Demonstration of ITER Operational Scenarios on DIII-D

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for

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ITER demonstration discharges support further development of operating scenarios

- Develop sample discharges for further experiments in support of ITER
- Provide a better basis for projection to ITER performance
- Identify issues requiring further study

➤ This talk will
  - describe the discharges we've developed,
  - discuss some of the ITER physics issues raised by these experiments, and
  - present projections to ITER performance

DIII-D demonstration discharges meet ITER normalized performance targets

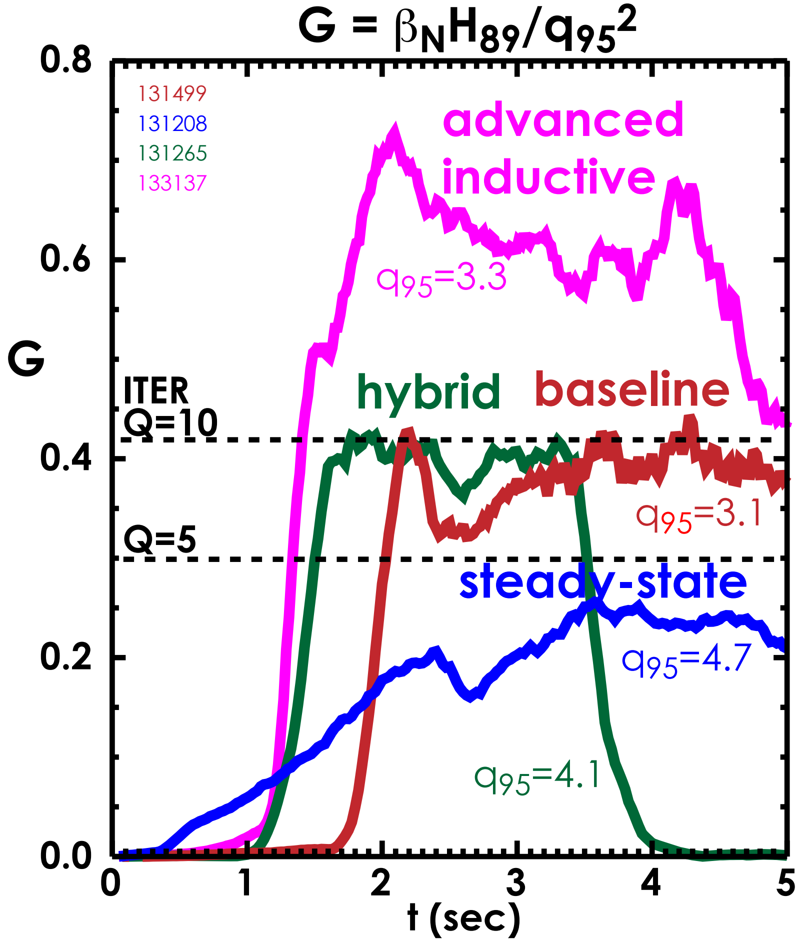
Four ITER scenarios are addressed on DIII-D:

Baseline:
conventional ELMy H-mode,
with Q=10 at I=15 MA.

Steady-state:
fully noninductive operation,
with Q~5 at I~9 MA.

Hybrid:
high neutron fluence, long pulse
at reduced current,
with Q~5-10 at I~11 MA.

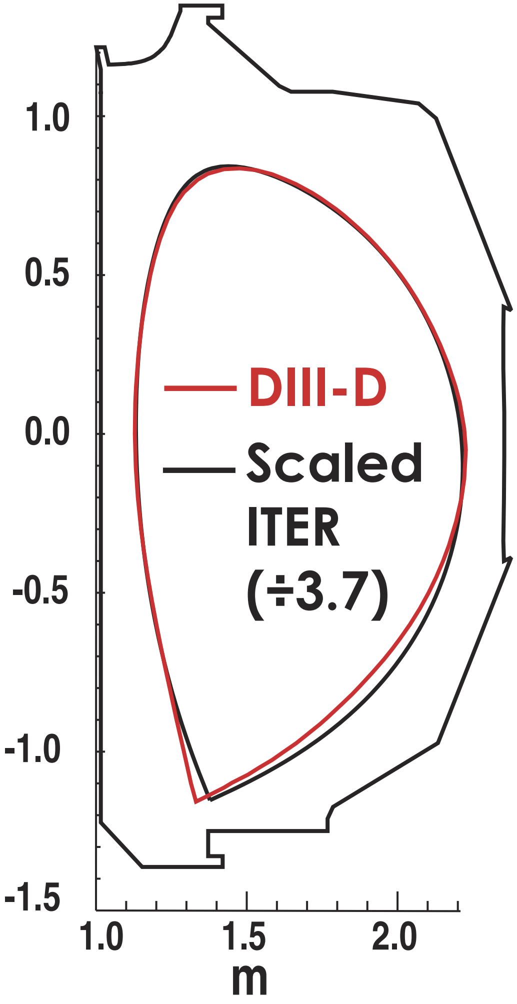
Advanced inductive:
high performance,
Q=20+, Pfus~700 MW, I=15+ MA.



