ITER FEAT Operation

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The technical requirements for the new ITER (ITER-FEAT)

1) Demonstrate inductively-driven plasmas at Q10,
2) Aim at demonstrating steady-state at Q5
3) Do not preclude ignition.
4) Demonstrate availability and integration of essential fusion technologies, and
5) Test components for a future reactor including blankets (> 0.5 MW/m^2, > 0.3 MW·a /m^2.)

ITER is planned to be the first fusion experimental reactor.

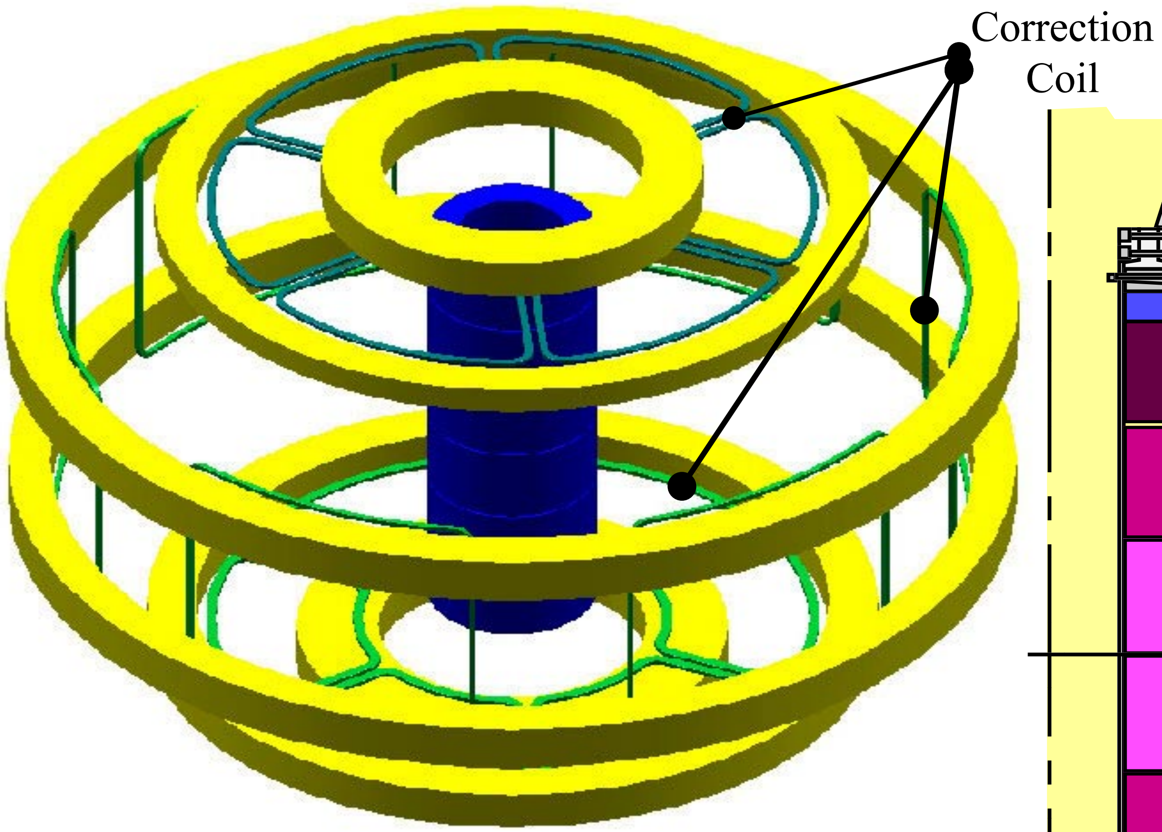
- Flexibility is required to
  1) cope with uncertainties,
  2) study/optimize burning plasma for various objectives, and
  3) introduce advanced features
- Involvement of the world-wide fusion community is essential to
  1) use ITER efficiently and
  2) promote scientific competition among the Parties

ITER Machine Capability

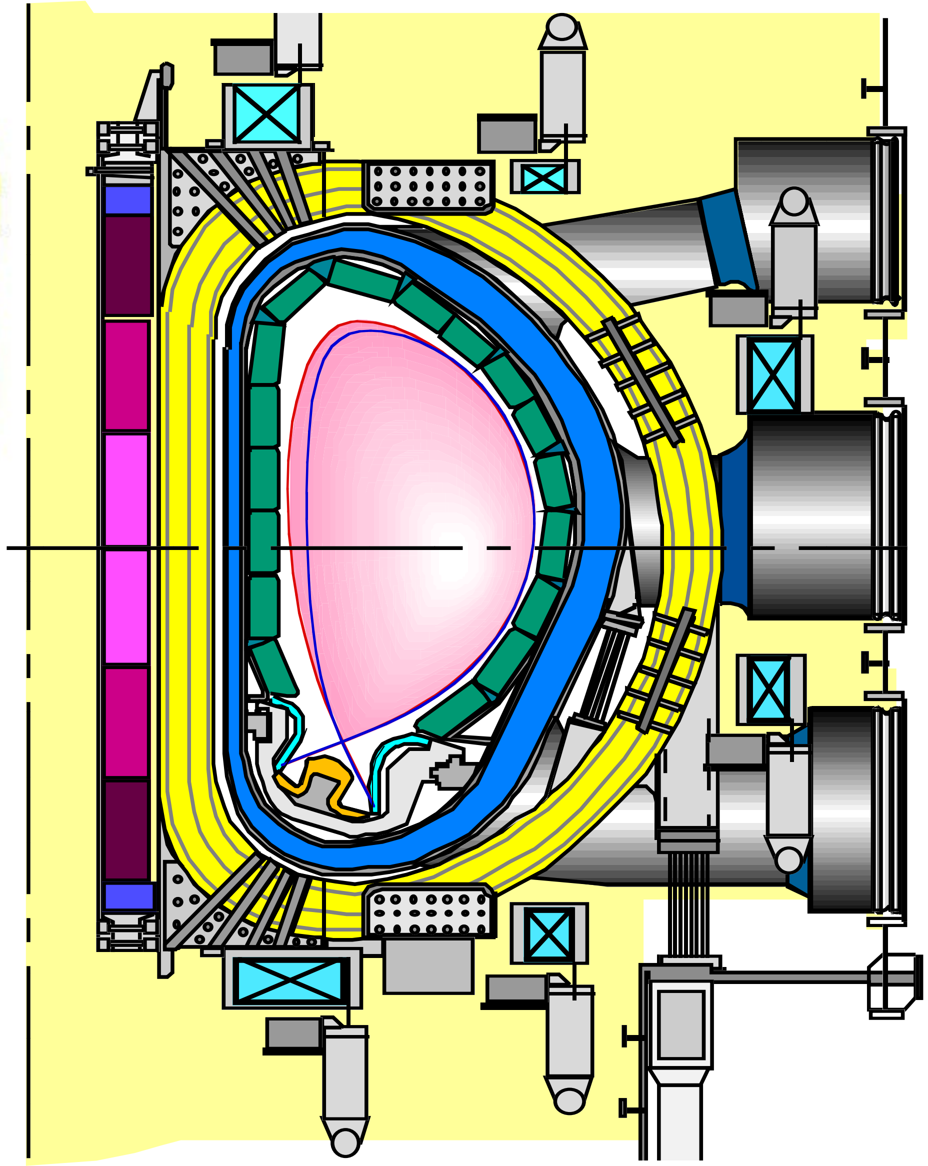
	Reference Performance	Flexibility
I_P (MA)	15 (flat top 400-500 s)	17 (flat top 100-200 s)
Fusion Power (MW)	500 (~2000s)	700 (100-200s)
κ_x/δ_x	1.85/0.49	2.0/0.55(a=1.85m)
Pumping	200 Pam^3/s	higher in shorter pulse

	Initial	Possible Upgrade	
NB (MW)	33	50	33
RF (MW)	40	80	100
ECCD for NT (MW)	(20)	(40)	
Saddle coils for RWM	20KA/10G/2Hz	~50KA	

