FIRE

An Opportunity to Test and Extend Confinement Understanding

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for the FIRE Team

Prepared for
Uniform Assessment
Snowmass Fusion Summer Study

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http://fire.pppl.gov

FIRE is a “Modest” Extrapolation in Plasma Confinement

Dimensionless Parameters

$\omega_c\tau$

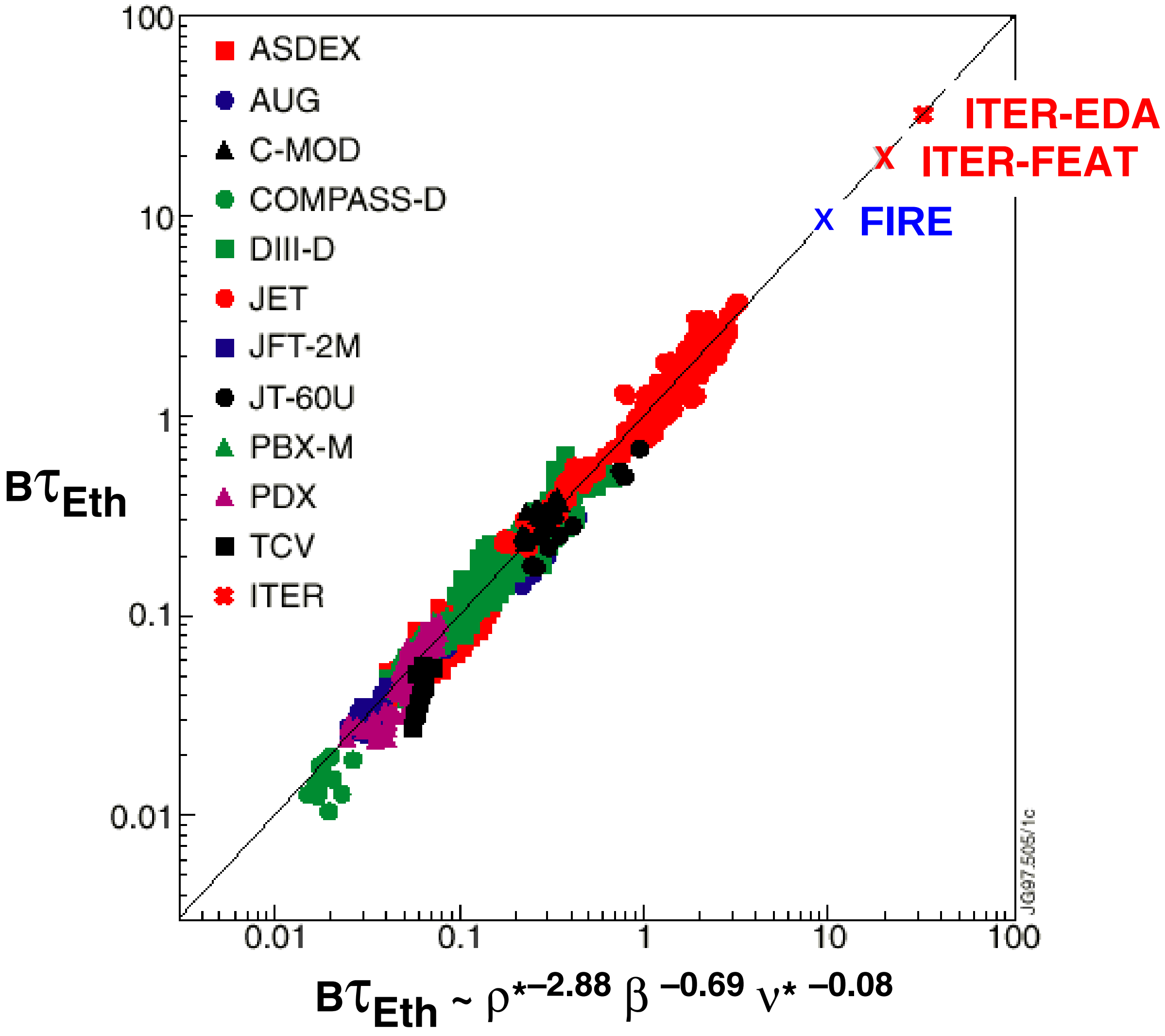
$\rho^* = \rho/a$

$\nu^* = \nu_c/\nu_b$

β

Similarity Parameter

$B\,R^{5/4}$



Kadomtsev, 1975

Transport Issues/Benefits from a Major Next Step Tokamak Experiment

- Predicting confinement and performance is a central issue for a next step experiment that challenges our understanding and predictive capability.

- Methods Available

  1. 0-D Statistical based models (eg ITER scalings for H-Mode)
     dimensionless variables ala wind tunnel
     projections from individual points(Barabaschi) or similar points(DM)

  2. 1 1/2-D (WHIST, TSC, Baldur, ASTRA)
     profiles and time evolution

  3. “First Principles” based core transport models
     - gyrokinetic/gyrofluid (GLF 23)
     - multi-mode model
  4. Edge Pedestal and density limit models
- What experimental capabilities or features in a next step experiment are needed to better resolve and understand transport issues?