$G = \beta_N H_{89}/q_{95}^2$ is a useful control room measure of expected fusion performance.

DIII-D has the unique capability to evaluate ITER scenarios while matching the design shape and aspect ratio

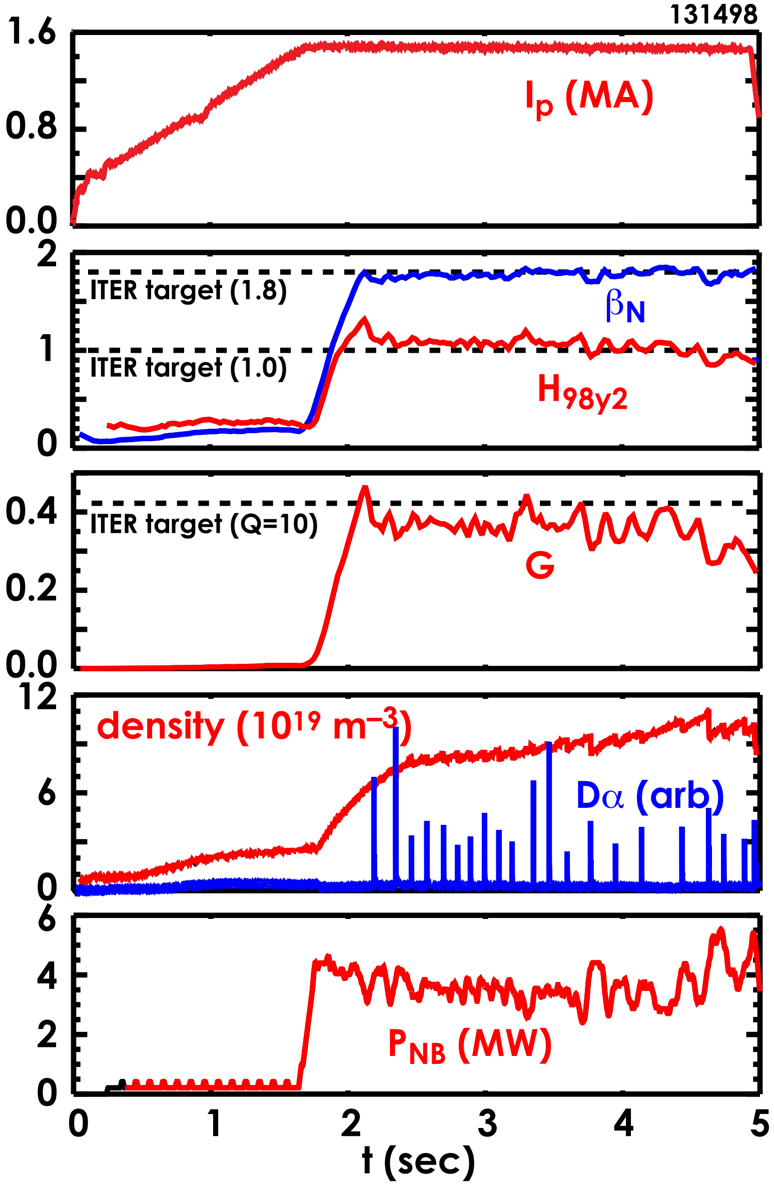
- **Reduce all ITER plasma dimensions by a factor of 3.7**
- **The DIII-D plasmas match the ITER design values for**
  - **plasma shape**
  - **aspect ratio**
  - **value of I/aB (normalized current)**
- **Target values for β_N and H_{98y2} were matched or exceeded**
  - evaluate performance in the current flat-top phase
  - co-NBI used throughout



