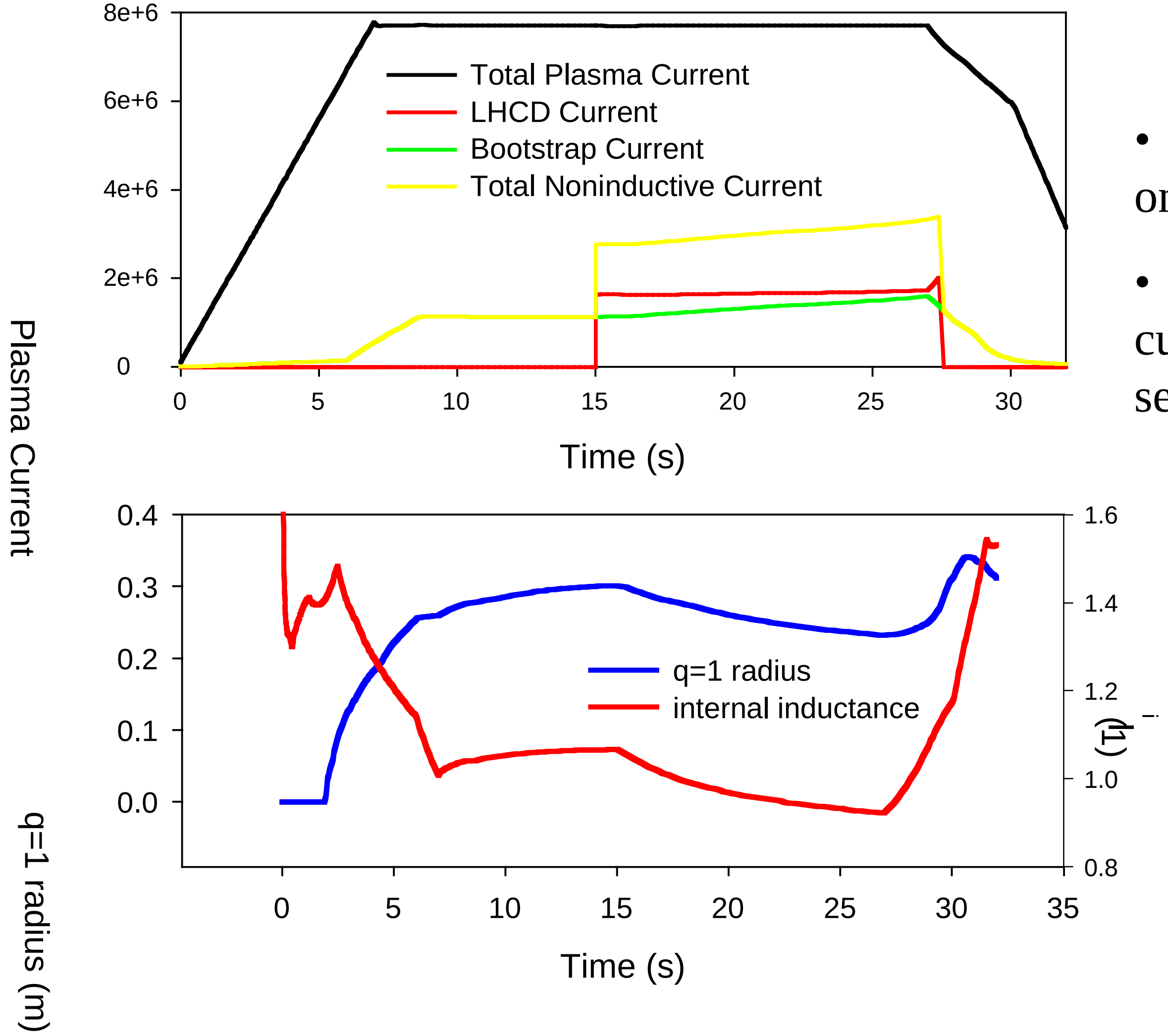
$\tau_E \sim 1$ sec (energy confinement time)

Other timescales of interest:

- Current redistribution time ~ 10 s
- Burn control time ~ 5-10 s
- Helium Ash buildup time ~ 5-10

