

Burning Plasma Projections Using The GLF23 Transport Model

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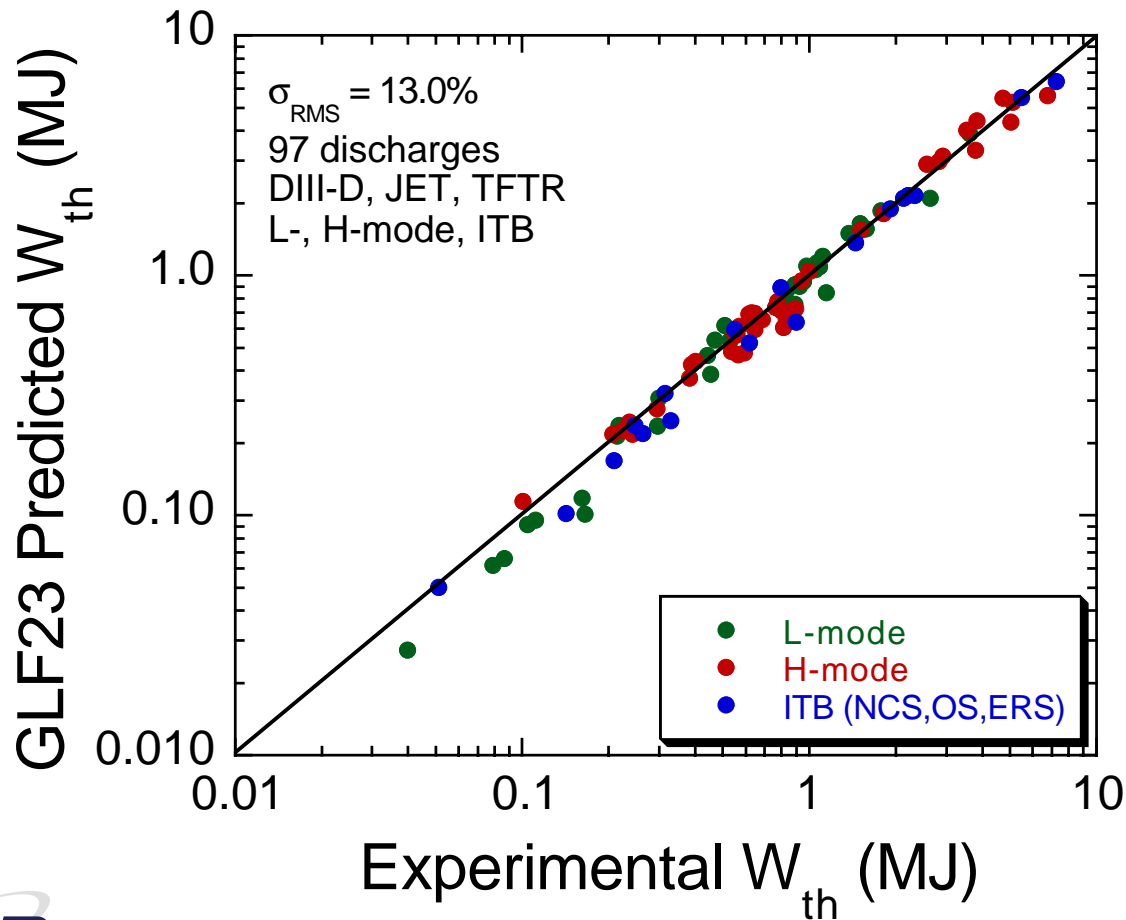
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GLF23 Transport Model With Real Geometry ExB Shear Shows Improved Agreement With L- and H-mode and ITB Profile Database

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

GLF23 Transport Modeling of C-mod

- **GLF23 model has been tested against 5 L- and H-mode C-mod discharges from the ITER Profile Database**
- **Unlike many other discharges from DIII-D, TFTR, and JET, C-mod operates at much higher densities and is RF heated**