Guidelines for Estimating Plasma Performance

Confinement (Elmy H-mode) - ITER98(y,2) based on today's data base

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

Density Limit - Based on today's tokamak data base

$$n_{20} \leq 0.8\, n_{GW} = 0.8\, I_p/\pi a^2,$$

Beta Limit - theory and tokamak data base

$\beta \leq \beta_N(I_p/aB)$, $\beta_N < 2.5$ conventional, $\beta_N \sim 4$ advanced

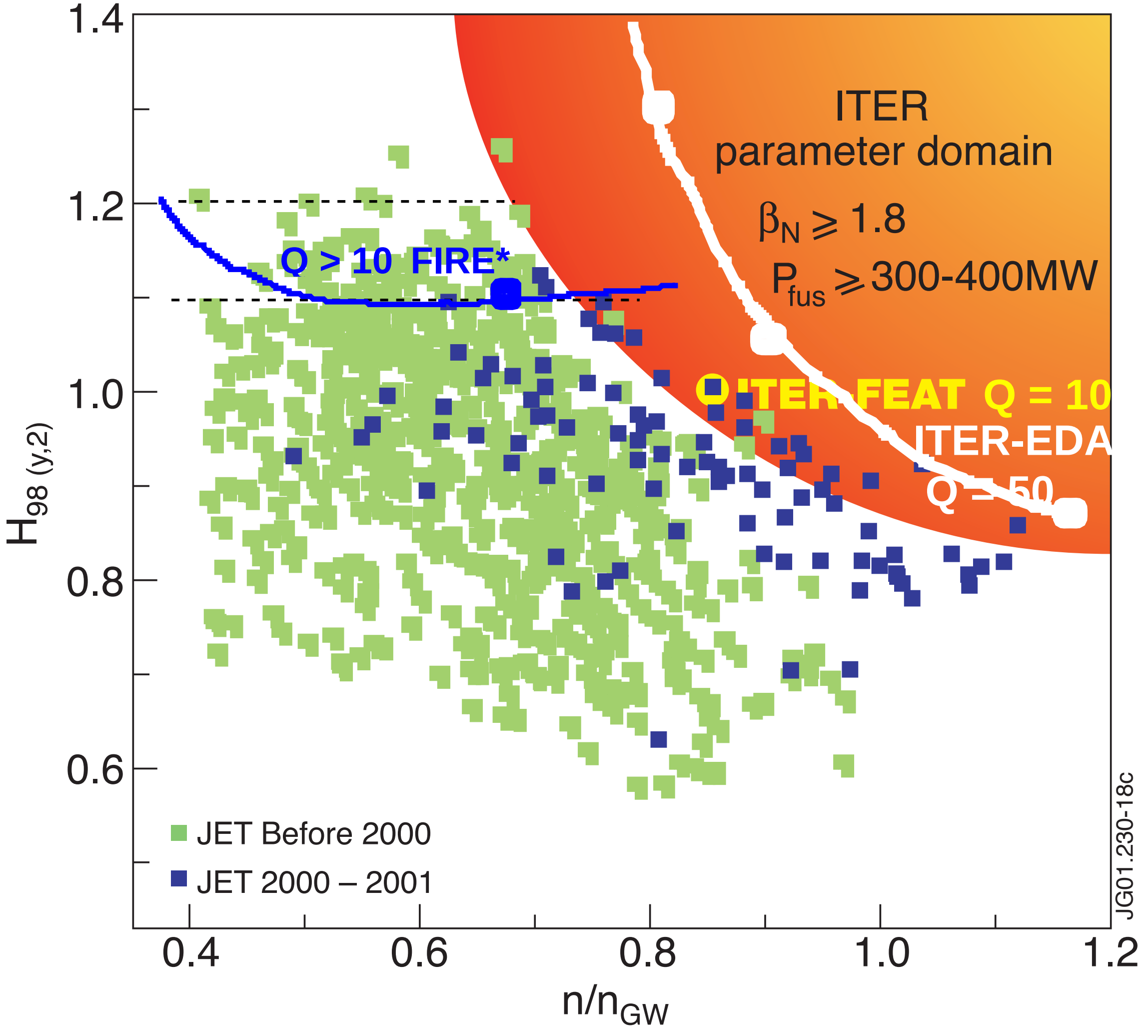
H-Mode Power Threshold - Based on today's tokamak data base

$Pth \geq (2.84/Ai)\, n_{20}^{0.58}\, B^{0.82}\, Ra^{0.81}$, same as ITER-FEAT

Helium Ash Confinement $\tau_{He} = 5\, \tau_E$, impurities = 3% Be, 0% W

Understanding is mainly empirical. Better understanding is needed from existing experiments with improved simulations, and a benchmark in alpha-dominated fusion plasmas is needed to confirm and extend the science basis.

