A SUSTAINABLE HIGH POWER DENSITY (SHPD) TOKAMAK TO ENABLE A COMPACT FUSION PILOT PLANT

ID: TH-P7/1015

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ABSTRACT

- Design parameters & physics missions identified for a new Sustained High Power Density (SHPD) tokamak
- Goal is to develop and test predicted sustainable plasma operating scenarios for a low capital cost fusion pilot plant.
- Simultaneously maintain (a) high pressure for high fusion power density, (b) high bootstrap fraction for sustainment and to minimize recirculating power, and (c) exhaust solution compatible with sustained high heat loads.
- Use self-consistent integrated modeling for physics optimization

BACKGROUND

- The US National Academies and US fusion community have advocated a strategy aiming toward a low capital cost pilot plant
- A compact, sustained fusion pilot plant (CFPP) requires very high pressure, high bootstrap fraction, and a high-heat flux capable exhaust system
  - High confinement critical for cost effectiveness
- Major advances in physics and technology required to achieve CFPP goals. Propose SHPD device to close these gaps and validate physics models
- Self-consistent integration of core, pedestal, and boundary/divertor plasma ("core-edge" integration) solutions critical to SHPD mission
  - High core pressure and high bootstrap fraction (Fig 1a)
  - High pedestal with high separatrix density for exhaust (Fig 1b)

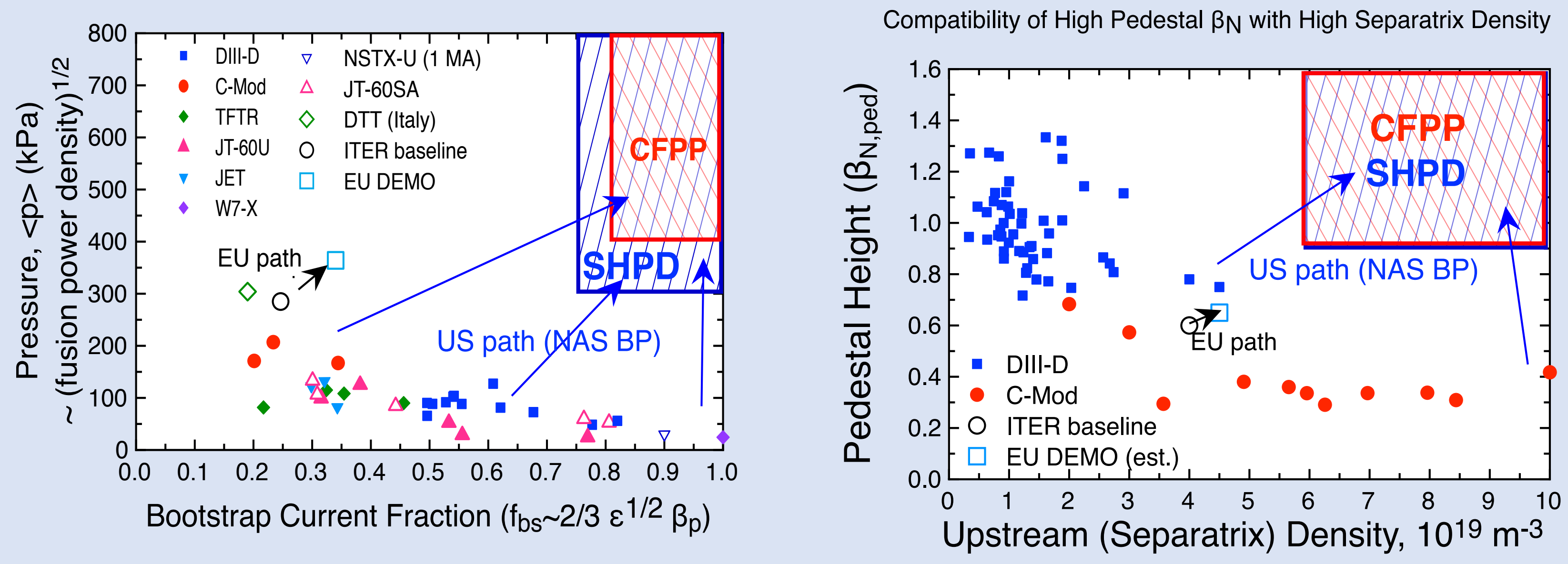

Fig 1: Desired parameter range for CFPP (red box) and SHPD (blue box) compared to achieved (solid) and planned (open) devices.

