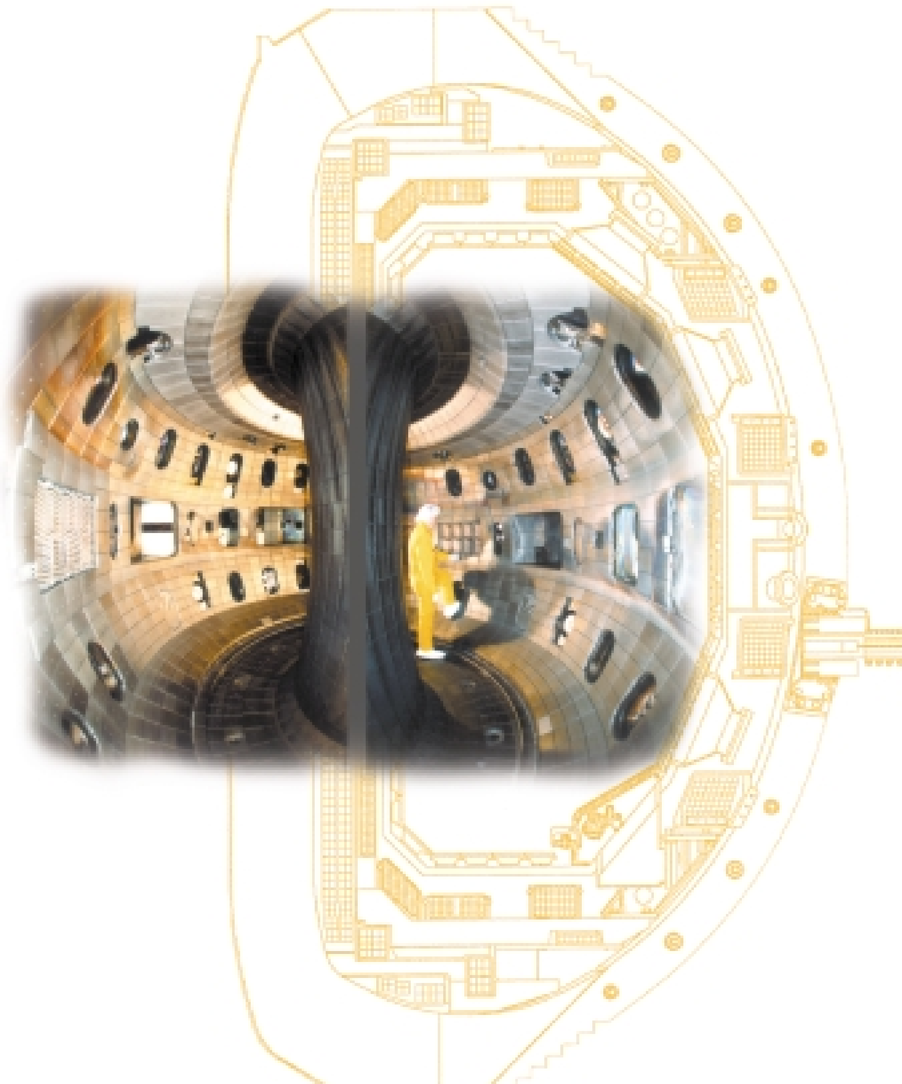

# Burning Plasma Projections Using The GLF23 Transport Model

by
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Presented at
Burning Plasma Workshop II