Divertor/Blanket	Exchangeable concept	

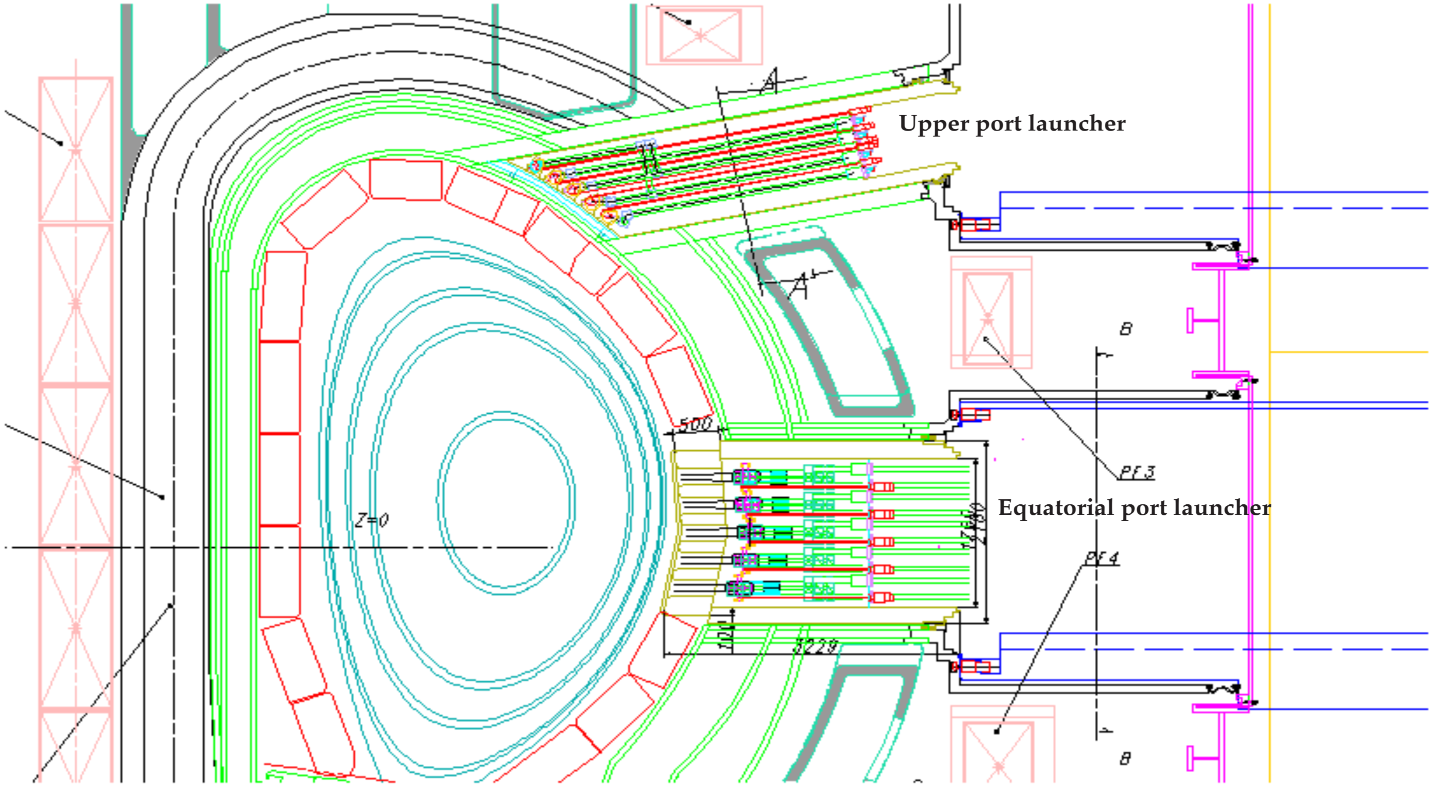


ITER Poloidal Field Coils



Correction Coils
6x3, 100-150kA/coil
For Resistive Wall Mode
~10G/20kA

Electron Cyclotron System



Overview of EC-launcher

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Upper launcher : poloidal steering = - 60 ~ -70°

toroidal angle = 24°

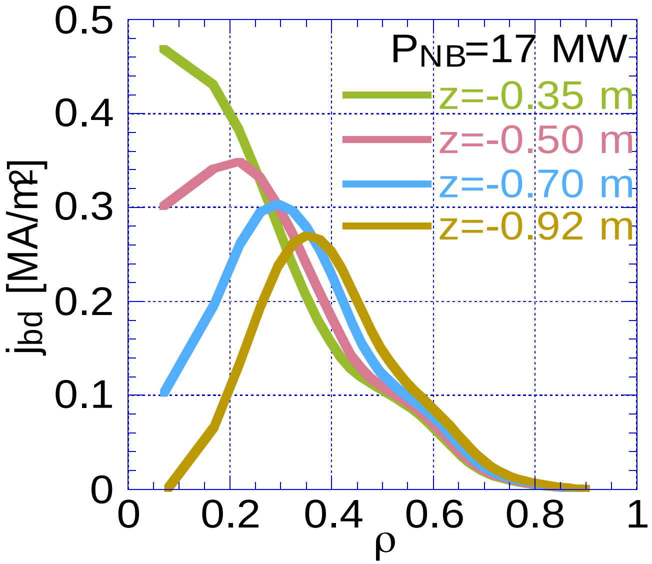
Equatorial launcher: toroidal steering = 20 - 45°

Equatorial port : standardized port plug for IC/EC/LH

Neutral Beam Injection for ITER

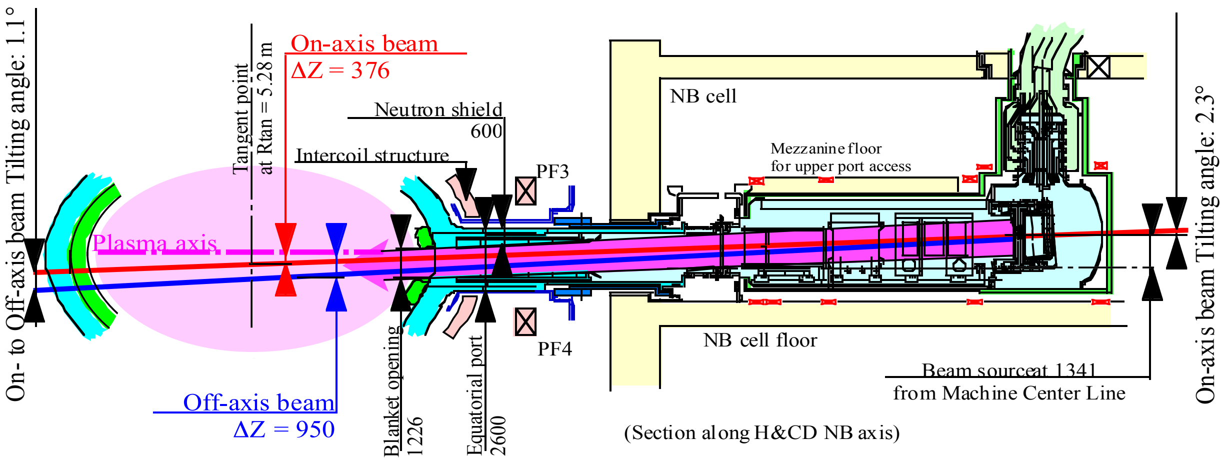
(1 MeV, 16.5 MW/Port)
Initial Installation 33 MW, Upgrade 50 MW

Beam Driven Current Profile



$\gamma \approx 0.4 \times 10^{20}$ A/Wm^2

NB Elevation Layout



Phased Operations

Hydrogen Phase

Confirmation of the machine performance and increase of reliability of the operation

- Full commissioning of the ITER system in a non-nuclear environment
- Development of operation scenarios with semi-detached divertor and ~70 MW
- Better control/mitigation of disruptions/VDEs/ELMs/runaway electrons
- Characterization of dusts
- Build-up of experimental groups in the world wide fusion community