CHALLENGES / METHODS / IMPLEMENTATION

CORE-EDGE INTEGRATION

The pedestal provides an interface between the core and boundary plasma, and must provide sufficient p_{ped} and $\beta_{p,ped}$ for core performance with a separatrix density consistent with a high-flux exhaust solution. The EPED model is used to predict pedestal structure as a function of shape, aspect ratio, and density to identify SHPD operating points. Heat flux (P/R, PB/R, PB_p/R) should be sufficient to test innovative divertor solutions applicable to CFPP.

INTEGRATED MODELING TO DEVELOP SHPD REFERENCE DESIGN POINT

Integrated modeling of core transport (TGLF), pedestal (EPED), heating & current drive, MHD equilibrium (EFIT) and stability (DCON/GATO), using IPS-FASTRAN suite. Nine dimensional scan over field, current, shape, size, aspect ratio, density, and heating power. Over 4000 cases studied to identify optimal physics parameters for SHPD. Confinement time (τ_E which can be expressed as an H_{98} factor), pressure, nTτ, and pedestal structure are self-consistently predicted by the physics models.

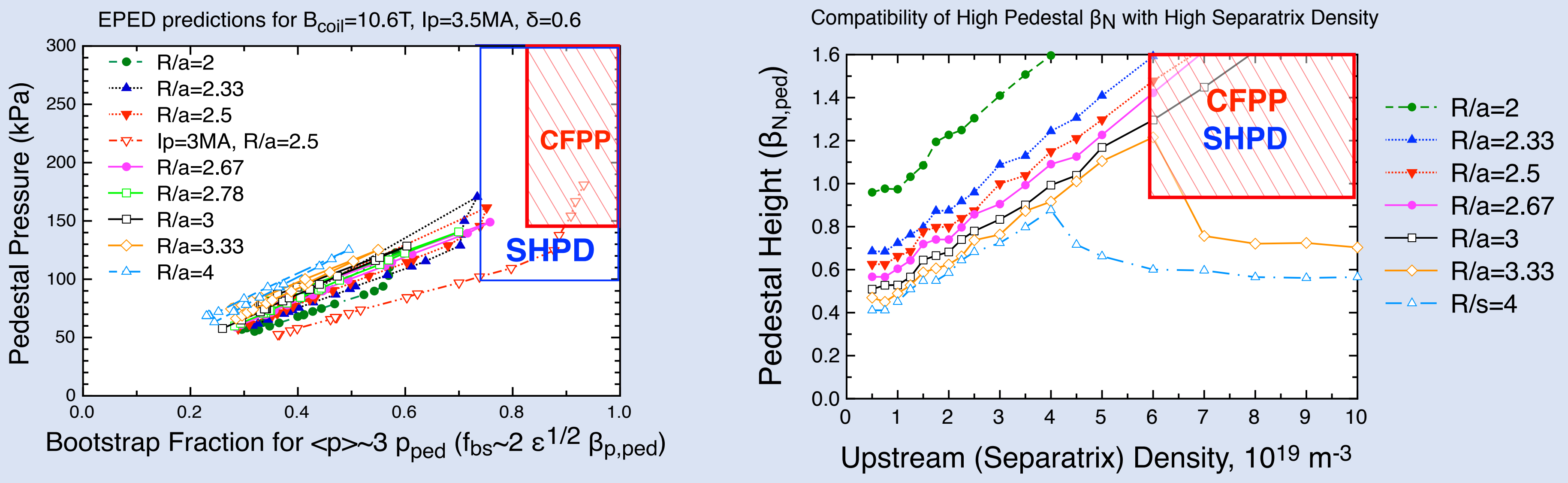

Fig 2: Predictions from the EPED model for a scan of aspect ratio and density for a strongly shaped plasma (δ=0.6) with B_t=10.6T at the coil, find pedestal conditions sufficient to meet SHPD goals (with typical levels of core confinement) can be achieved at intermediate R/a~2.3-2.7, with optimal density and a peeling-limited pedestal.

OUTCOME

CORE-EDGE INTEGRATION

EPED predicts that strongly shaped plasmas (δ~0.6) at intermediate field (10.6T at coil located at 1.5a) and aspect ratio (R/a~2.3-2.7) have pedestals consistent with SHPD goals (Fig 2). Pedestal is peeling limited, enabling relatively high separatrix density for radiative divertor solution consistent with high pedestal. Divertor metrics such as PB_θ/R (Fig 3) in range needed to develop innovative divertor solution for pilot plant.

INTEGRATED MODELING TO DEVELOP SHPD REFERENCE DESIGN POINT

A reference design point (Table 1) is identified via optimization for key performance parameters, including bootstrap fraction and PB/R (Fig 4). Addressing the core-edge integration mission is facilitated by capability to operate at fields up to 7T and current to 2.5MA, with heating power of at least 40MW, with options to 60MW.