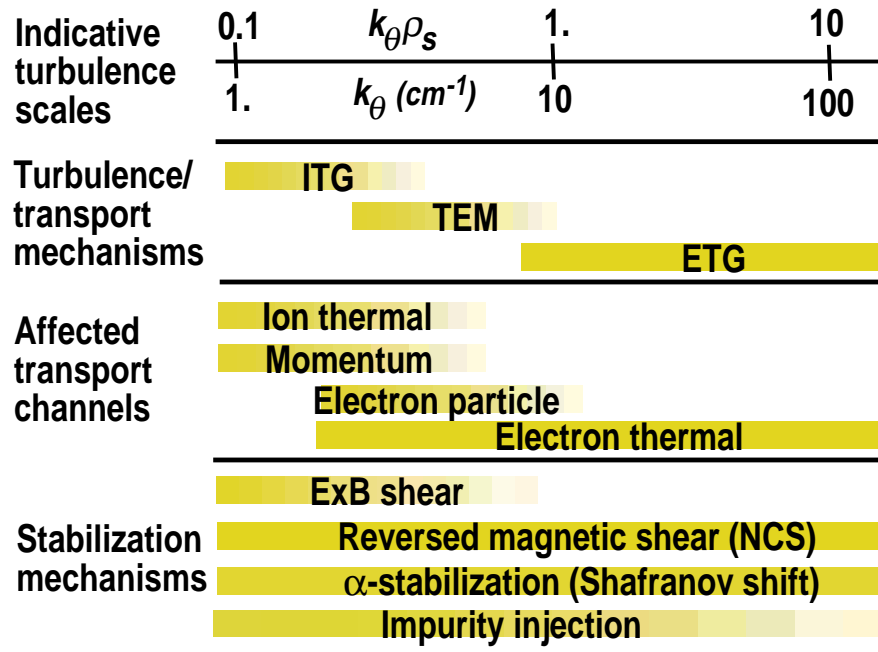
Discharge	126007	301009	116027	214017	116024
Type	L-	L-	H-	H-	H-
R (m)	0.68	0.68	0.68	0.68	0.68
a (m)	0.22	0.22	0.22	0.22	0.22
κ	1.64	1.60	1.65	1.60	1.65
δ	0.41	0.45	0.41	0.40	0.42
B_T (T)	5.24	5.33	5.22	5.21	5.21
I_P (MA)	0.80	0.82	1.02	1.04	1.03
\bar{n}_e (10^{19} m^{-3})	9.73	14.40	39.10	29.80	28.50
Z_{eff}	1.51	1.72	1.09	1.55	1.94
P_{RF} (MW)	1.04	2.56	2.46	2.26	2.11
τ_E^{th} (ms)	25.00	33.00	64.00	65.00	77.00
Diagnostic Time (s)	0.86	0.93	0.90	0.75	0.87

Turbulence Suppression Mechanisms Are Essential in Understanding ITB Formation

Two transport suppression mechanisms are known to be essential in reproducing the ITB formation in DIII-D NCS, JET OS, and TFTR ERS discharges in simulations using the GLF23 model

- ExB shear stabilization

- Shafranov shift stabilization (α -stabilization)



Predictive Modeling of Burning Plasma Devices

- **Transport simulations using GLF23 model have been carried out for various burning plasma designs**
 - **Temperature profiles predicted while computing the effects of ExB shear and alpha-stabilization**
 - **Densities, equilibrium, sources(except alpha heating), and sinks taken as inputs from analysis codes**
 - **XPTOR parallel transport code**
- **Fusion power predicted for a range of pedestal temperatures in IGNITOR, FIRE, and ITER-FEAT**
- **Impact of reversed q-profile and alpha-stabilization studied**
 - **ExB shear effects expected to be small - large toroidal field and low rotation velocities**

Burning Plasma Design Parameters

Physical Qty	IGNITOR	FIRE	ITER-FEAT
R (m)	1.33	2.13	6.20
a (m)	0.46	0.60	2.00
κ	1.80	1.80	1.78
δ	0.40	0.40	0.40
B_T (T)	13.0	10.0	5.30
I_P (MA)	12.0	7.70	15.0
\bar{n}_e (10^{20} m^{-3})	4.70	4.90	1.03
Z_{eff}	1.20	1.41	1.70
P_{Aux} (MW)	10.0	11.4	50.0
P_{Ω} (MW)	5.90	1.65	1.00
P_{Rad} (MW)	0.86	9.20	22.0
Q_{Fus} - Target	8.60	10.0	10.0