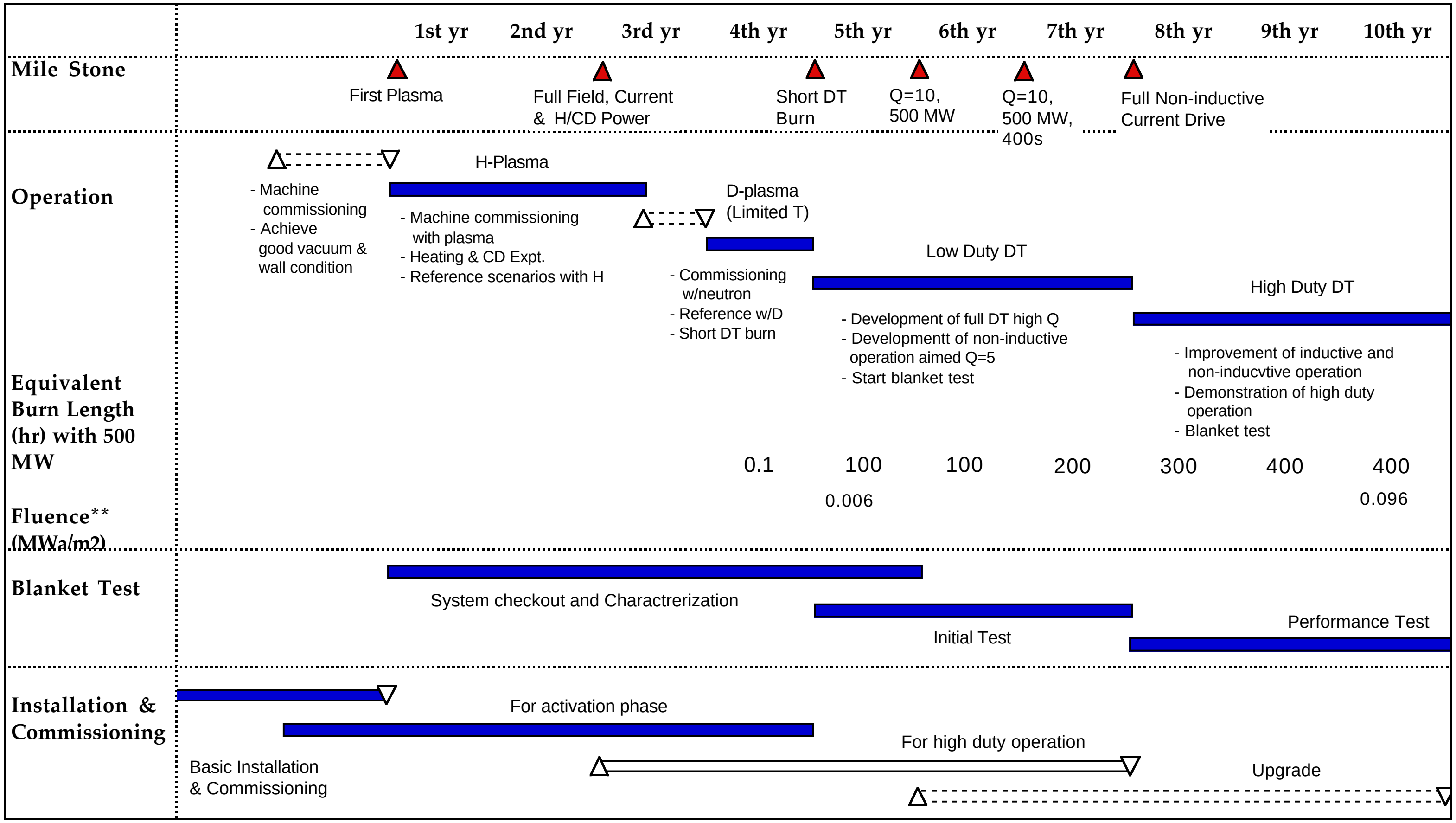
Deuterium Phase

Nuclear commissioning and confirmation of the basic plasma characteristics

- No human access into the vessel

Deuterium Tritium Phase

- Research of long burning plasmas
- Optimization of operations for various objectives
- Engineering tests including blanket tests for the next step



*Average Fluence at First Wall (Neutron wall load is 0.56 MW/m2 in average and 0.77MW/m2 at outboard midplane.)

Net consumption of tritium

The first ten years ~ 5kg

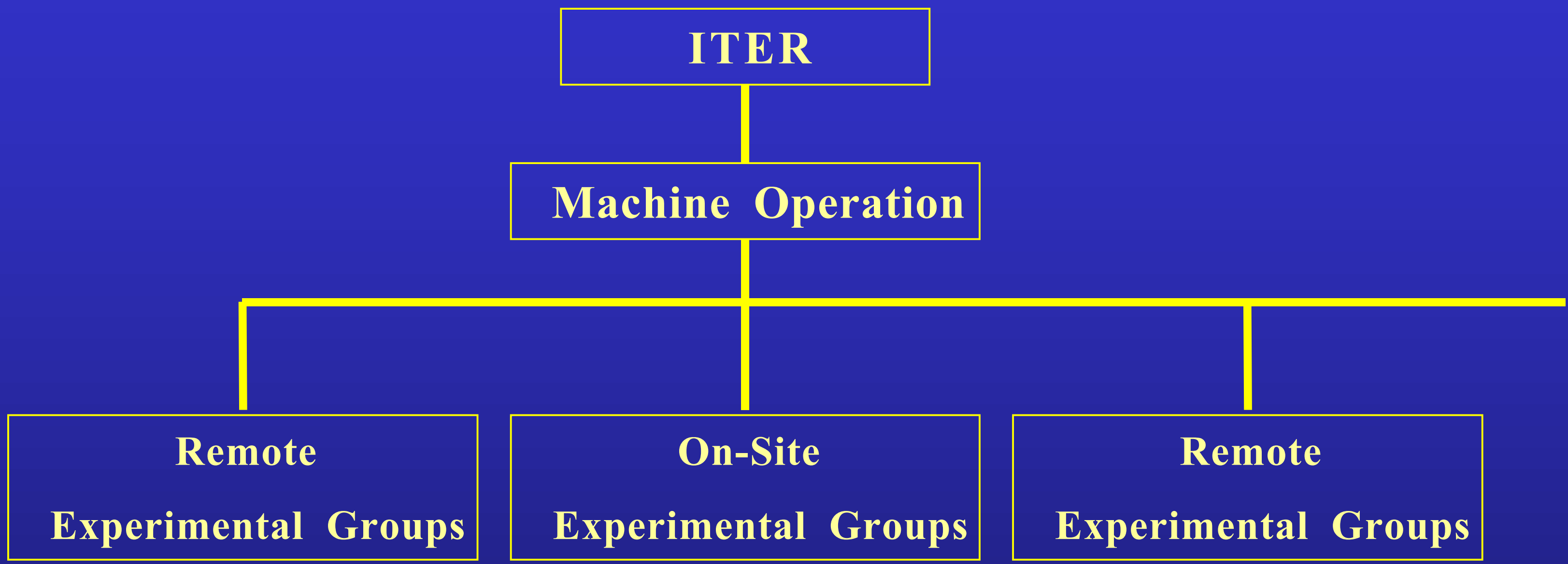
Average 0.3/Blanket test area 0.4 MWa/m^2 ~ 15 kg (Minimum requirement)

Average 0.5/ Blanket test area 0.7 MWa/m^2 ~ 25 kg (Design value)

~30kg of tritium could be supplied with external sources

Remote Experiment

Efficient use of ITER, Involvement of worldwide fusion community and Promotion of Scientific Competition

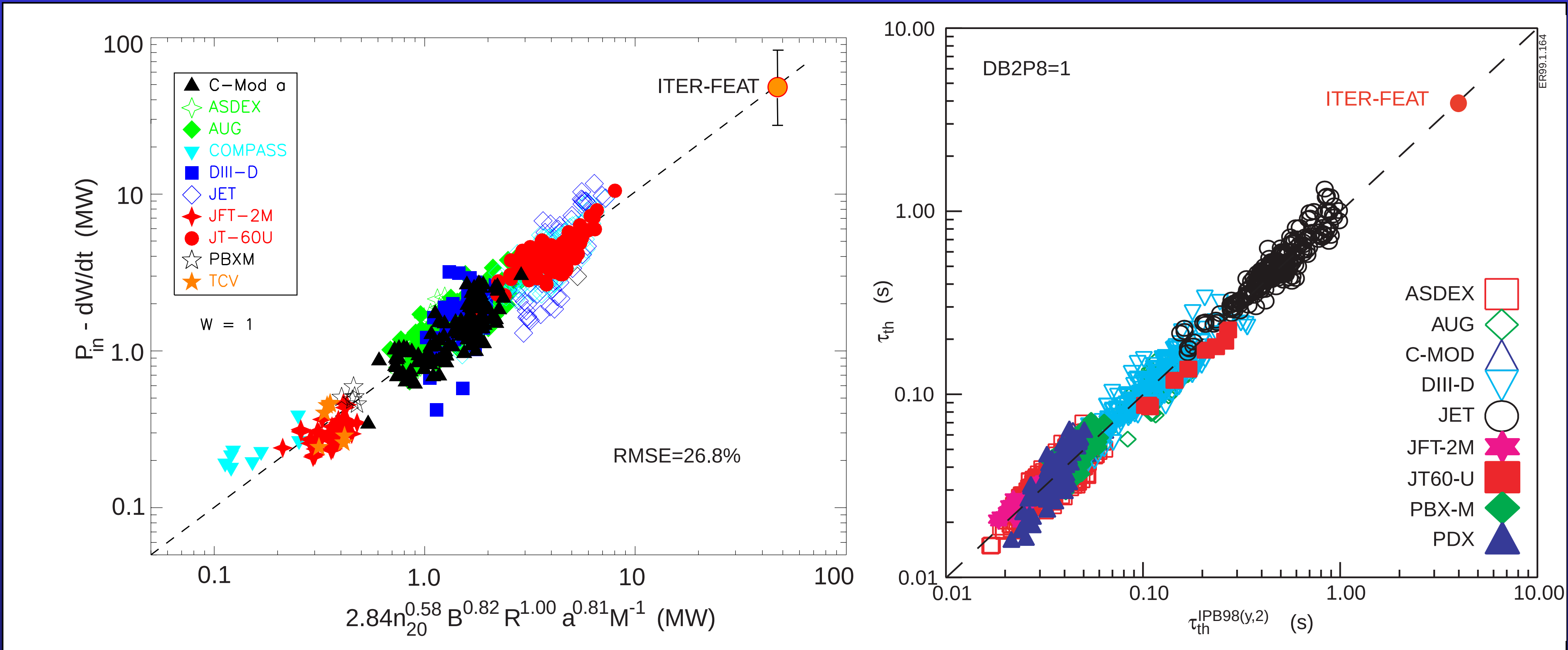


Example:

- 3 shift/day on site: Most people during day(1st/2nd shifts) for experimentation. Less people during night shift for machine monitoring and support of remote experiments.
- 1 or 2 shift(s)/day on remote experimental sites: Experimentation during day

In any case,experimentation will be done within the envelope of the machine parameters agreed to inadvance.