Comparison Operating Ranges of ITER-EDA, ITER-FEAT and FIRE with JET H-Mode Data



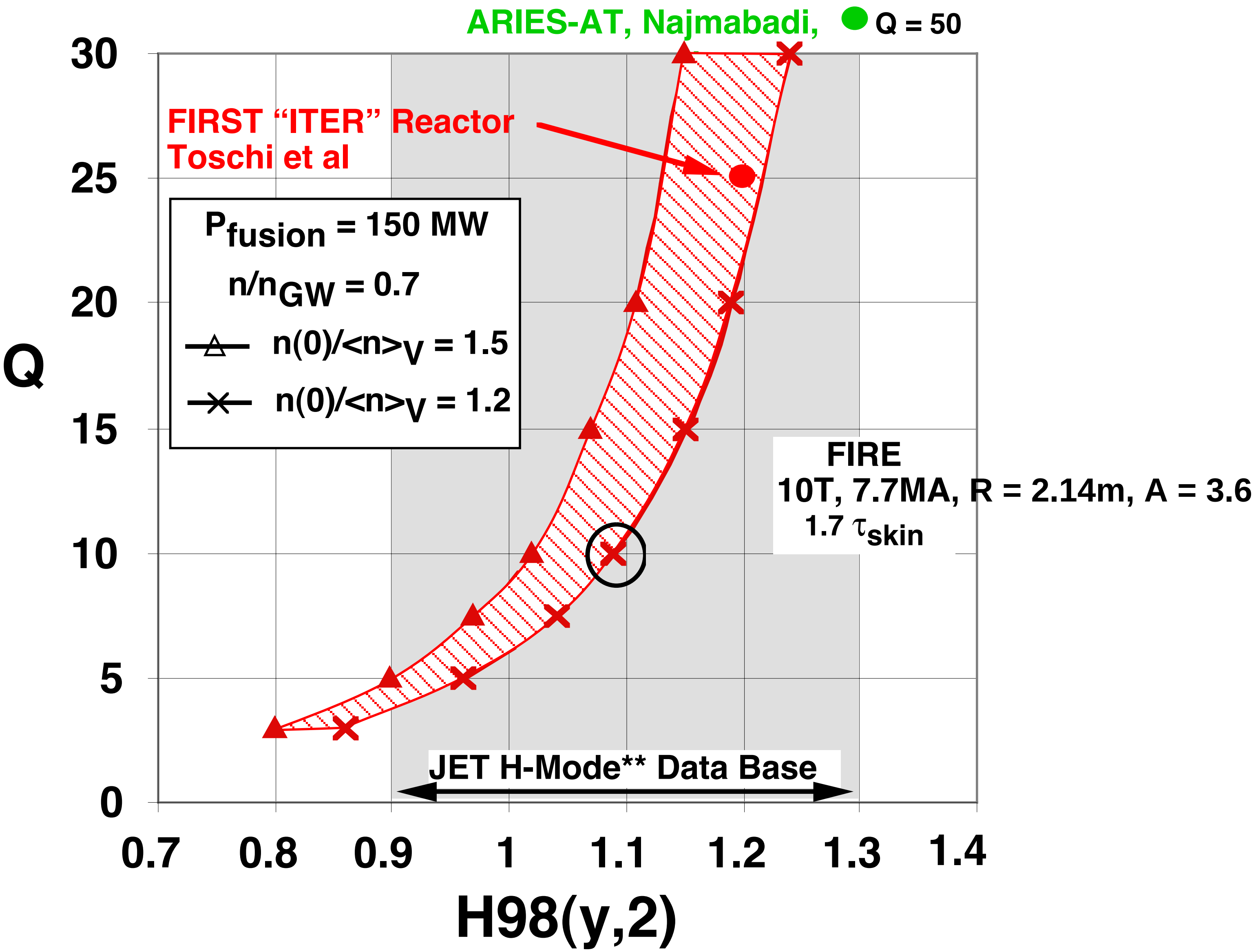
- Extension of JET parameter domain leading to simultaneous realization of $H_{98(y,2)} = 1$, $n/n_{GW} > 0.9$ and $\beta_N \geqslant 1.8$ using different approaches and

- In addition Plasma purity as required for ITER: Zeff ~ 1.5

- For quasi-stationary phases of several seconds

- **A more extensive study of the operating range with the latest public data base DB3v10 will be done for Snowmass. Also Cordey EPS paper showing H(n/nGW, δ, n(0)/<n>, etc**