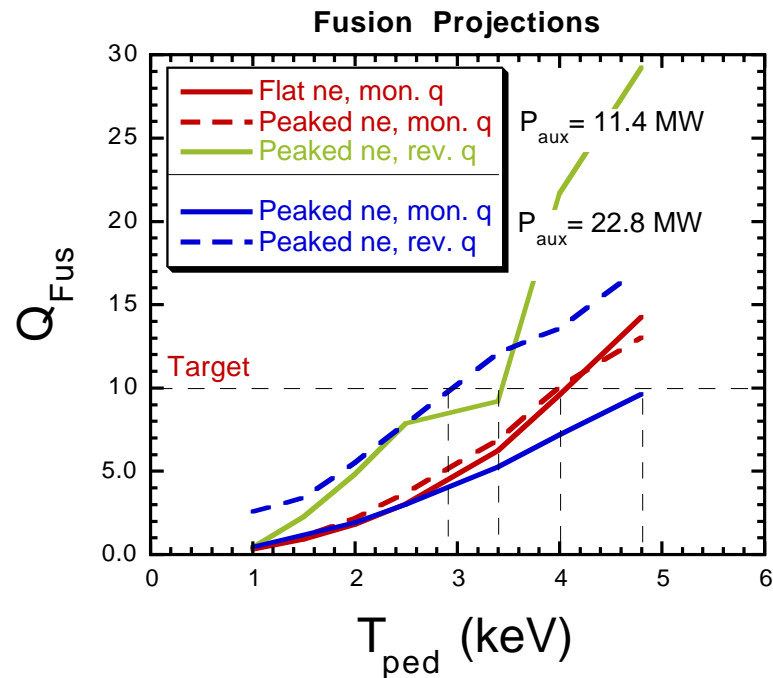
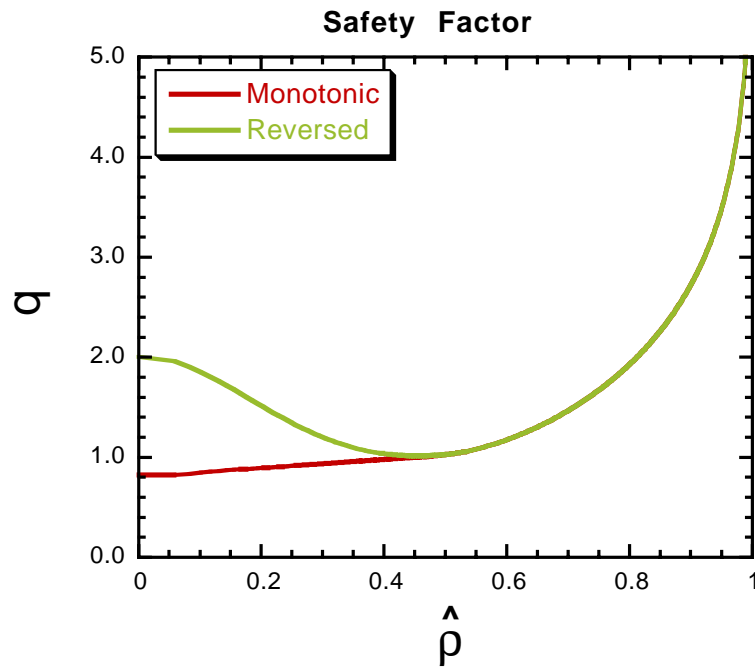
Burning Plasma Design Parameters

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Fusion Projections for FIRE

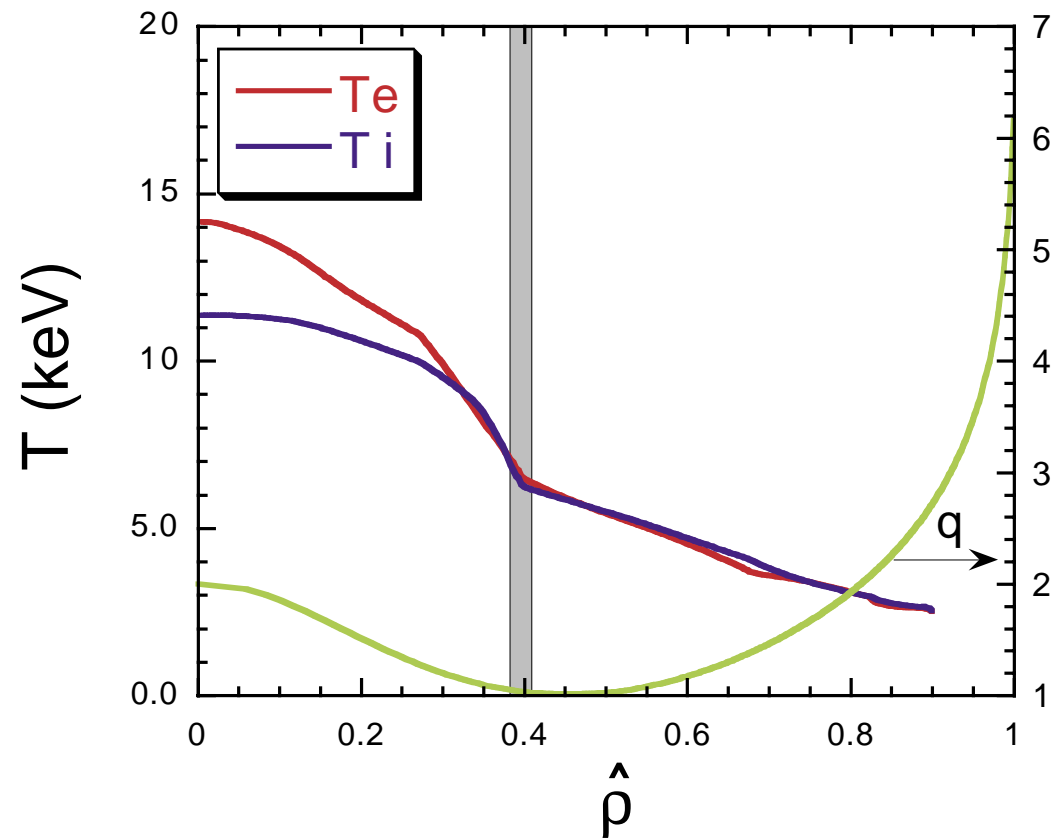
Temperature profiles predicted for monotonic and reversed q-profiles while computing the effects of ExB shear and alpha-stabilization