Standard Operations ELMy H- mode

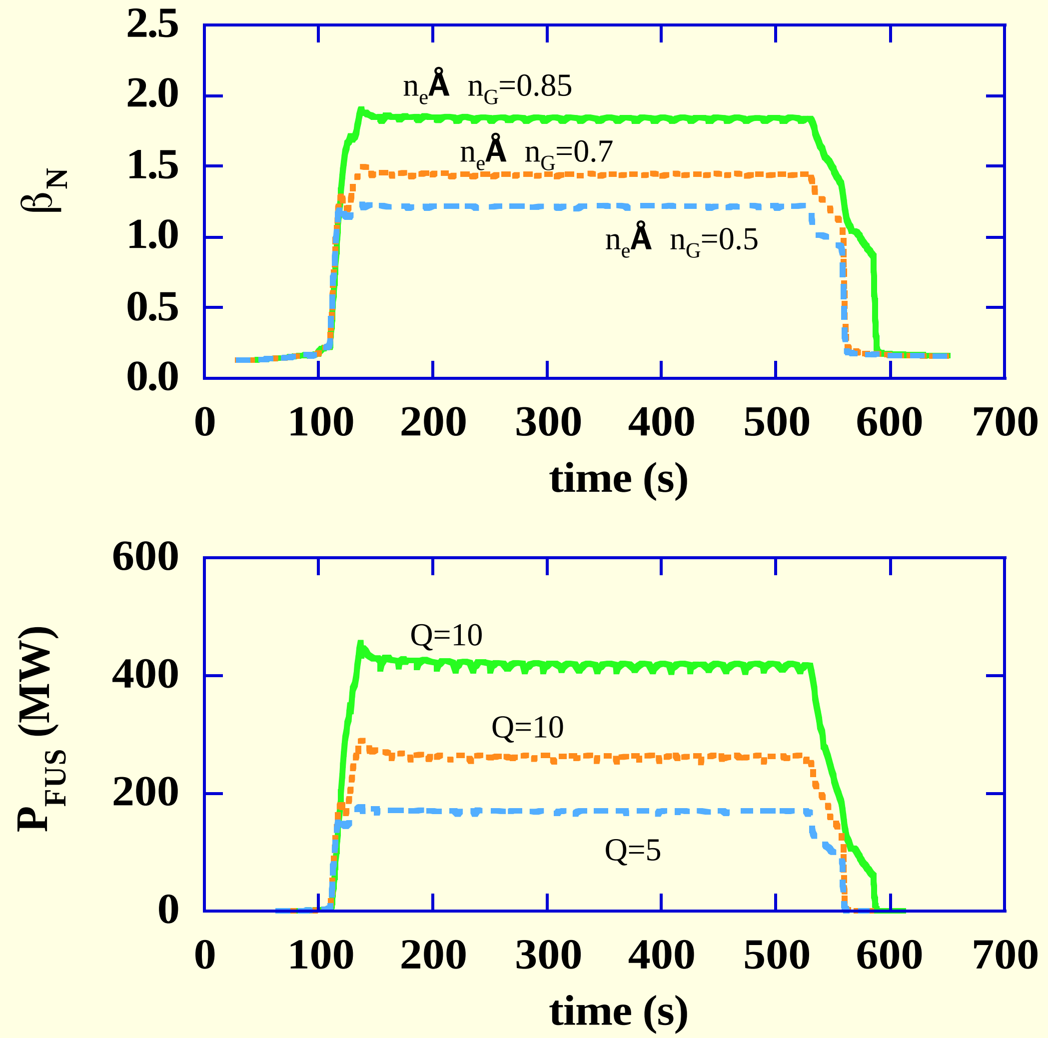


$$P_{LH} = 2.84M^{-1}B_T^{0.82}\overline{n}_e^{0.58}R^{1.00}a^{0.81}$$

$$\tau_{E,th}^{IPB98(y,2)} = 0.144I_p^{0.93}B_T^{0.15}P^{-0.69}n_e^{0.41}M^{0.19}R^{1.97}\varepsilon^{0.58}\kappa_a^{0.78}, \quad \tau_E = H_H\tau_{E,th}^{IPB98(y,2)}$$

(s, MA, T, MW, 10^{20}m^{-3}, AMU, m and $\kappa_a = S_x / \pi a^2$)