May 1, 2001

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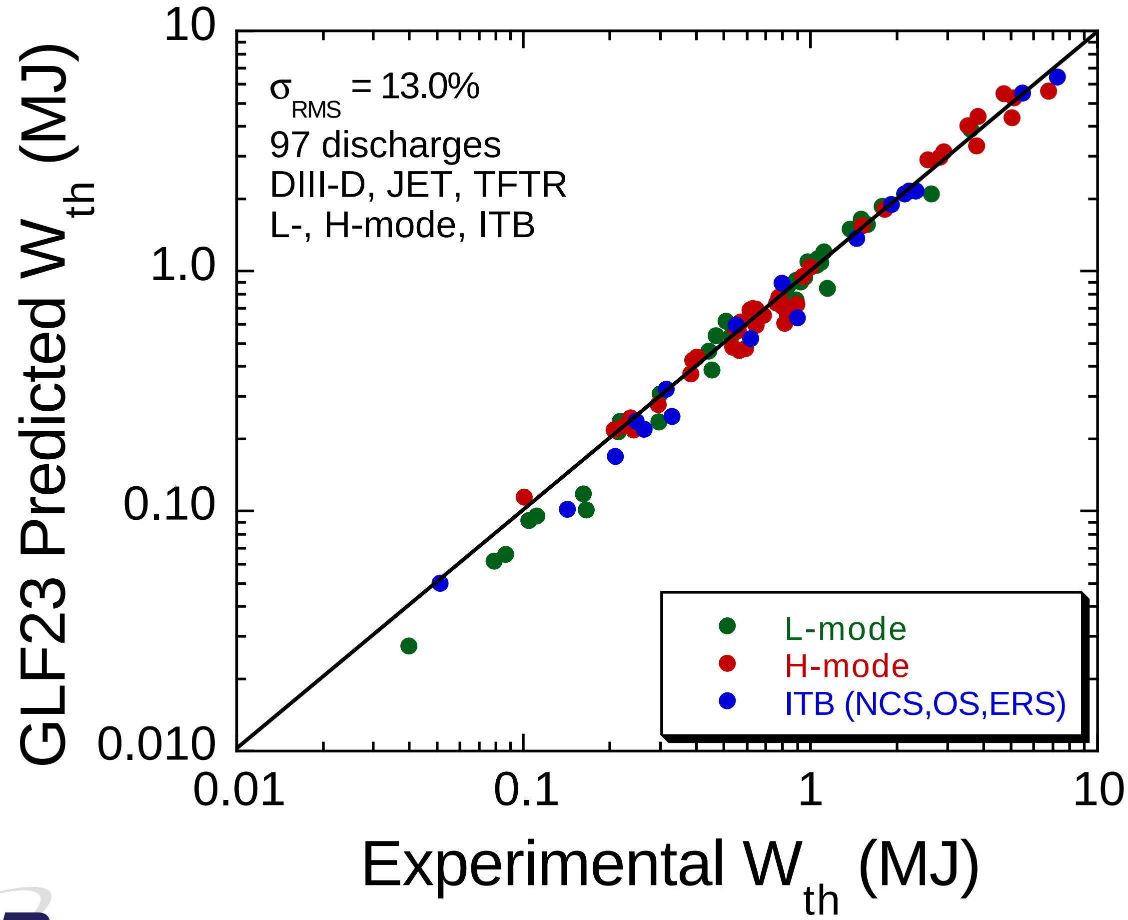
# GLF23 Transport Model With Real Geometry ExB Shear Shows Improved Agreement With L- and H-mode and ITB Profile Database

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




* $T_e$, $T_i$, $v_\phi$ predicted for ITBs

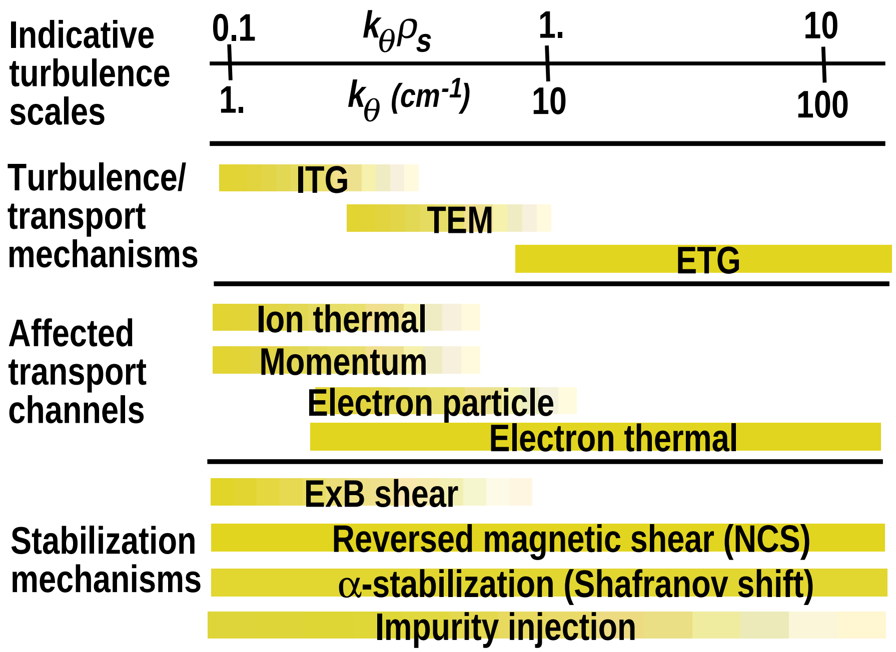
# *GLF23 Transport Modeling of C-mod*

- ***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 |
| $\kappa$ | 1.64 | 1.60 | 1.65 | 1.60 | 1.65 |
| $\delta$ | 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 |
| $\tau_E^{th}$ (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