- $n_{ped} = 3.6 \times 10^{20} \text{ m}^{-3}$, $n_{e0}/n_{ped} = 1.5$
- **ExB shear effects small since no toroidal rotation except for peaked density, reversed shear case where ITB develops**
- **Alpha heating computed using TRANSP reaction rates**



GLF23 Predicts an ITB In FIRE as a Result of Alpha-stabilization of the ITG Mode

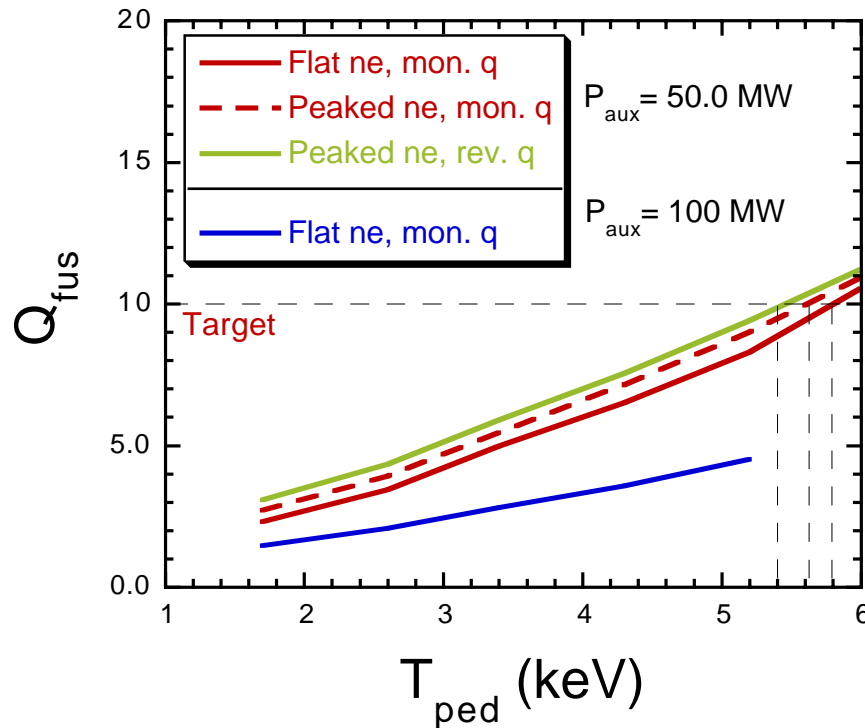
- Barrier only forms if some density peaking is present
- Diamagnetic component of $E \times B$ shear helps after ITB is formed



Fusion Projections for ITER-FEAT

■ **A pedestal temperature of 5.75 keV is needed in ITER-FEAT to attain the Q=10 target for a flat density profile**