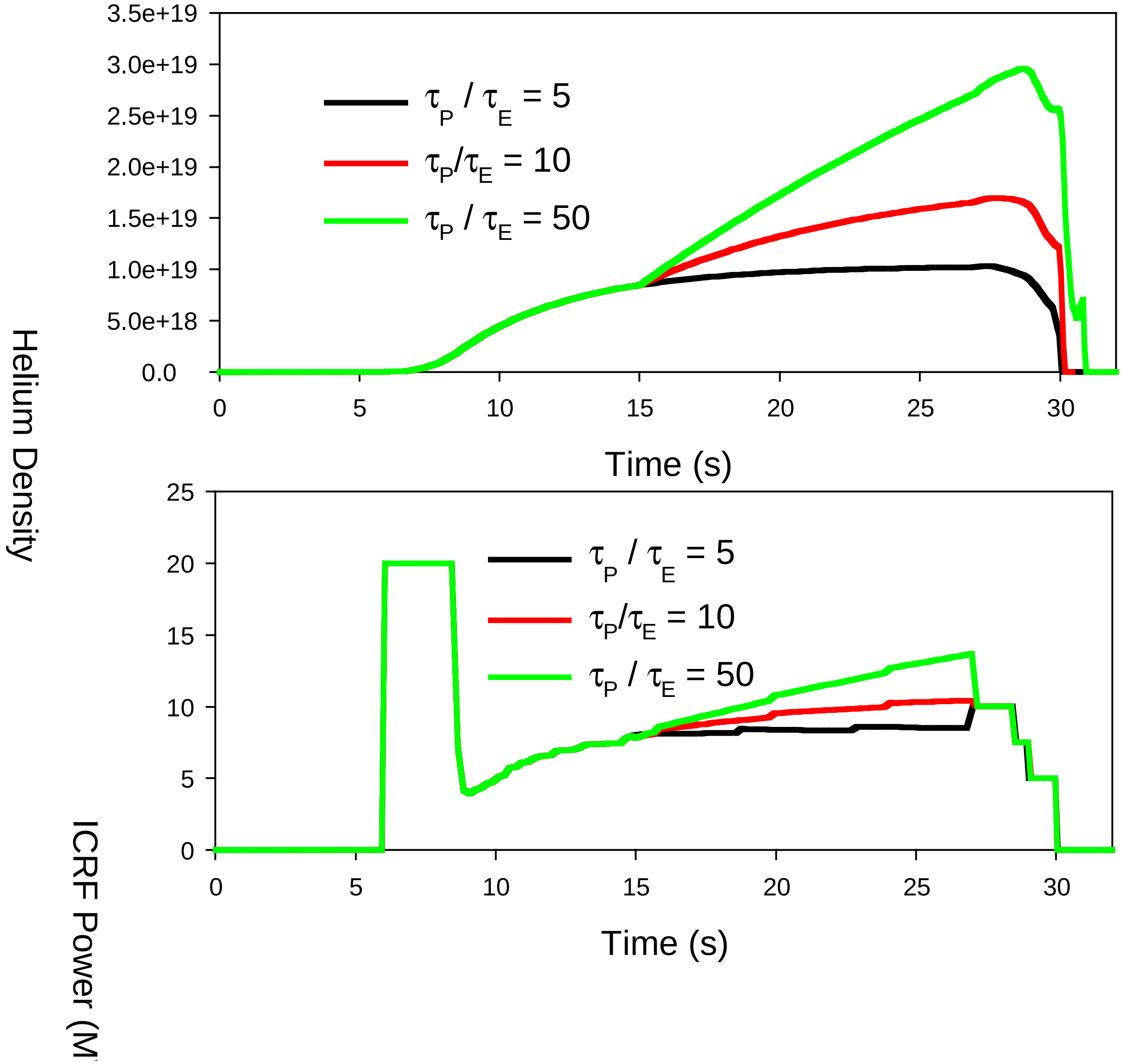
These transient phenomena and others being studied with TSC

TSC simulation of LHCD added to reference discharge shows it takes 10-20 sec to equilibrate



- 1.75 MA LHCD turned on at t=15 s
- requires over 10 sec for current profile to adjust as seen by q=1 radius and l_i