ITER startup study: JP6.082 G. Jackson, PO3.014 T. Casper

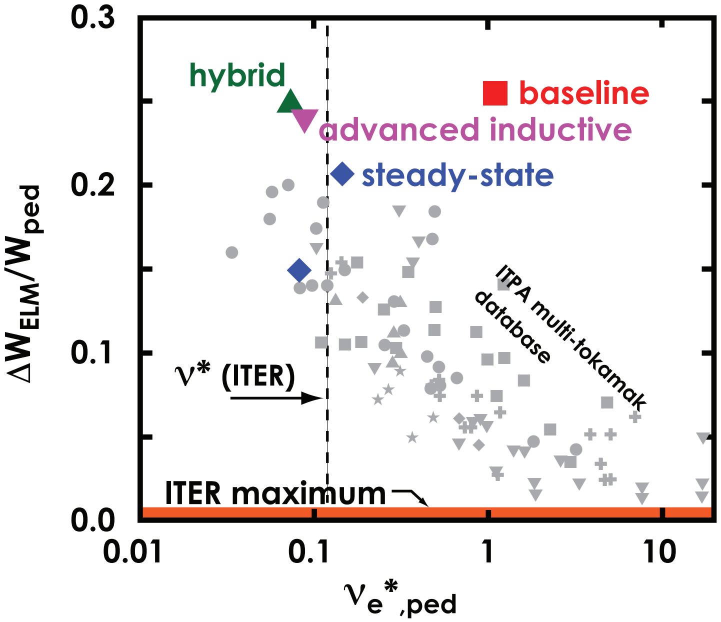
ITER baseline scenario parameters matched on DIII-D

- → I/aB equivalent to 15 MA in ITER, $q_{95} = 3.1$
- → 3 second H-mode is ~ $3\tau_R$, approximately the same as in ITER
- → Absolute density ~ same as in ITER, $n/n_{GW} \sim 0.65$ (vs. 0.85 in ITER)
- → Operation limited to $\beta_N \lesssim 2$,
  - – occasional disruptions when 2/1 tearing modes appear

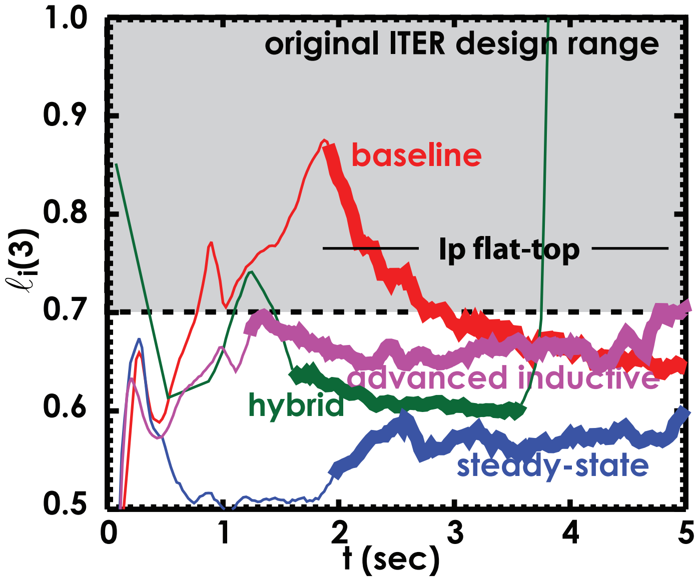


Concerns identified for the baseline scenario include ELMs and internal inductance

- **Fractional energy loss at ELMs substantially exceeds ITER limits**
  - **– type I ELMs have large radial extent**
  - **– energy loss/ELM $> 0.1\times W_{tot}$**
  - **➔ strong motivation for more work on ELM control/modification/mitigation**