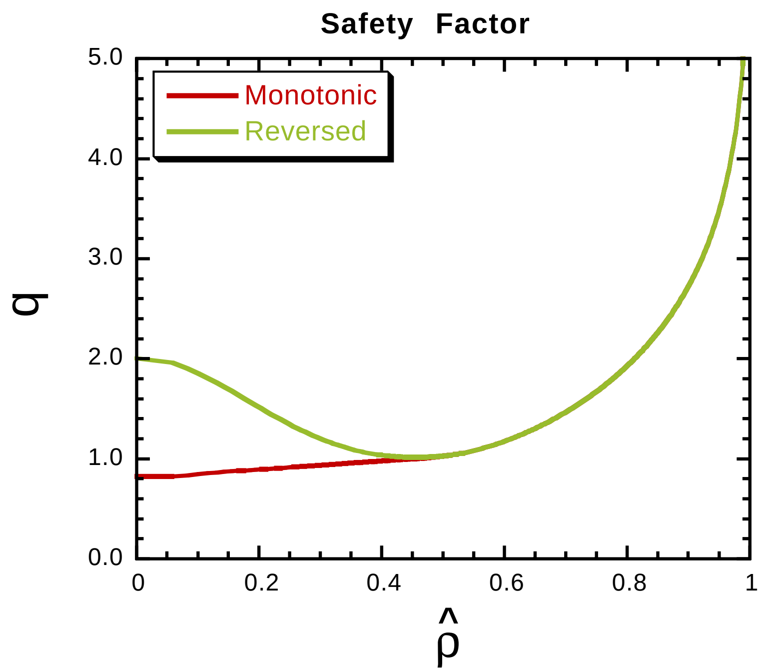
- ***Transport simulations using GLF23 model have been carried out for various burning plasma designs***
  - *Temperature profiles predicted while computing the effects of ExB shear and alpha-stabilization*
  - *Densities, equilibrium, sources(except alpha heating), and sinks taken as inputs from analysis 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*

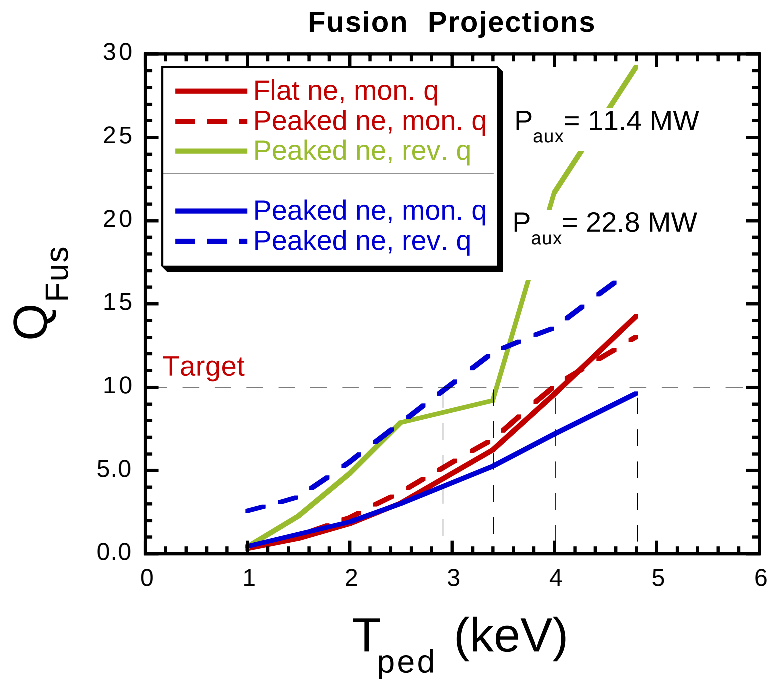
# *Burning Plasma Design Parameters*

| Physical Qty | IGNITOR | FIRE | ITER-FEAT |
|---|---|---|---|
| R (m) | 1.33 | 2.14 | 6.20 |
| a (m) | 0.46 | 0.60 | 2.00 |
| $\kappa$ | 1.80 | 1.80 | 1.78 |
| $\delta$ | 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 |
| $P_\Omega$ (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 |