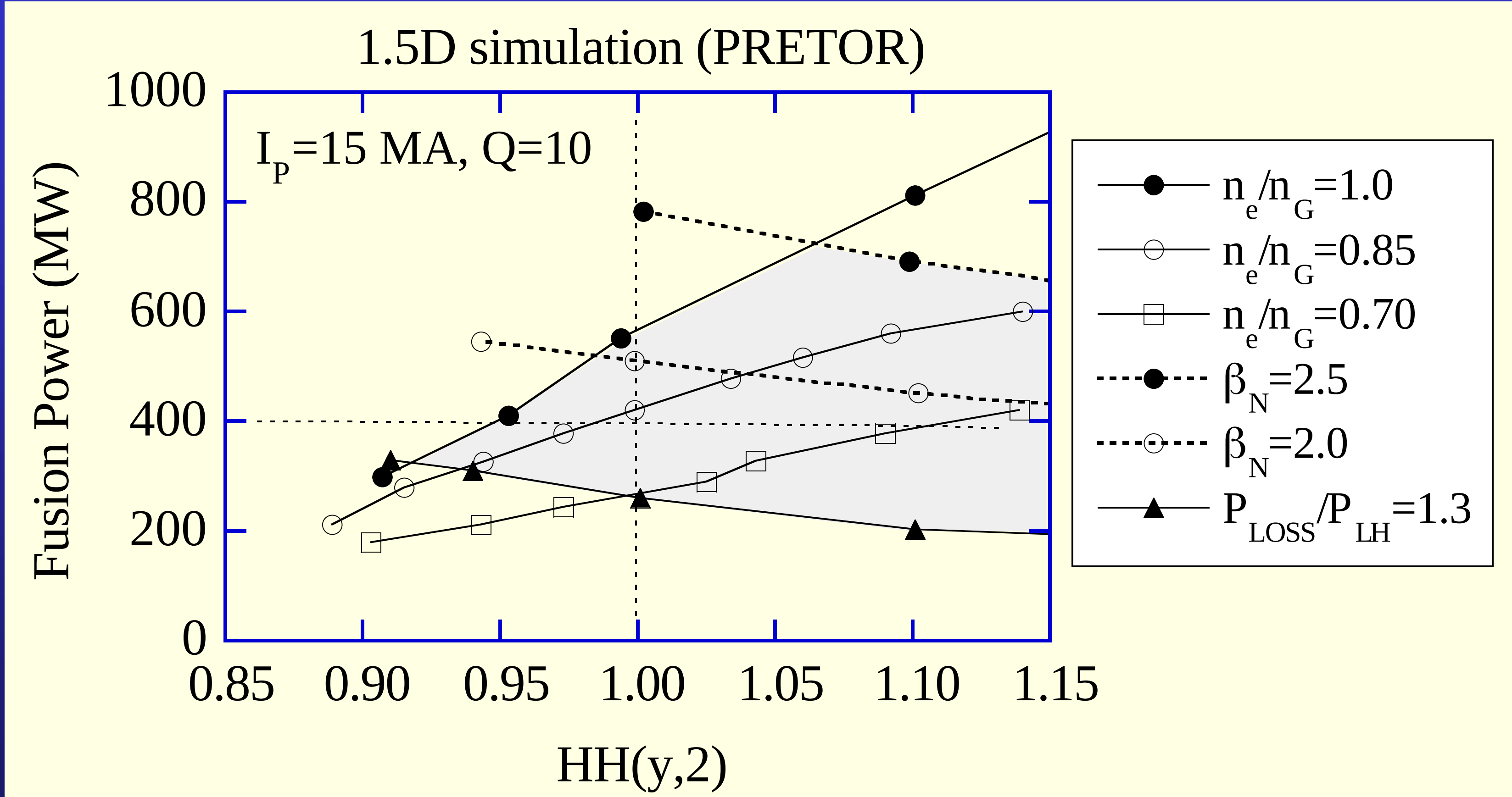
Fusion Power v.s. Density with 15 MA



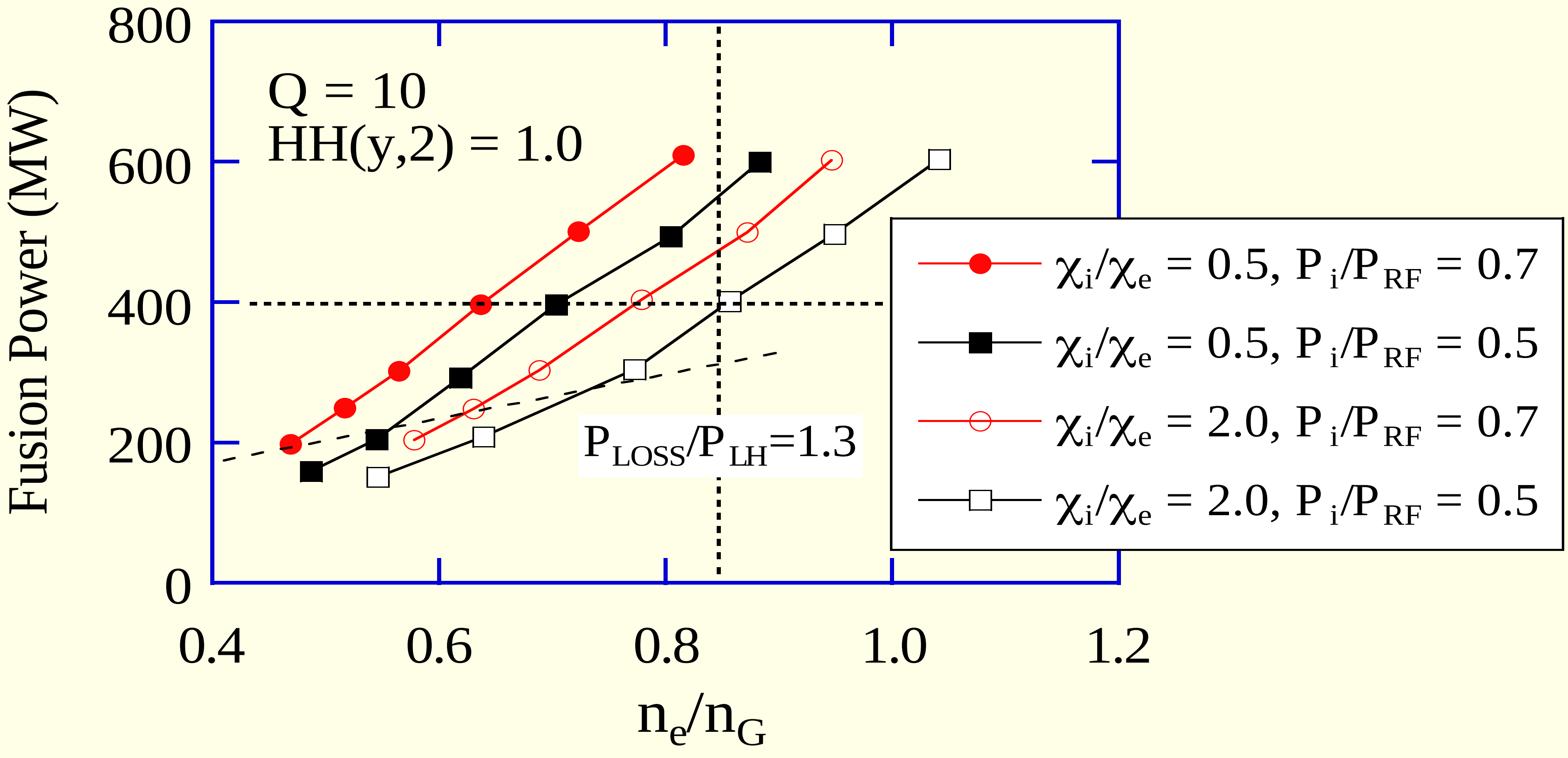
H_H = 1.0, *τ_{He}^*/τ_E=5,* *Peak divertor heat load < 10 MW/m²*