Projections to FIRE Compared to Envisioned Reactors

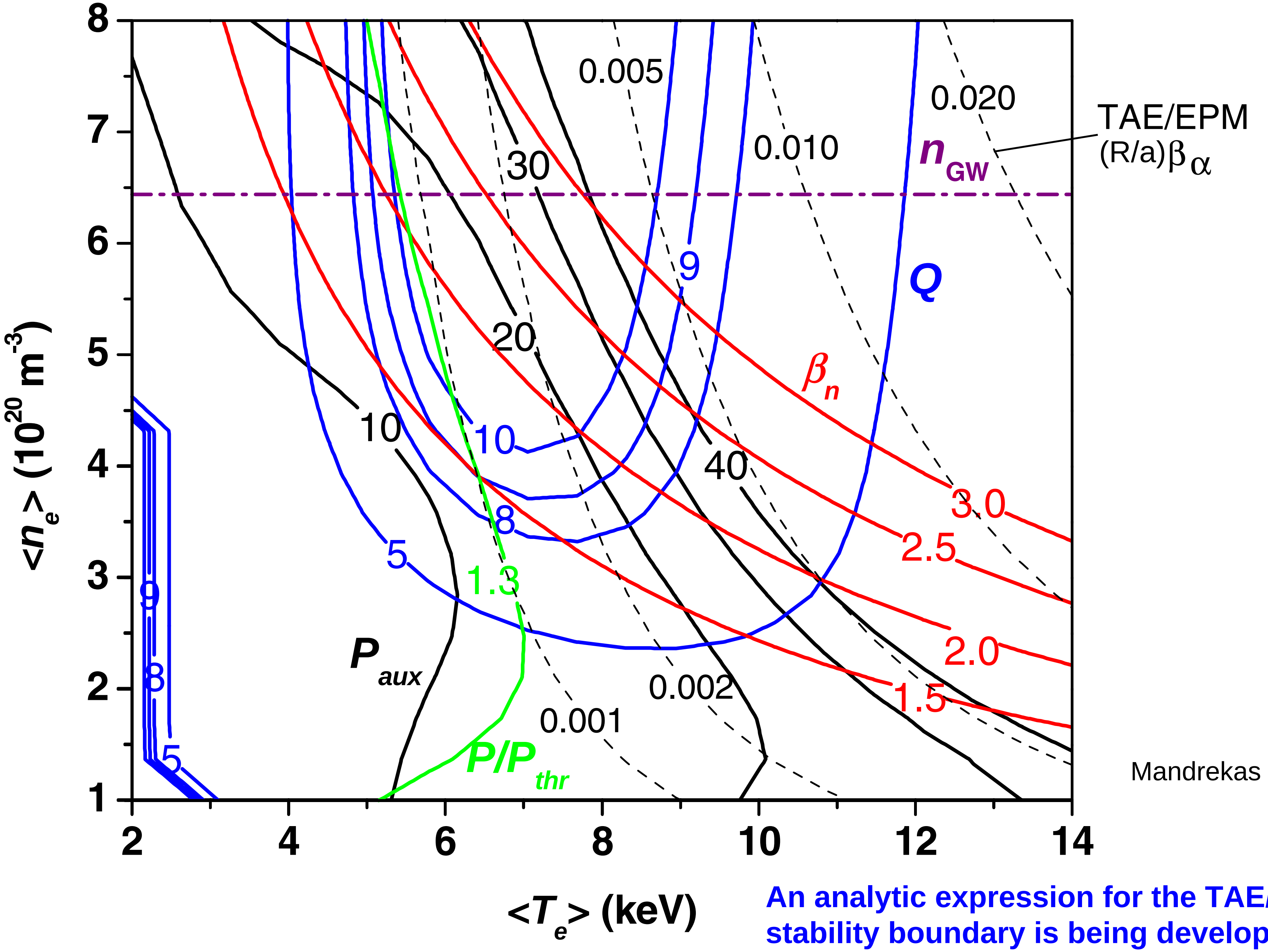


ARIES-AT, Najmabadi, ● Q = 50

FIRST “ITER” Reactor
Toschi et al

FIRE
10T, 7.7MA, R = 2.14m, A = 3.6
1.7 τ_{skin}

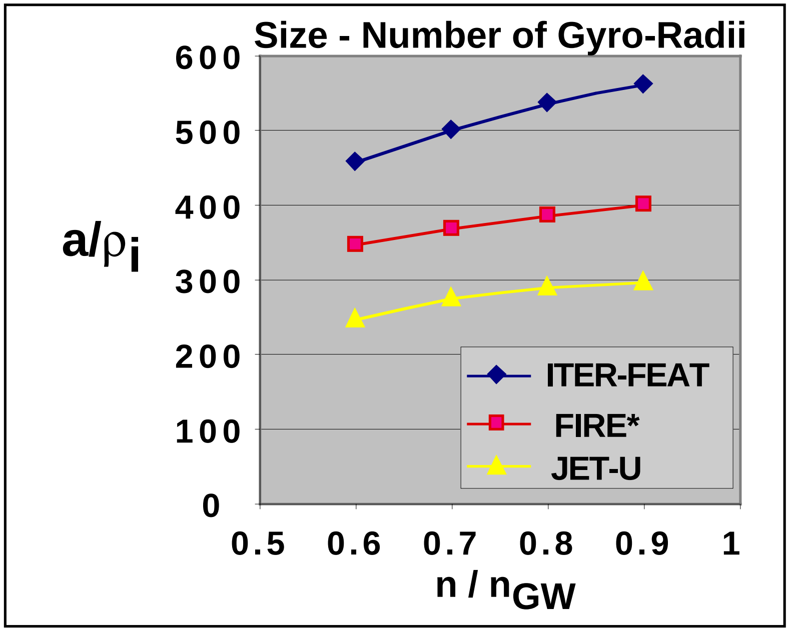
FIRE 10T, 7.7 MA, H(y,2) = 1.14, α_n = 0.2