# Fusion Projections for FIRE

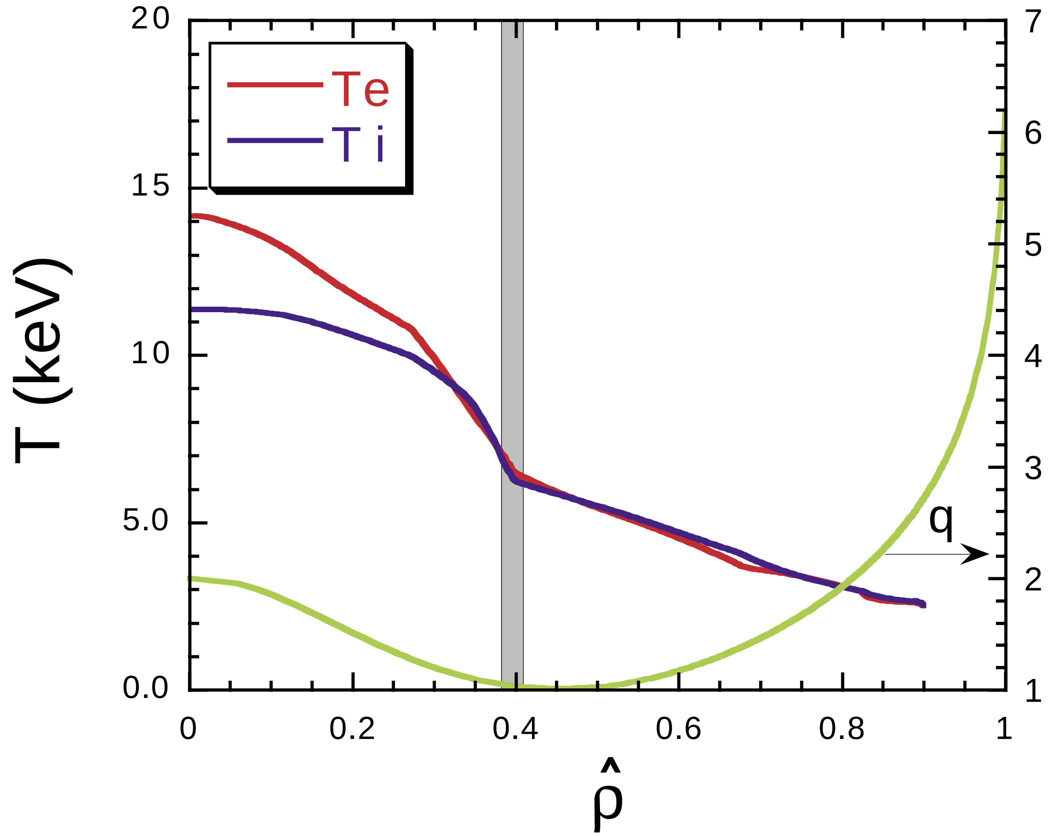
- ***Temperature profiles predicted for monotonic and reversed q-profiles while computing the effects of ExB shear and alpha-stabilization***
  - ***$n_{ped} = 3.6 \times 10^{20}\ m^{-3}$, $n_{e0}/n_{ped} = 1.5$***
  - ***ExB shear effects small since no toroidal rotation except for peaked density, reversed shear case where ITB develops***
  - ***Alpha heating computed using TRANSP reaction rates***