Comparison of 3 TSC FIRE simulations where τ_P is changed suddenly at t=15 from $5\tau_E$ to $10\tau_E$ or $50\tau_E$



• natural equilibration time for helium ash is 10-20 sec

• note, shows the importance of particle control in divertor

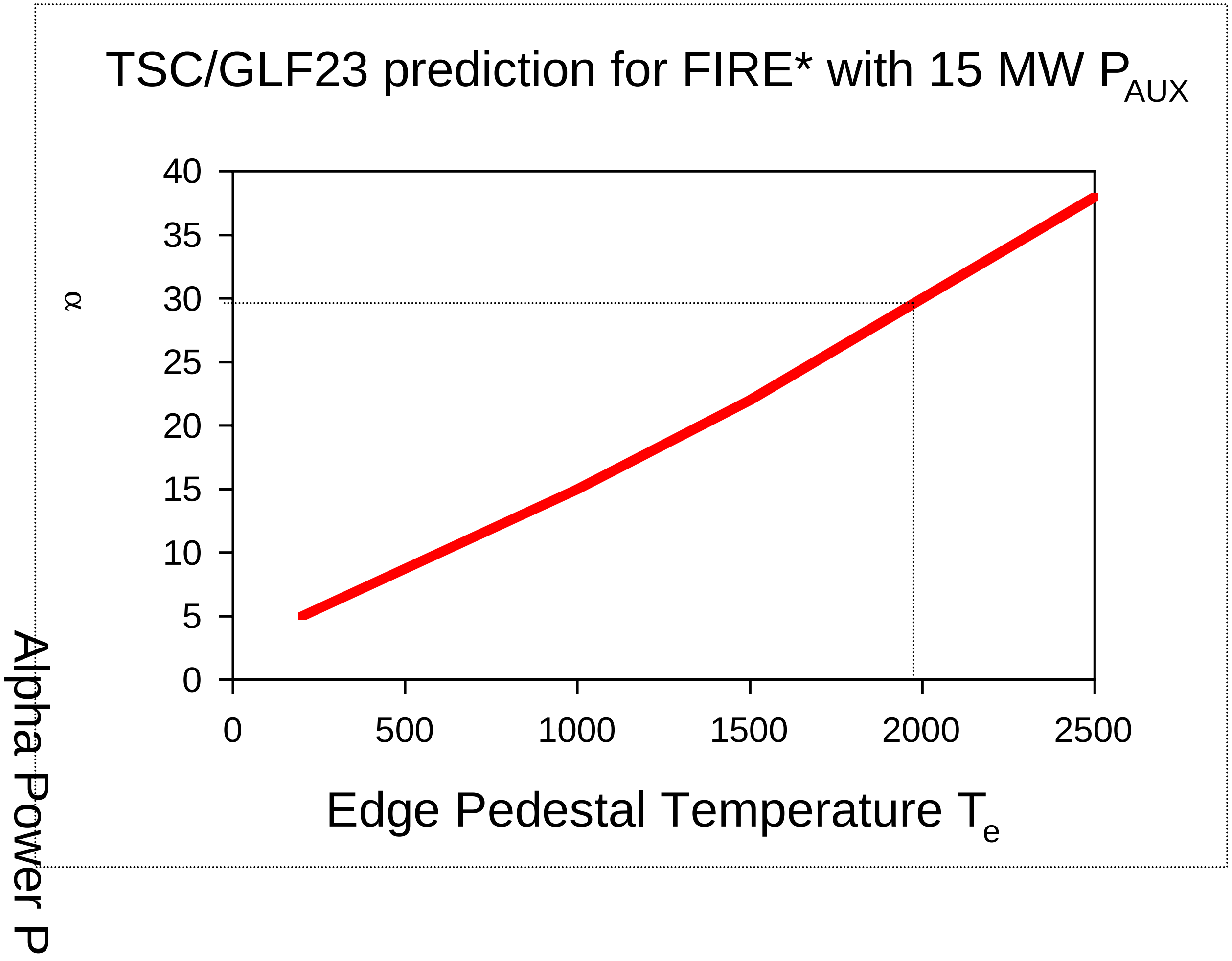
fl Power required to keep stored energy at 40 MJ

GLF23 Transport Model has been incorporated in TSC code and applied to FIRE*

- Gives consistent result when applied to TFTR calibration shot 50911 (T_{e0} = 4 keV, T_{i0} = 7 keV)
- No rotation stabilization
- Results depend strongly on (assumed) edge pedestal Temperature..need 2 keV
- More optimistic than Kinsey's UFA results.