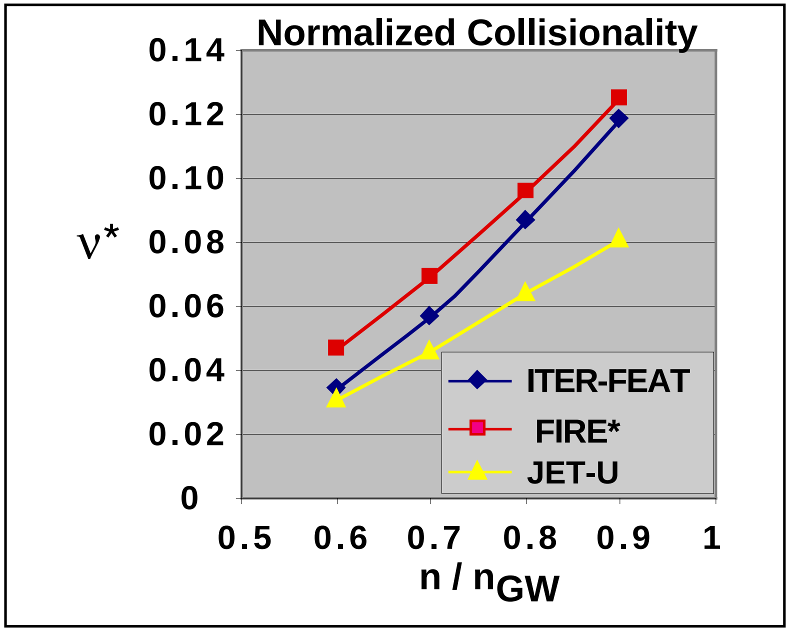


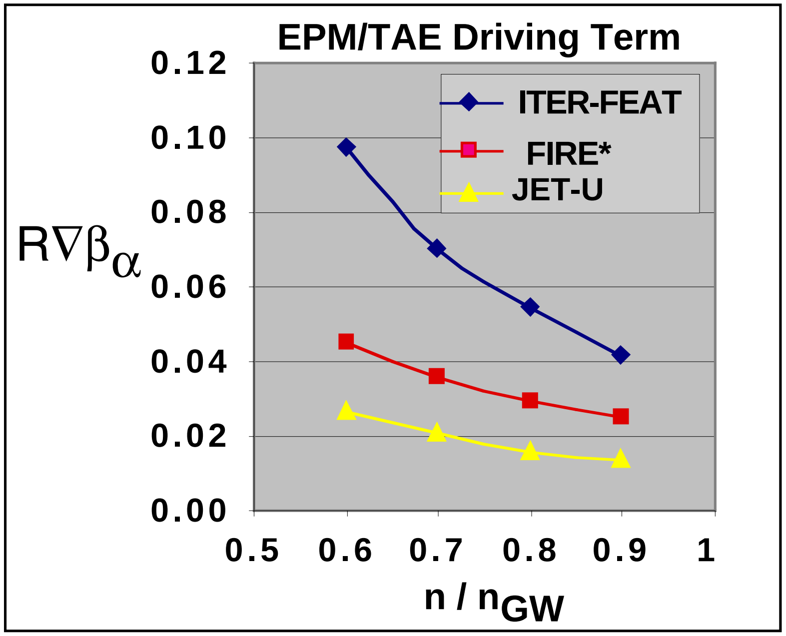
An analytic expression for the TAE/EPM stability boundary is being developed.

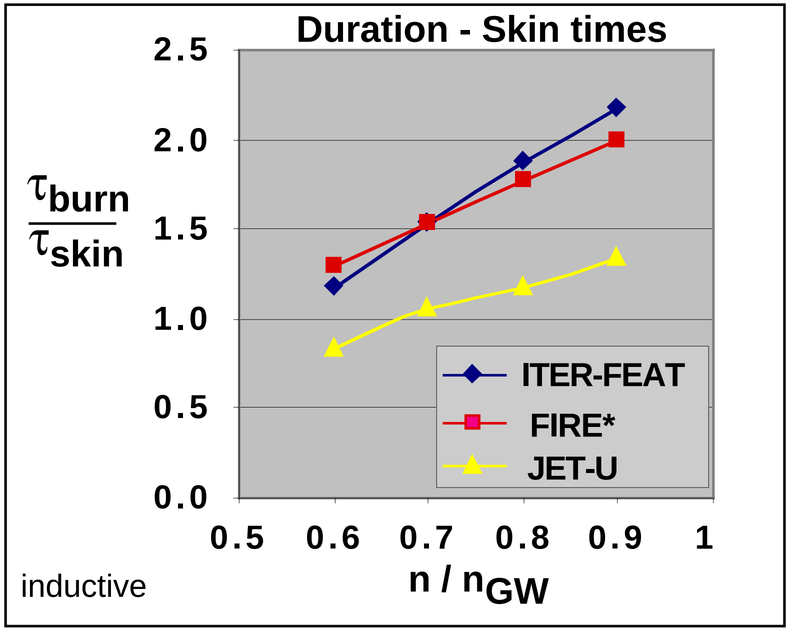
Parameters for H-Modes in Potential Next Step D-T Plasmas