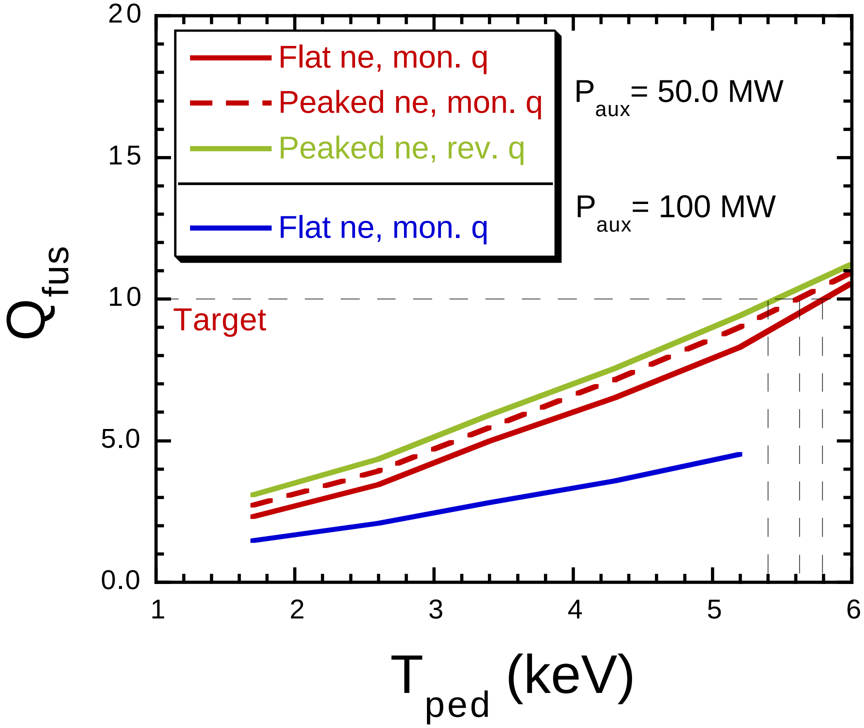
# GLF23 Predicts an ITB In FIRE as a Result of Alpha-stabilization of the ITG Mode

- Barrier only forms if some density peaking is present
- Diamagnetic component of ExB 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***
  - $n_{ped} = 1.03 \times 10^{20}\ m^{-3}$, $n_{e0}/n_{ped} = 1.0$
  - ***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***

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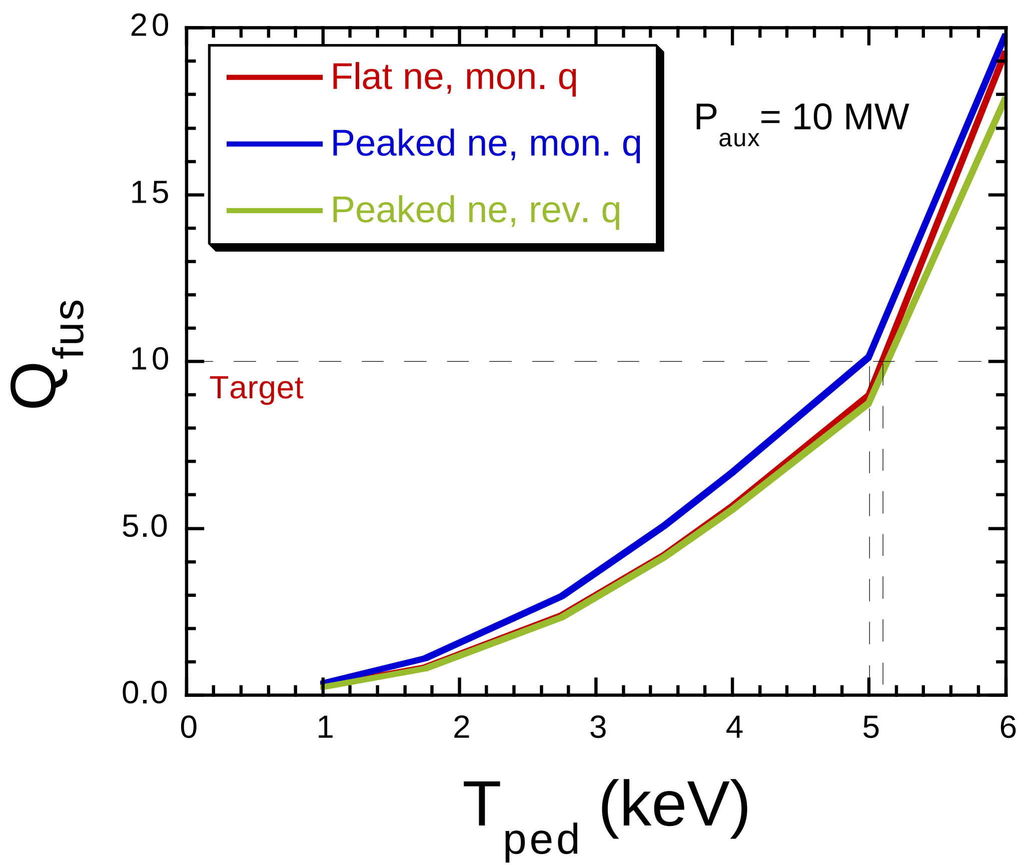
# Fusion Projections for IGNITOR

- ***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: $n_{ped}$ = 4.62x$10^{20}$ $m^{-3}$, $n_{e0}$ /$n_{ped}$ = 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

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# 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