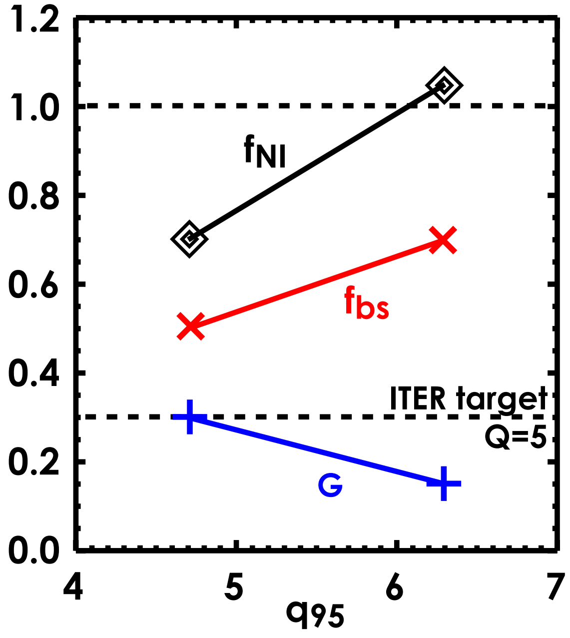


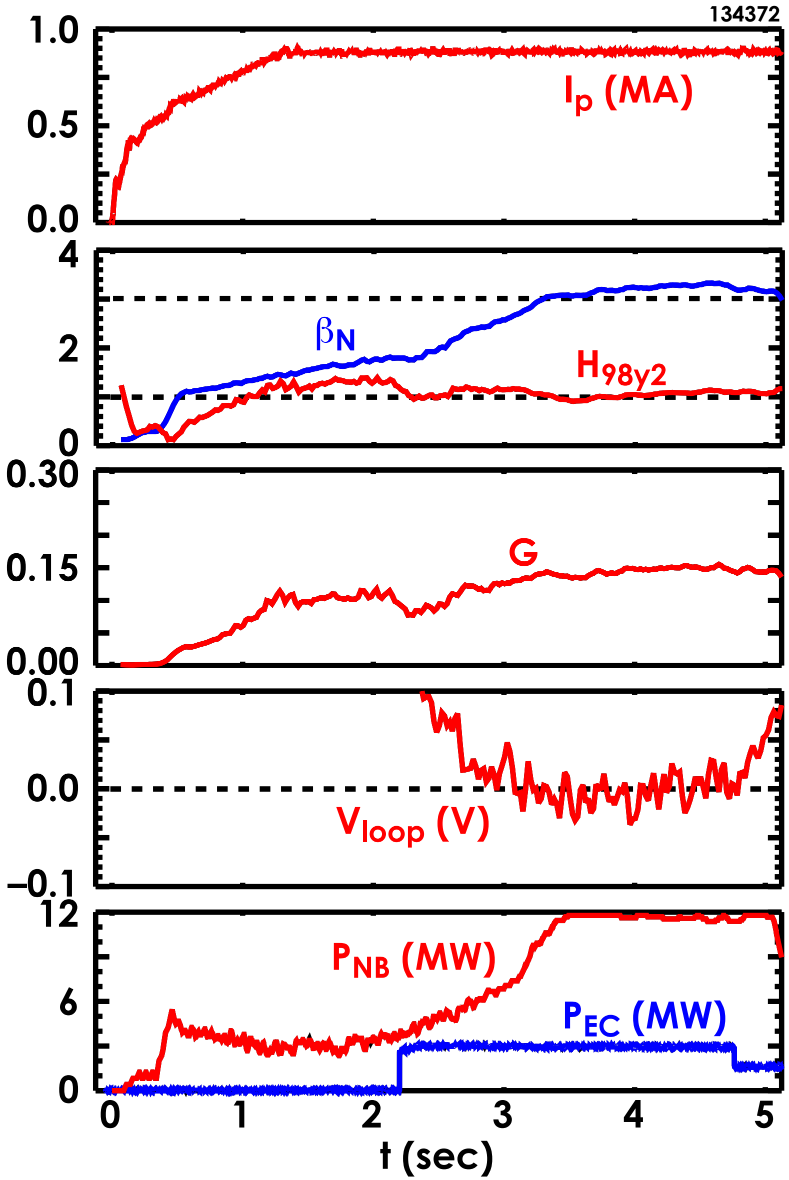
- **Internal inductance, $\ell_i(3)$, for all scenarios in DIII-D was outside original ITER range for adequate control of plasma shape and position**
  - **➔ has helped to successfully motivate change in ITER PF control range requirements**