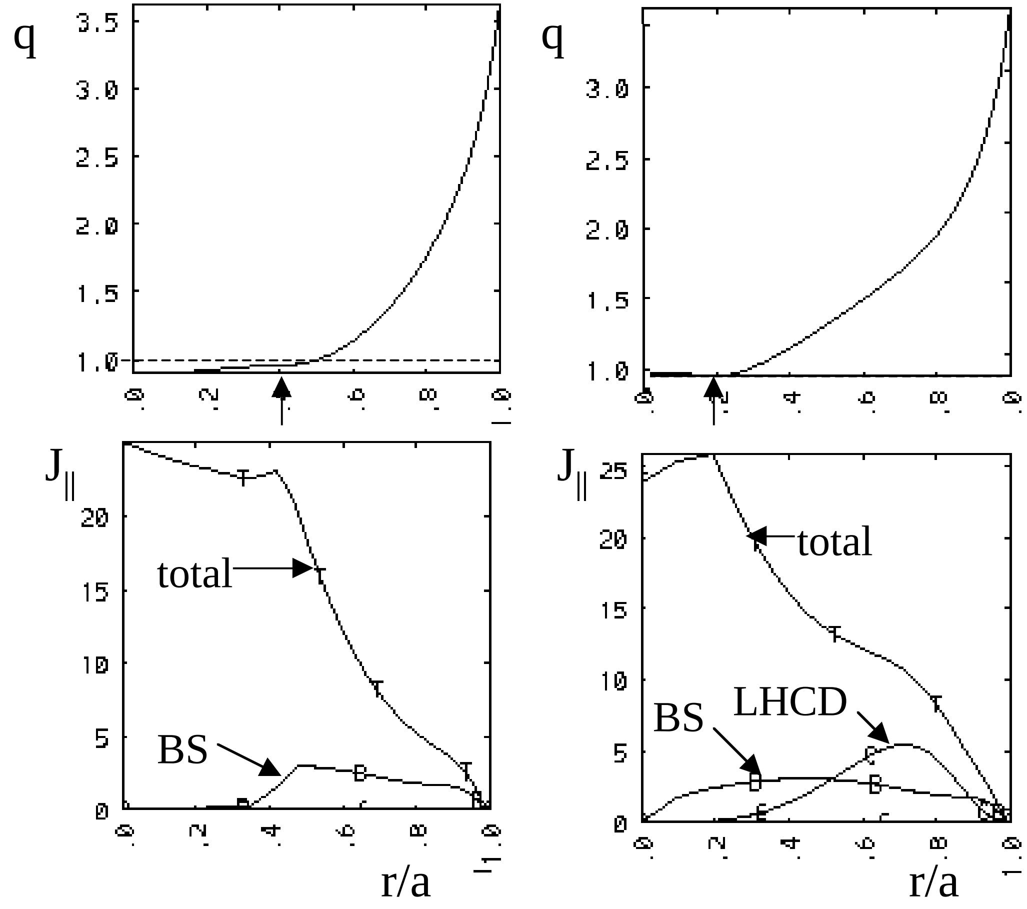
(4 keV for the old FIRE)