ITER-FEAT (15 MA): Q = 10, H = 0.95, FIRE*(7.7 MA): Q = 10, H = 1.03, JET-U (6 MA): Q = 0.64, H = 1.1

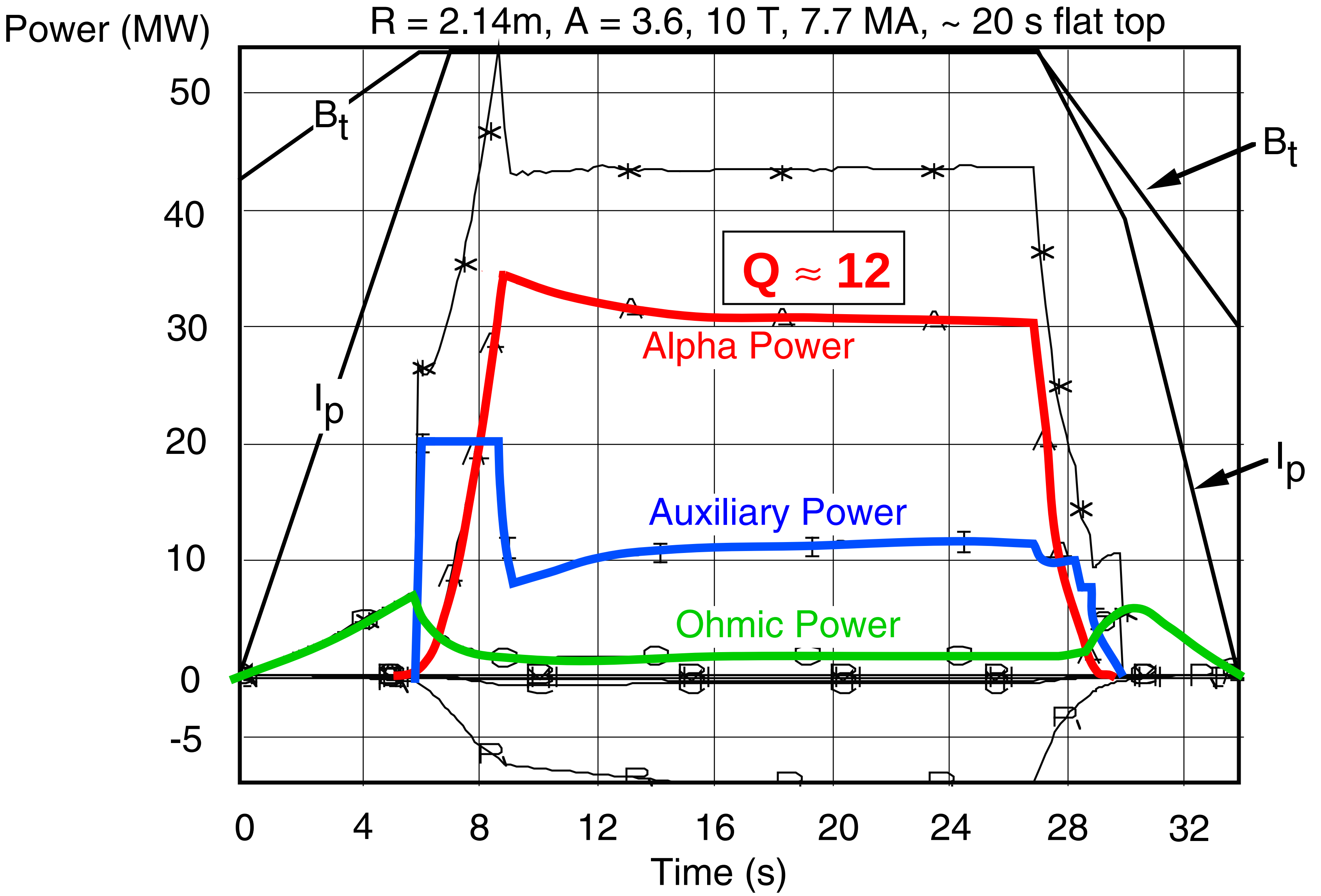








1 1/2-D Simulation of Elmy H-Mode in FIRE (TSC)