$n_G = I_P/\pi a^2$ and $\beta_N = \beta(\%)/[I_P/aB_T]$

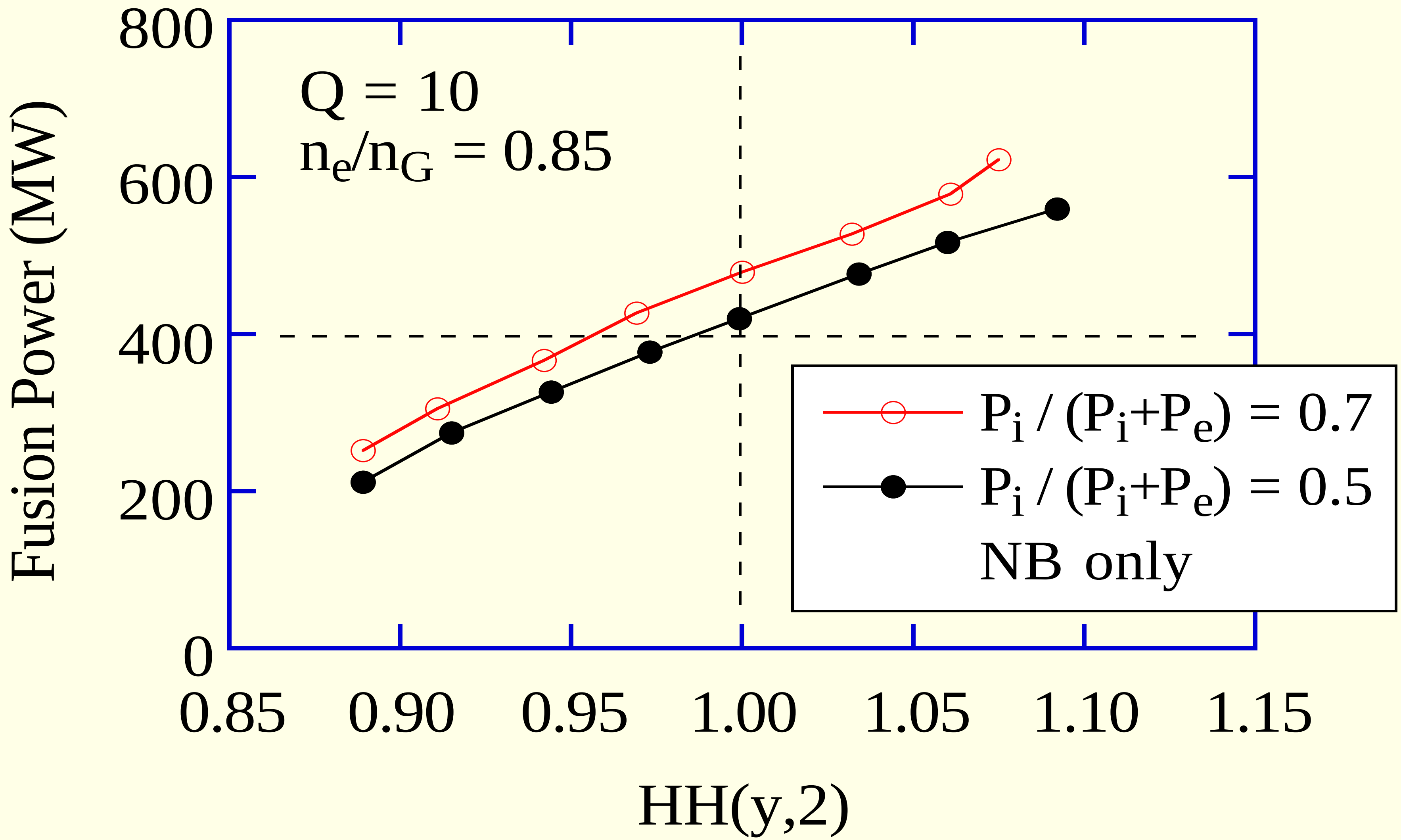
Operation Space with Q =10



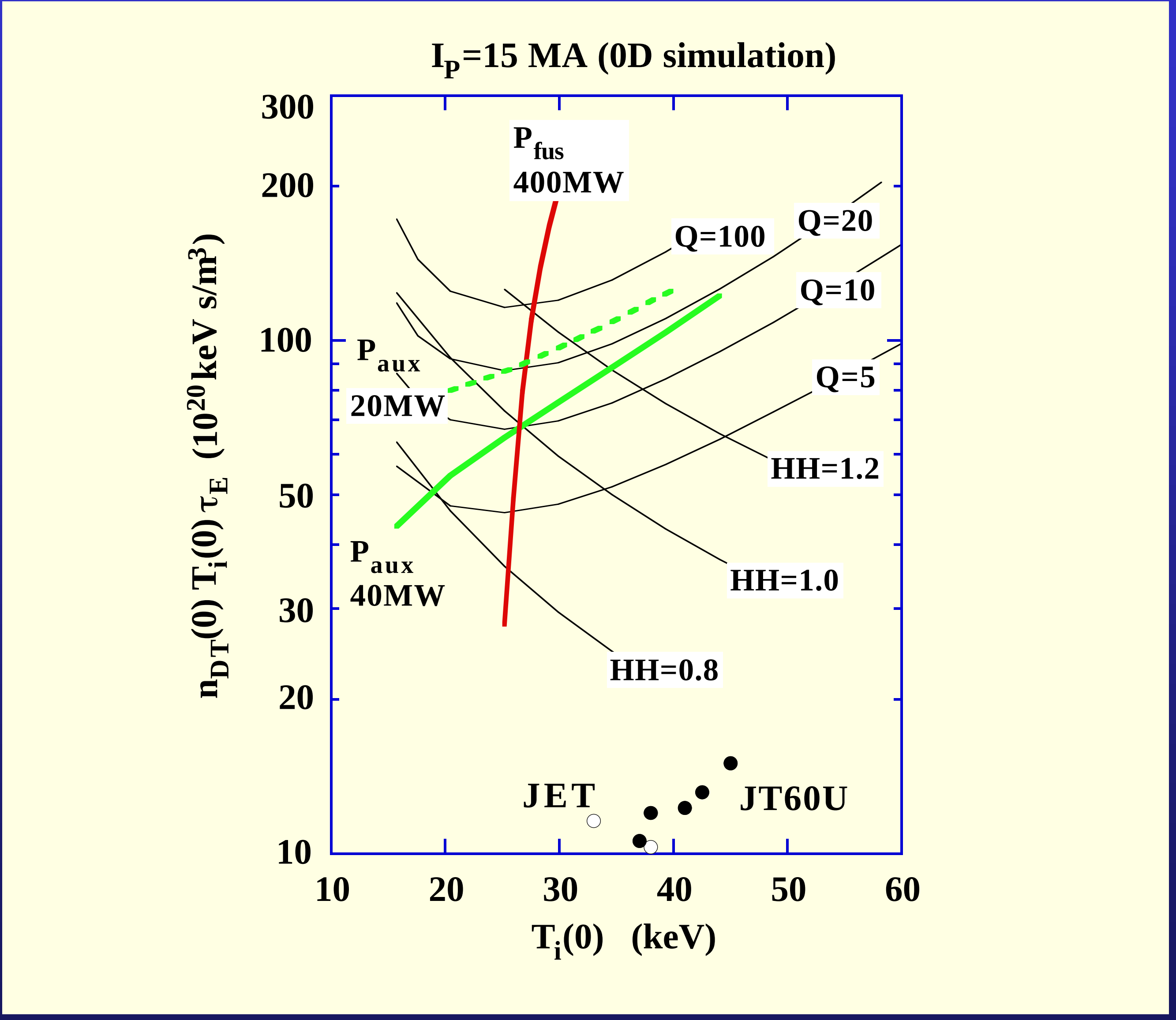
Density v.s. Fusion Power with 15 MA



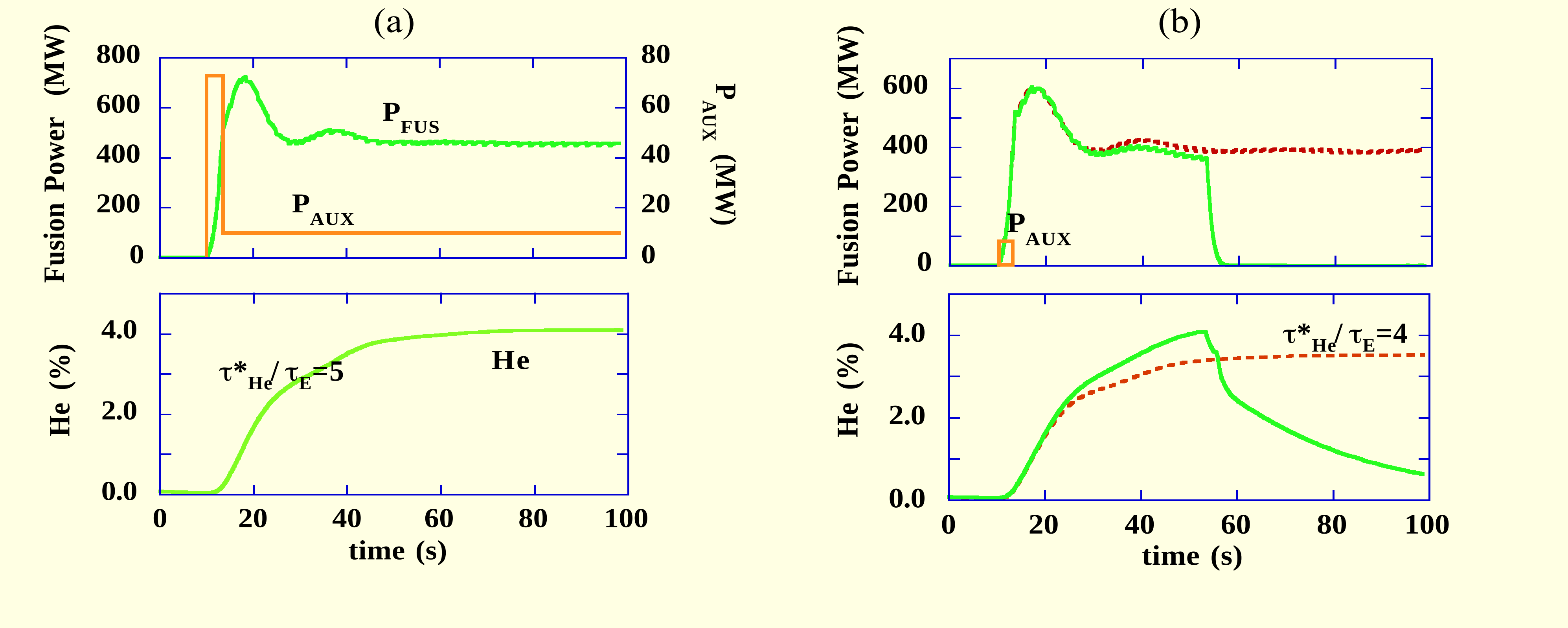
Ion Heating with 15MA



Operation branches with constant heating power and constant fusion power with n_e/n_G = 0.85 and 15 MA