- This is being investigated


TSC/GLF23 prediction for FIRE* with 15 MW P_{AUX}

LHCD studies have been performed for FIRE* using JSOLVER and TSC/LSC

- Radius of q=1 surface can be decreased by application of LHCD near edge



I(LHCD)	r/a(q=1)
0.0	0.425
1.0	0.35
1.5	0.30
2.0	0.20
2.35	0.10
2.55	0.00

LHCD for NTM Control in FIRE

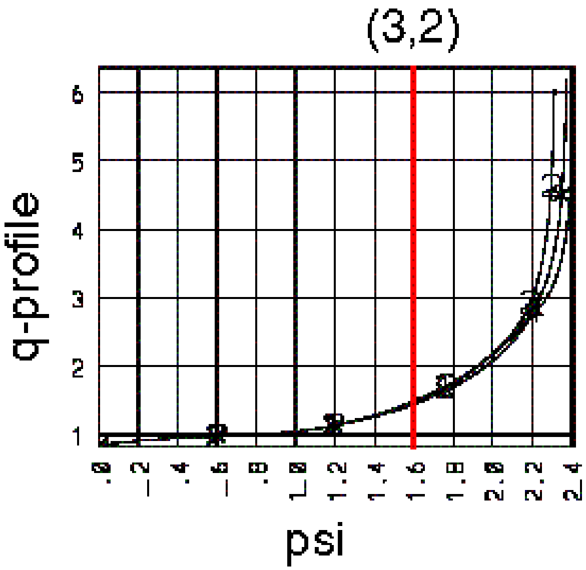
LSC lower hybrid calculation

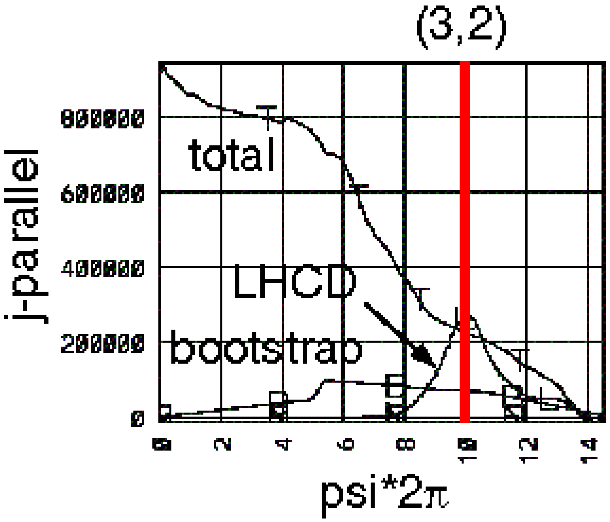
$N_{||} = 2.5$, $\Delta N_{||} = 0.25$

$P_{LH} = 15$ MW, $I_{LH} = 1.1$ MA

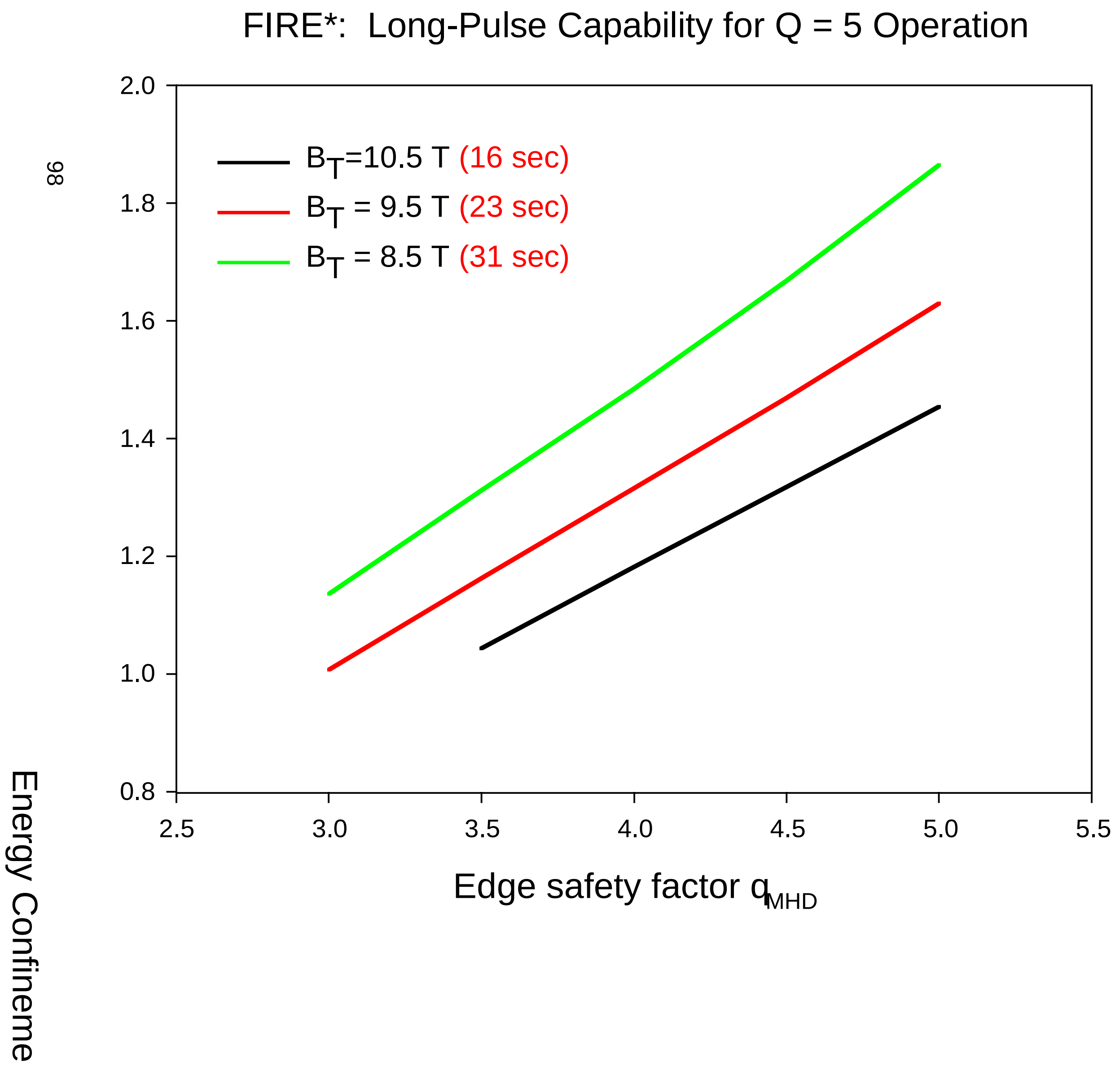
Need to examine:

- Narrower deposition
- Density and temperature dependence
- Reduction of power
- PEST-III evaluation of Δ′

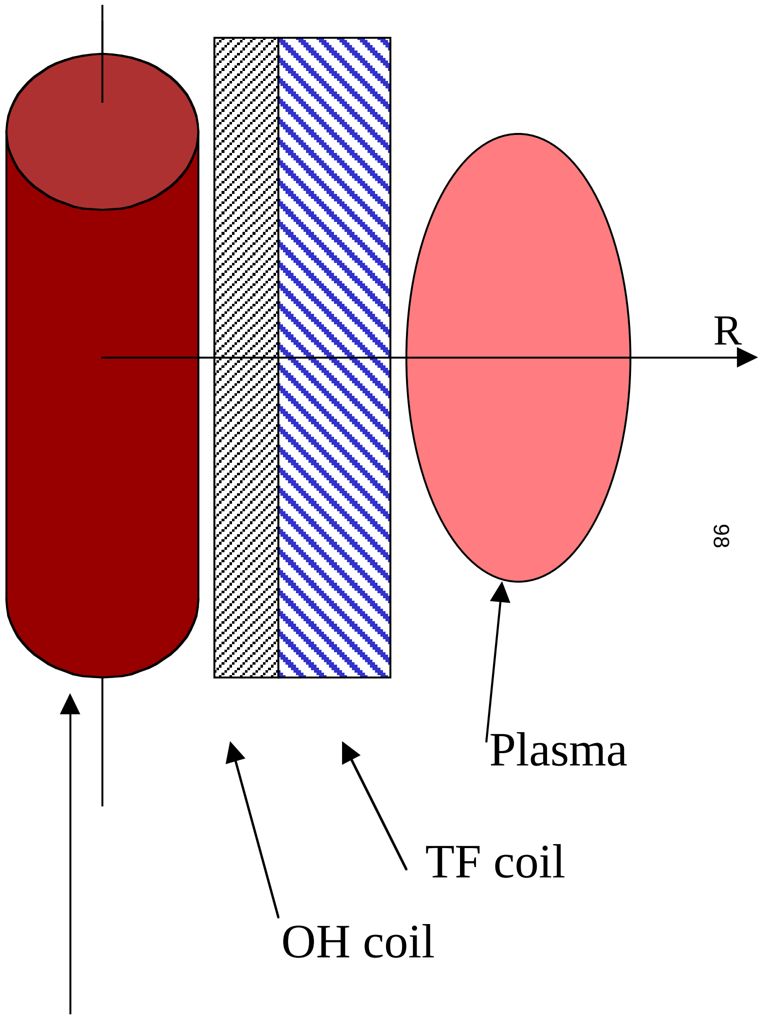




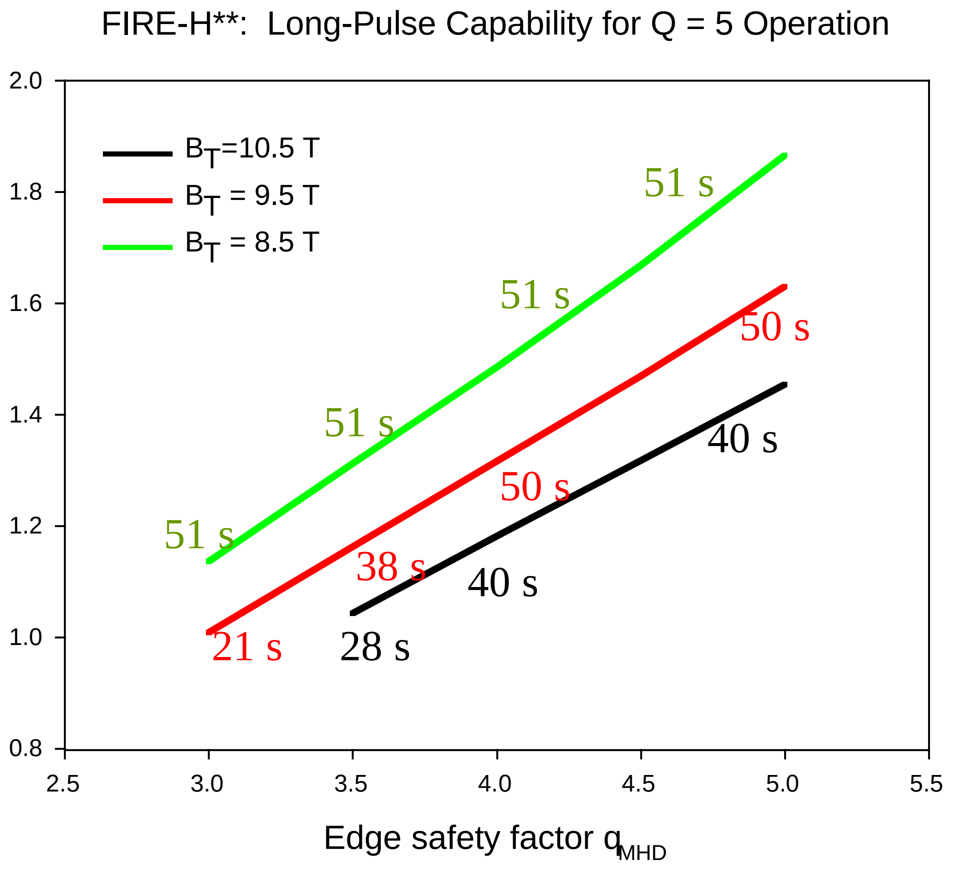
Systems Code analysis of Long-Pulse AT FIRE* Discharges



Possible upgrade to provide long pulse high-q capability at full field



Proposed new center conductor to provide 2 T toroidal field for long pulse operation



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Energy Confineme

Physics Areas Requiring Further Attention:

- Disruption Physics: VDE, loads, runaway electrons, mitigation
- Transport Modeling: pedestal physics, ELMs, H-mode access
- RF Physics: Energy, current, rotation profiles: ICRH & LHCD
- Energetic Particle Modes: map out stability boundaries, effects
- Advanced Modes: modeling and prototyping, RWM control
- Error field correction coils: requirements, use for RWM
- MHD physics: 1/1 mode, NTM stabilization , RWM, ELMs
- Edge Physics: UEDGE/DEGAS2 modeling, $n_{sep} / \langle n_e \rangle$
- AT modes: ITBs with low toroidal rotation, flat density, $T_e \sim T_i$