Fully noninductive operation demonstrated in ITER shape

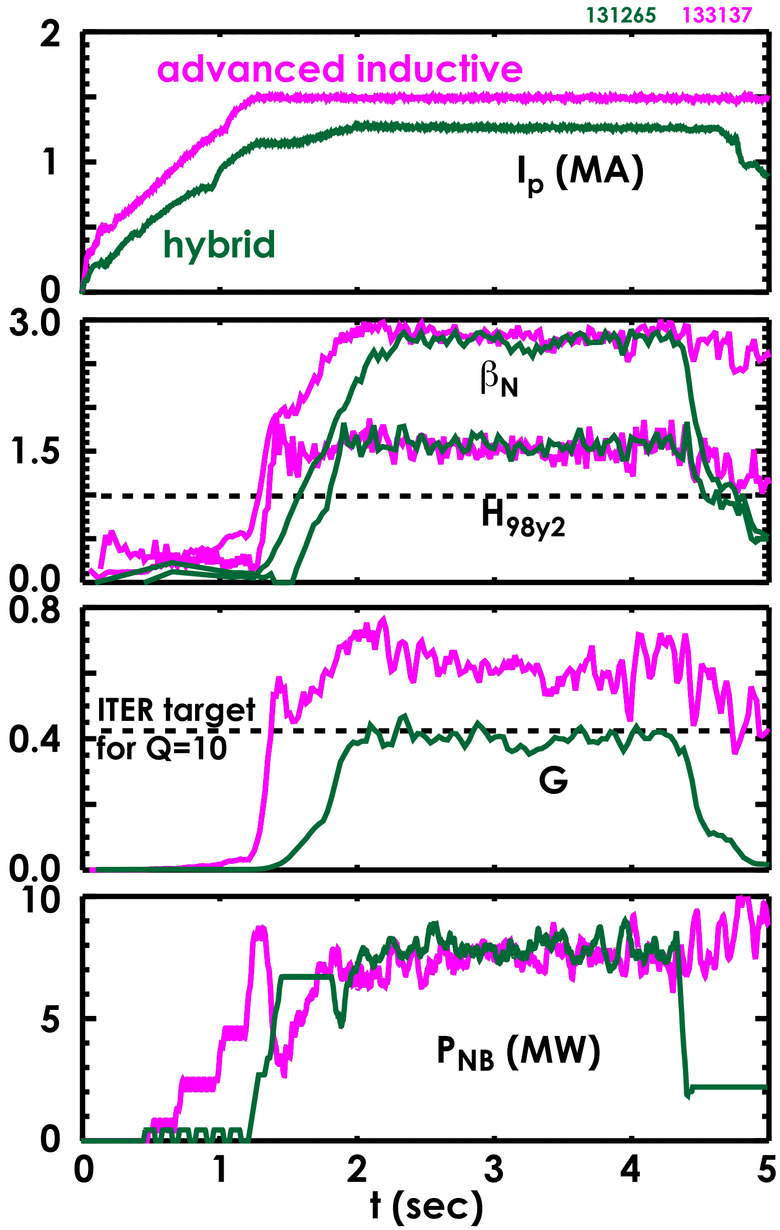
- **Fully noninductive operation achieved in 8.5 MA (ITER equivalent) discharge with β_N = 3.1 – high bootstrap fraction, ~70%**
- **Note trade-off between fusion performance (G) and noninductive fraction with varying q_{95}**





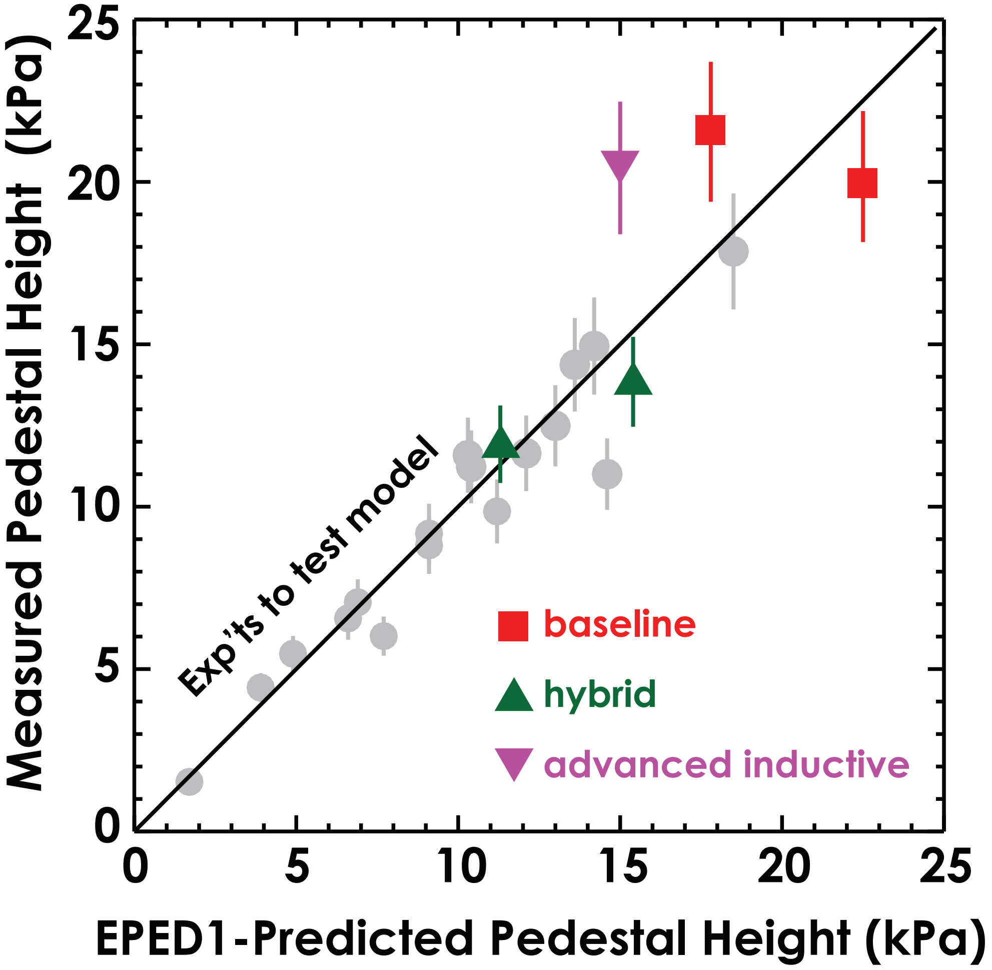
Hybrid plasmas lead to long pulse & high fluence in ITER; advanced inductive discharges provide a path to Q ≥ 20