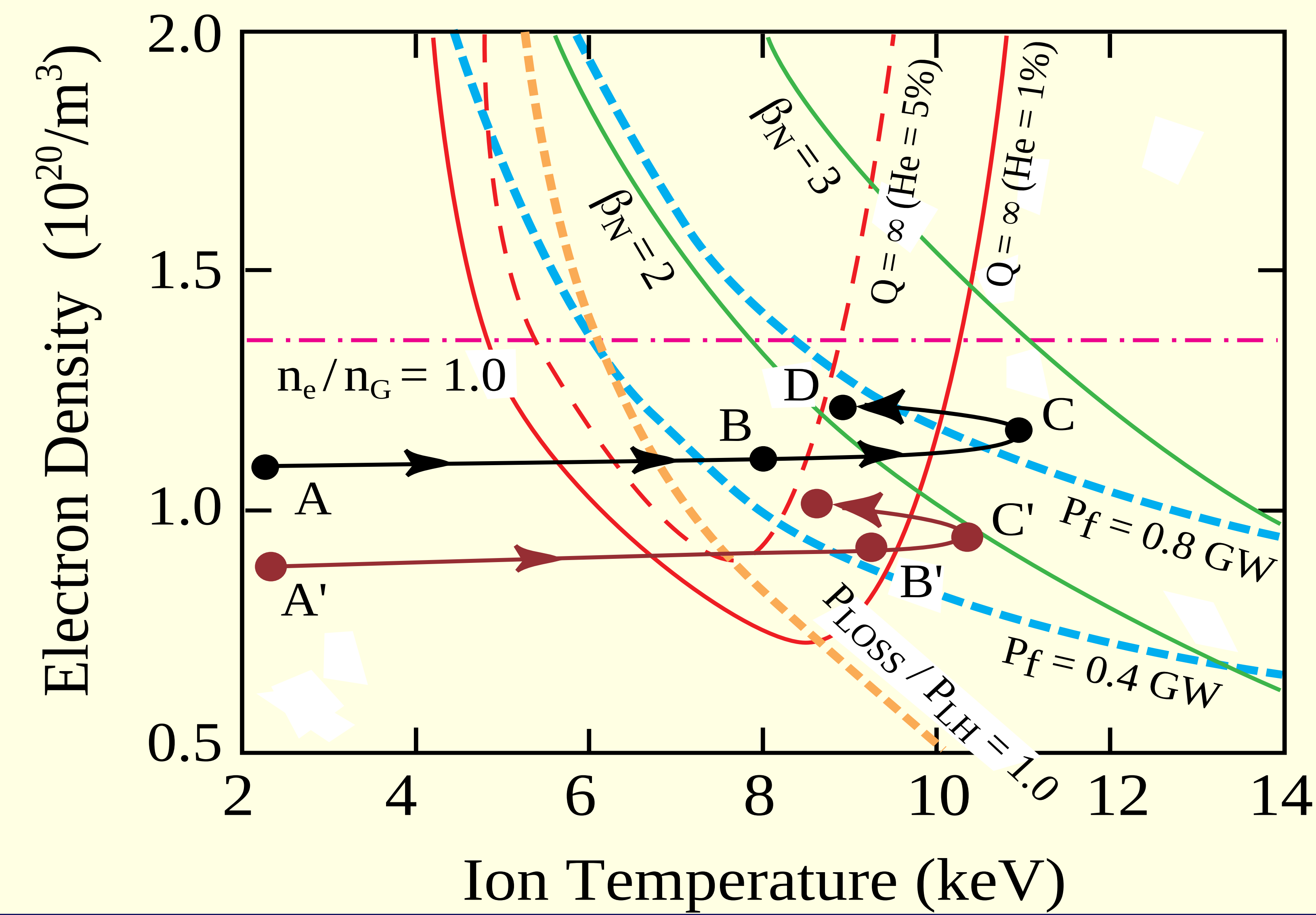


Very High Q and Q ∞ with 17 MA



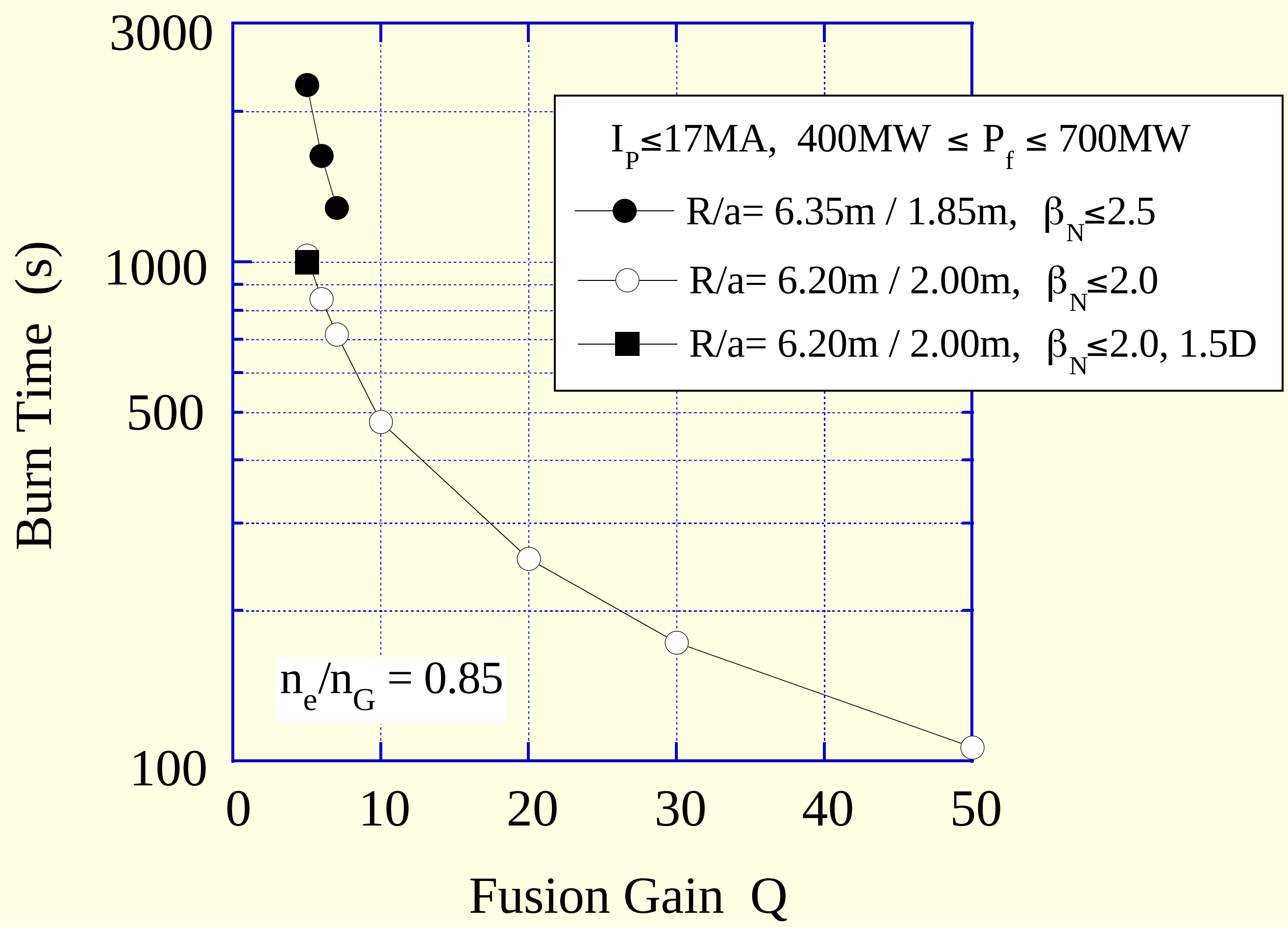
$\langle n_e \rangle = 1.1 \times 10^{20}/m^3$ ($\langle n_e \rangle / n_G = 0.81$), $\tau_E = \tau_E(y,2)$

Possible experiment of the thermal instability with 17 MA



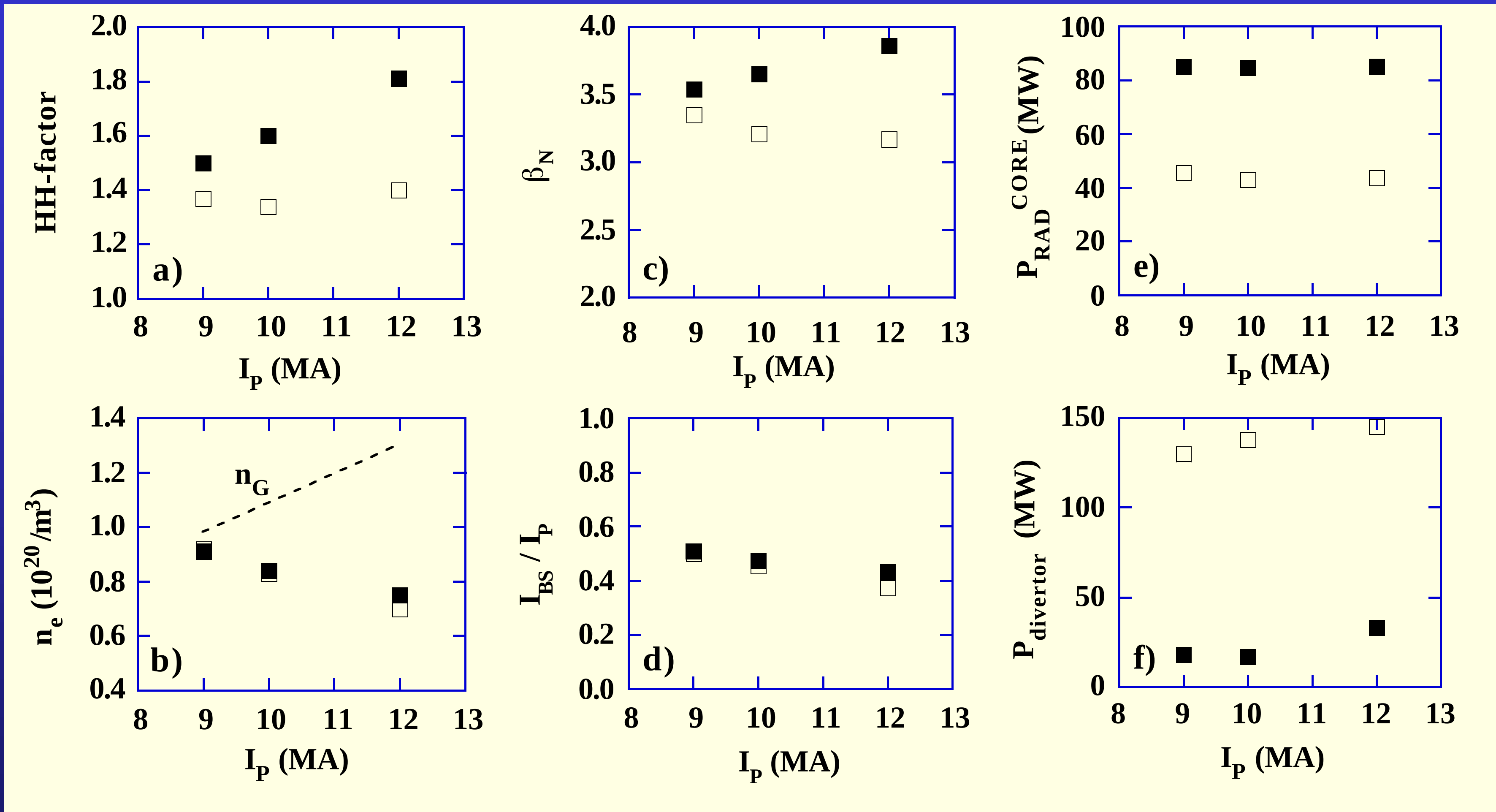
Inductive ⇒ Hybrid operation with $H_H = 1$