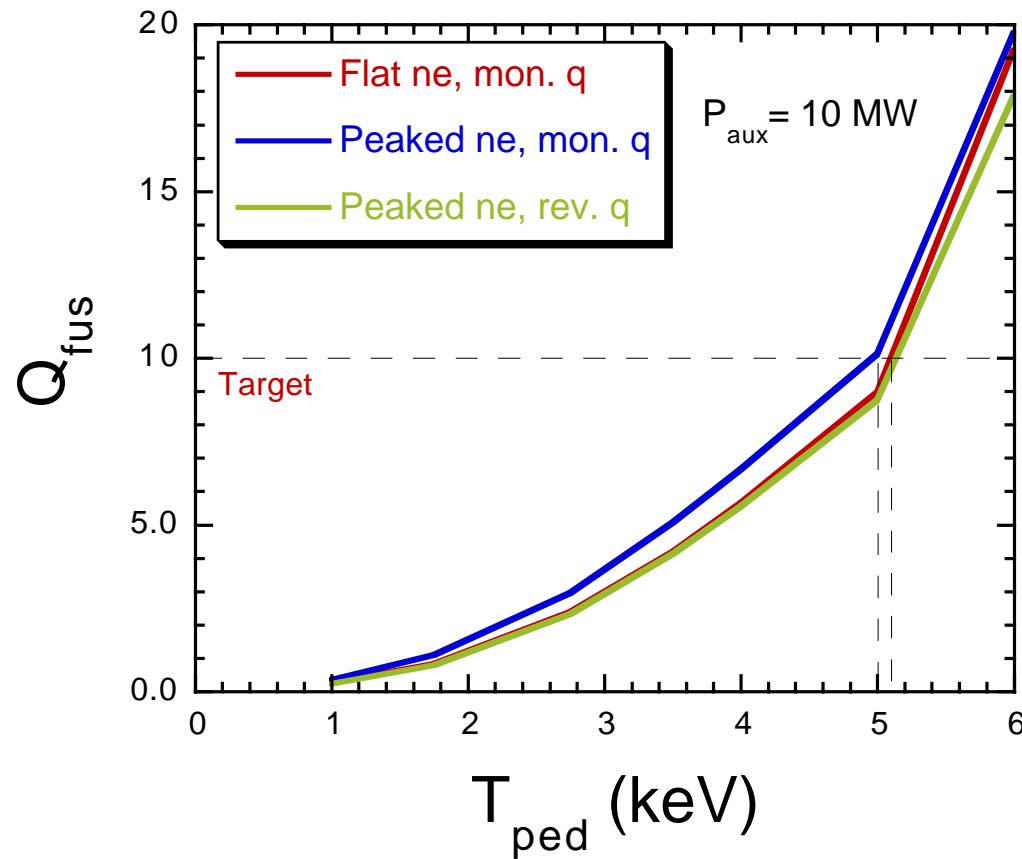
- $n_{ped} = 1.03 \times 10^{20} \text{ m}^{-3}$, $n_{e0}/n_{ped} = 1.0$
- **Some benefit from reversed magnetic shear and peaked density profile is evident w/ T_{ped} reduced to 5.4 keV for Q=10**
- **Increasing P_{NBI} from 50 to 100 MW increases fusion power, but reduces Q significantly**



Fusion Projections for IGNITOR

■ **IGNITOR requires a pedestal temperature of 5.0 keV for $Q=10$ and can attain $Q=5$ at a $T_{ped} = 3.75$ keV**

- **Base case: $n_{ped} = 4.62 \times 10^{20} \text{ m}^{-3}$, $n_{e0}/n_{ped} = 1.0$**



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

Conclusions

- **The GLF23 transport model has been tested against a large profile database including nearly a 100 L-, H-mode and ITB discharges with an RMS error of nearly 13%**
 - **Predicts temperature and toroidal velocity profiles in discharges with ITBs resulting from ExB shear and alpha-stabilization of ITG/TEM/ETG modes**
 - **Alpha-stabilization can be an important ingredient in obtaining ITBs in the electron and ion channels of reversed shear discharges**
- **The fusion power gain Q_{fus} has been predicted for a range of pedestal temperatures in IGNITOR, FIRE, and ITER-FEAT.**
- **Reversed shear and modest density peaking can lead to an ITB driven by alpha-stabilization**
 - **Required T_{ped} reduced from 4.1 to 3.4 keV in FIRE and from 5.8 to 5.4 keV for $Q_{fus}=10$ target in ITER-FEAT**
 - **ITB aided by diamagnetic component of ExB shear**
 - **Little or no benefit to confinement from reversed magnetic shear for flat density profiles cases**
 - **Fusion power for IGNITOR insensitive to moderate density peaking and reversed magnetic shear**