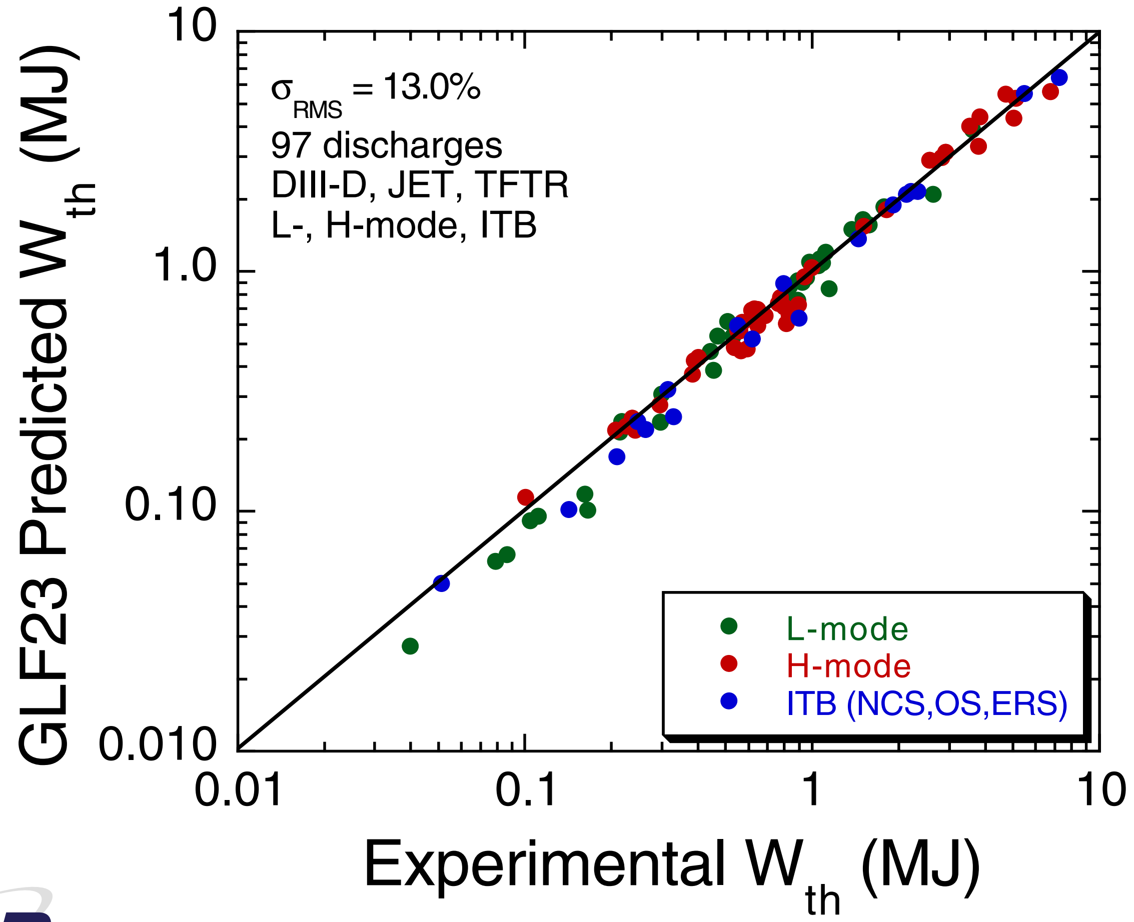


- ITER98(y,2) scaling with H(y,2) = 1.1, n(0)/<n> = 1.2, and $n/n_{GW} = 0.67$
- Burn Time ≈ 20 s ≈ 21 τ_E ≈ 4 τ_{He} ≈ 2 τ_{skin}

Q = Pfusion/(Paux + Poh)

GLF23 Transport Model With Real Geometry ExB Shear Shows Improved Agreement With L- and H-mode and ITB Profile Database

- ***Statistics computed incremental stored energy (subtracting pedestal region) using exactly same model used for ITB simulations***



* T_e , T_i , v_ϕ predicted for ITBs

Pedestal Temperature Requirements for Q=10

Device	Flat ne◆	Peaked ne*	Peaked ne w/ reversed q
IGNITOR❖	5.1	5.0	5.1
FIRE	4.1	4.0	3.4
ITER-FEAT✦	5.8	5.6	5.4

◆ flat density cases have monotonic safety factor profile

* $n_{eo} / n_{ped} = 1.5$ with n_{ped} held fixed from flat density case

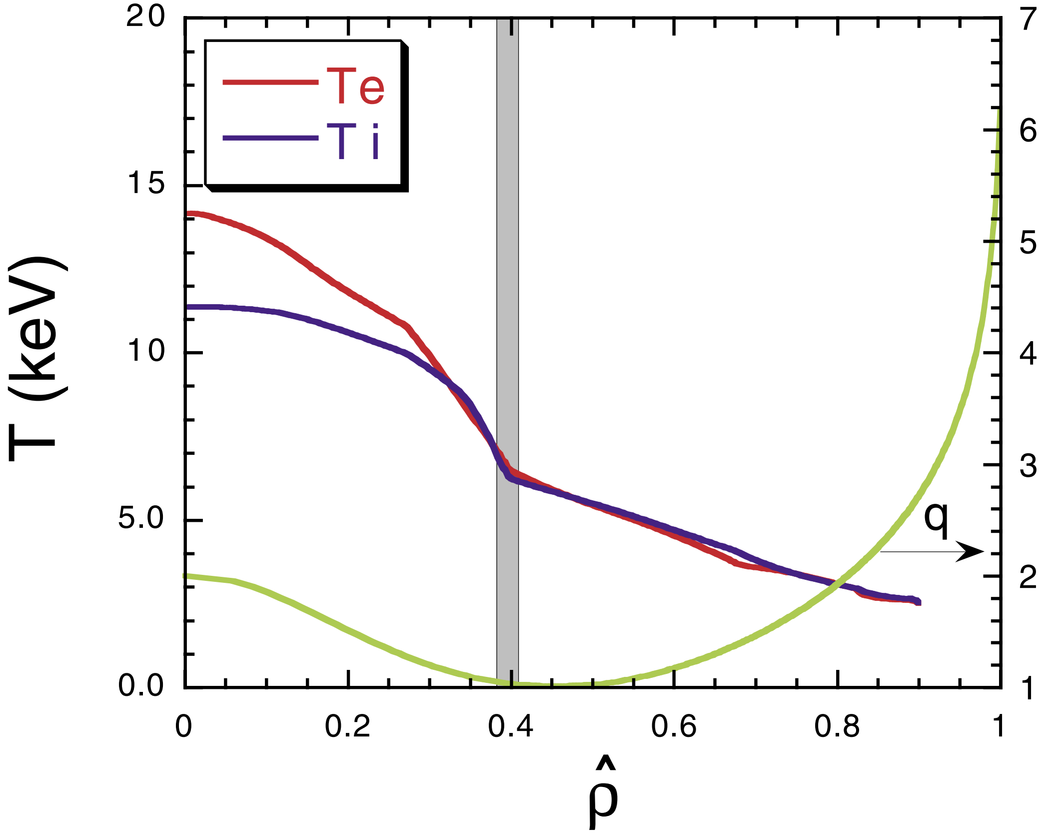
❖ 10 MW auxiliary heating

11.4 MW auxiliary heating

✦ 50 MW auxiliary heating

GLF23 Predicts an Internal Transport Barrier in FIRE as a Result of Shafranov-Shift Stabilization of the ITG Mode

- ***Barrier only forms if some density peaking is present.***
- ***Diamagnetic component of ExB shear helps after ITB is formed.***