- AI: I/aB → 14.8 MA in ITER, q_{95} = 3.3
  hybrid: I/aB → 11.6 MA, q95 = 4.1
- Both hybrid and advanced inductive scenario plasmas have sustained high performance (β_N = 2.8) with excellent confinement (H_{98y2} = 1.5)
- Some issues to be addressed:
  - requirements and methods for access to these regimes in ITER,
  - performance with conditions more relevant to ITER
    (rotation, collisionality, divertor parameters, …)
  - ELM mitigation



A good fit to pedestal parameters in the ITER scenarios is obtained from a new predictive model

- Compare the ITER scenario pedestal heights with the EPED1 predictive model → very good fit.
- For ITER parameters, in the baseline scenario EPED1 gives $\beta_{N,ped} = 0.65$ at $\rho = 0.96$.



EPED1 model: NI1.001 P. Snyder

Performance projections indicate ITER will meet its physics and technology objectives, with a good margin

- **Project using various confinement scalings:**
  - **ITER 89P** (Bohm-like)
  - **IPB 98y2** (intermediate)
  - **DS03** (gyroBohm-like)
- **Use the same β_N, H, and profiles as in DIII-D; reset $n/n_{GW} = 0.85$; assume $T_i = T_e$**
- **Solve for required P_{aux} (or H if ignited), P_{fus} and Q**

	Base-line	Hybrid	AI	Steady-state
P_{fus}(ITER)	**400**	**400**	**700**	**350**
β_N	**1.8**	**2.8**	**2.8**	**3.1**
Q				
ITER	**10**	**5**	**≥20**	**5**
89P	**10.3**	**5.8^***	**13.5**	**2.7^***
98y2	**22.4^+**	**23.3**	**∞**	**5.8^***
DS03	**∞^+**	**∞^+**	**∞**	**19.8**

* P_{aux}(required) > P_{aux}(ITER) = 73 MW

$^+$ $P_{conduction} < P_{L\text{-}H}$ (Y. Martin)

– all scaled cases yield P_{fusion} ≥ ITER scenario value

Summary: DIII-D has demonstrated the performance required to meet ITER goals for four key scenarios

- **The DIII-D ITER Demonstration discharge study addresses many of the key ITER physics issues,**
  - **ELMs, L-H transition, pedestal scaling, beta limits, …**

- **DIII-D results have influenced the ITER design,**
  - **expanding the operating range of the plasma shape control system**

- **DIII-D evaluation of ITER scenarios should be extended and improved**
  - **vary NBI power and torque to operate with reduced plasma rotation**
  - **extend operation with $T_e = T_i$**
  - **determine sensitivity of performance to shape**
  - **assess impact of ELM suppression**
  - **include startup and rampdown constraints in demonstration discharges**

➜ For more detail on this topic,
visit Edward Doyle’s poster (JP6.061) this afternoon