Longer pulse: smaller current driven partially by non-inductive method



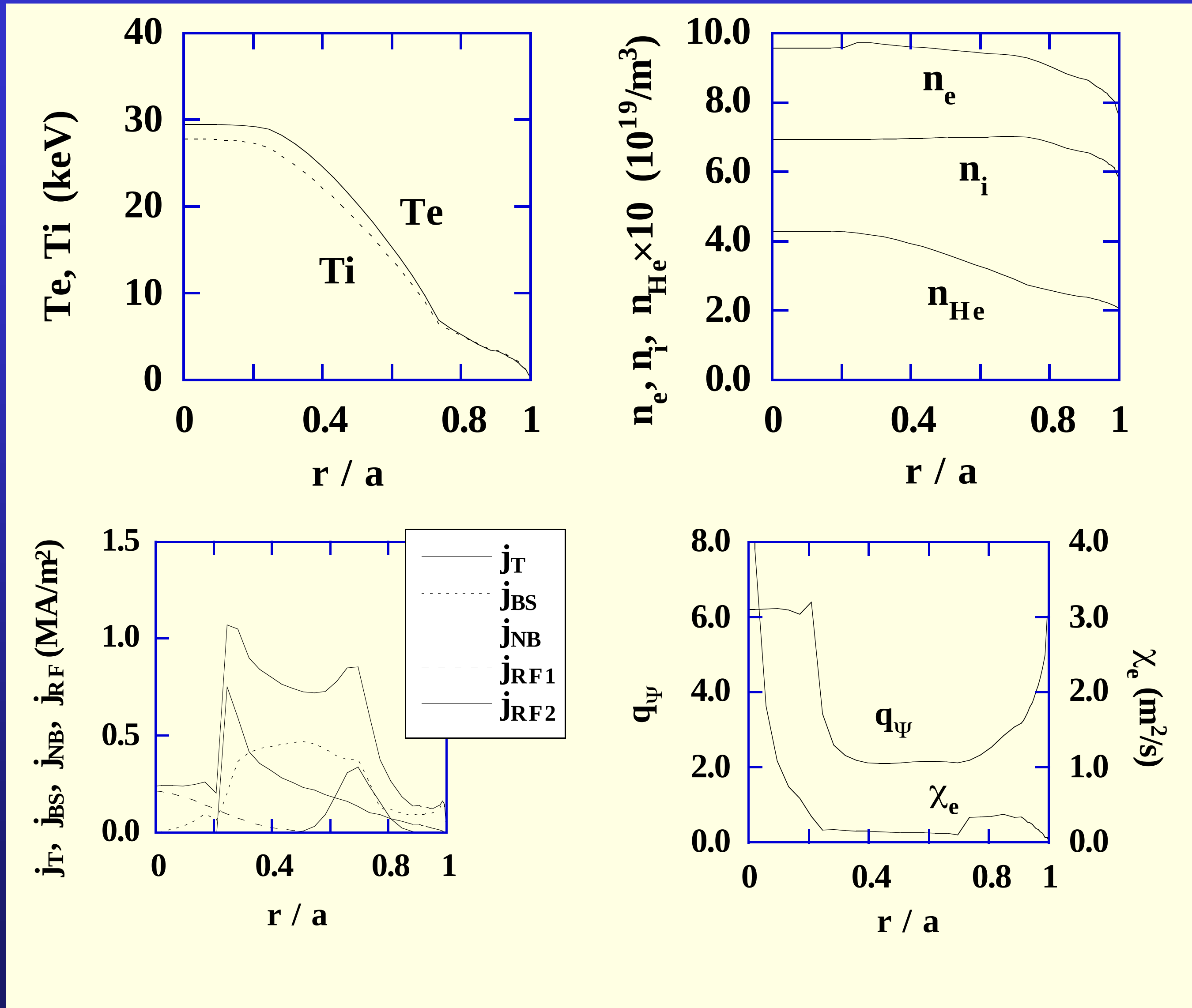
Operation for blanket test : 1000s, 500 MW and 0.77 MW/m² for the test area

Non-inductive steady-state operation with Q=5 and flat density profile



R/a/ κ_{95} = 6.5m / 1.7m / 2.0, P_{FUS}/P_{CD} = 500 MW / 100 MW (n,o).
Argon impurity (up to 0.5%) and carbon impurity (up to 1.2%) are seeded (n).
30 MW of $P_{Divetor}$ is corresponding to ~5 MW/m² of target heat load.

Non-inductive steady-state operation with Q=5 and 9MA

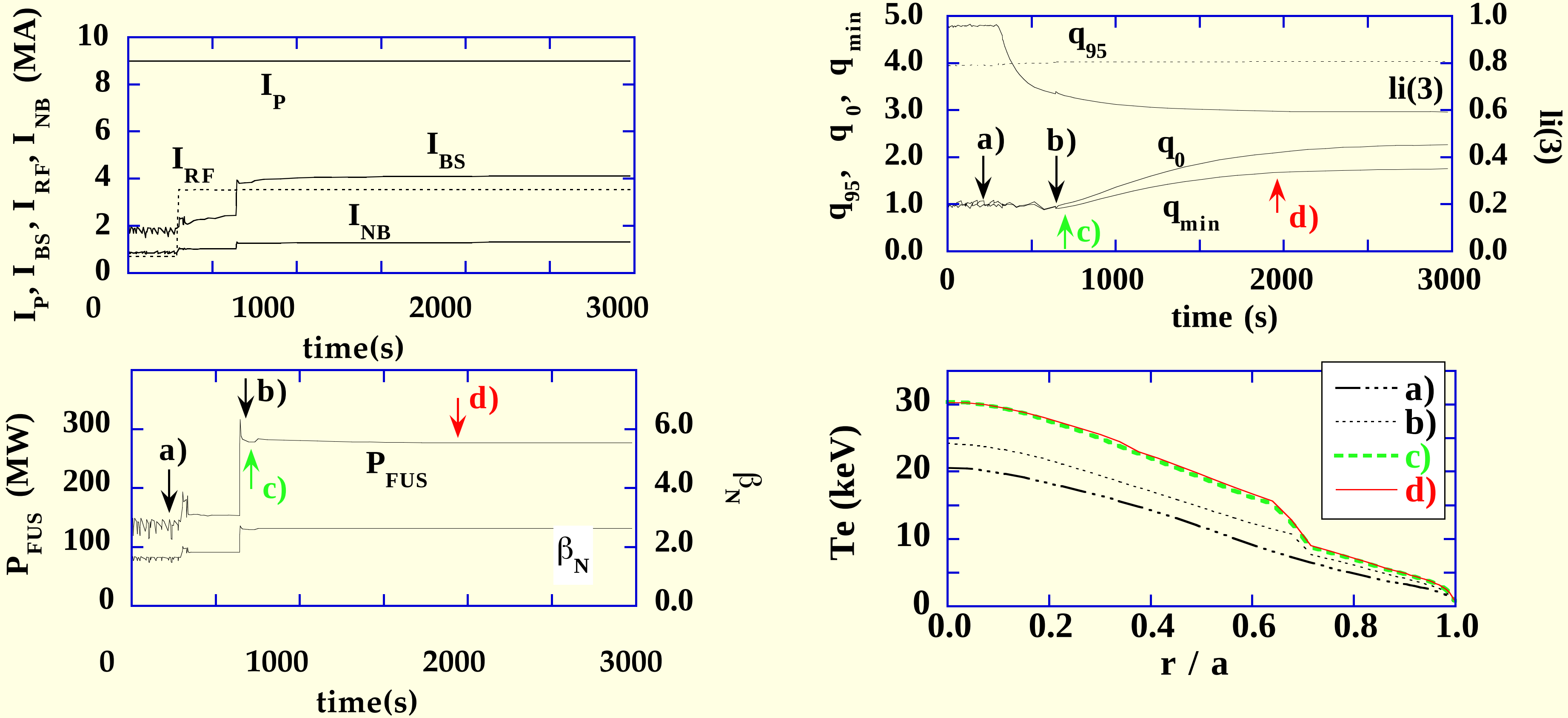


P_{FUS} / P_{CD} = 500 MW / 100 MW (Q=5),

Z_{eff} = 2.7 (Be / C / Ar = 2% / 0.4% / 0.45%), $P_{Divertor}$ 20 MW, H_H = 1.5, β_N = 3.5

On axis (EC, IC or NB : 5 MW), off-axis (NB and EC : 60 MW) and peripheral region (EC and LH : 35MW)

Time Behavior ofNon-inductive Operation with Internal Transport Barrier



$<n_e>=0.67\times10^{20}/m^3$ ($<n_e>/n_G = 0.8$), HH = 1→ 1.4, P_{FUS} / P_{CD} = 280 MW / 80 MW (Q=3.5)

On axis (EC) : 20 MW, γ_{20}(EC) = 0.15,

Off axis (NB) : 20 MW, γ_{20}(NB) = 0.18→ 0.28

Far off axis (LH) : 40 MW, γ_{20}(LH) = 0.3

Conclusions

The flexibility of ITER will allow research in a large operation spac

(P_{fusion}, Q, n, β, pulse length, I_p -----)

(Confirm predictable operation ⇒ Explore frontier)

- **Predictable operations and extended operations with Q~10, and I_p=15 MA**
  - **150–700MW, n/n_G=0.5–1 β_N =1.2–2.4**
- **Very high Q or ignition operations at 17 MA**
  - **A high possibility to achieve the ignition**
  - **Research of control very high Q/ignition and higher β/higher P_{fusion}**
- **Hybrid and non-inductive operations**
  - **1000 s / 500 MW/Q=5 with reasonable parameters for blanket test (0.77 MW/m^2)**
  - **Research of fully non-inductive driven operations aiming at Q=5 (higher β/higher confinement, methods included in ITER)**

The remote experimental concept will increase efficiency, involve the worldwide fusion community and promote scientific competition