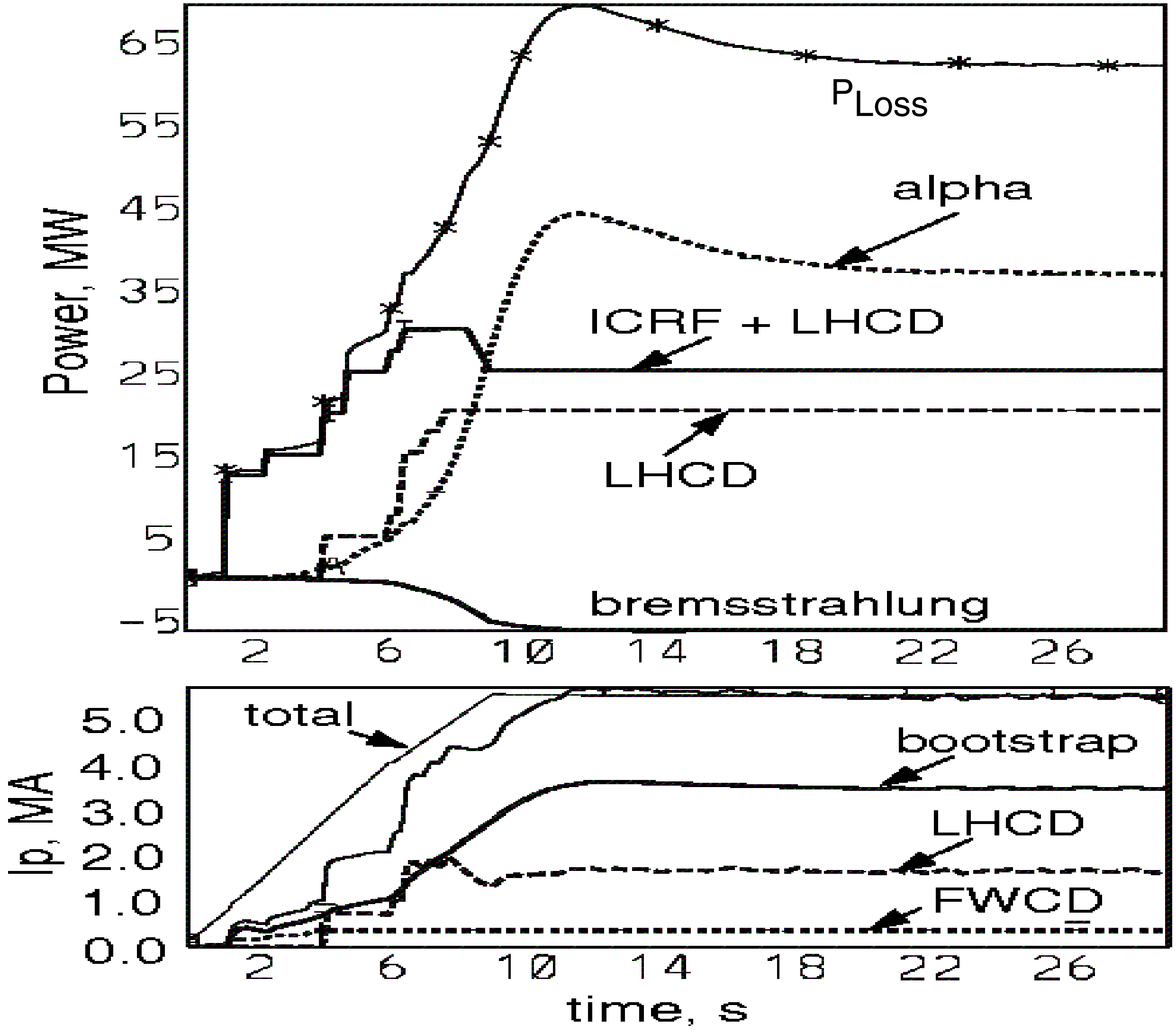


Kinsey, Waltz and Staebler
UFA BPS Workshop 2

1 1/2 D Simulation of a Burning (Self-Drive > 50%) Plasma in FIRE

- $\chi(r)$ matching exp't data, $H(y, 2) = 1.6$, other models available (eg. GLF23)
- $\beta_N = 3.0$, $f_{BS} = 64\%$, reversed shear, $q_{min} \approx 2.7$ at $r/a \approx 0.8$, 3/2,5/2 NTM stable

partial wall for n= 1



60 % self-heated

64% self-current drive

TSC -C. Kessel APS-DPP

Confinement Status and Needs Regarding FIRE

- Present confinement understanding provides a reasonable estimate of burning plasma performance. However, the desire to reduce size (cost) drives one to reduce the margin.

- A combined experimental, theoretical and simulation initiative with the goal of improving the predictions for a Next Step Experiment, such as FIRE, would serve to highlight and focus effort on this area. The VBPX.

- What capabilities are needed in a Next Step Experiment to help resolve the confinement issues critical to understanding and predicting the performance of a fusion plasma? How does one characterize the plasma boundary in terms of dimensionless or dimensional parameters

- Fusion reactors of the future would benefit from improvements such as $H \approx 1.2$, modest peaking and $n \approx n_{GW}$ as well as advanced tokamak features. The NSO should be able to explore these areas.

- The effort in preparation for the Snowmass Summer Study 2002 will energize the effort on confinement issues.