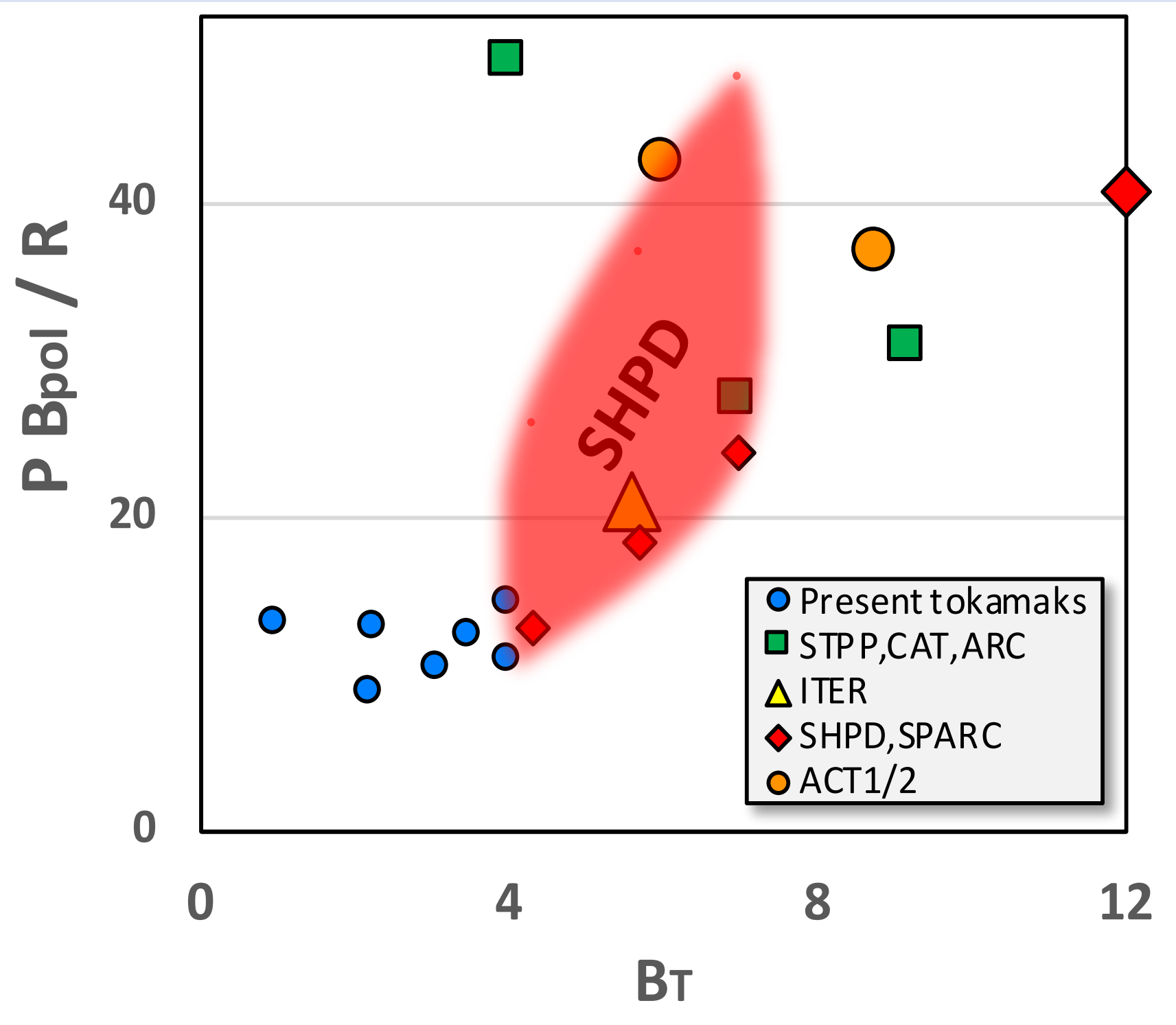

Fig 3: Pilot plants (green) operate at high field and divertor heat flux. SHPD (red shaded) can develop innovative divertor solutions at pilot-level fluxes.

Parameter	Range
Major Radius	1.25m
R/a	2.5
Triangularity	0.7
Elongation	2.1
Toroidal Field	4 – 7 T
$P_{H\&CD}$	40–60 MW
q_{95}	6.5 - 11
β_N	to 3.8
$\beta_N/4\ l_i$	to 1.5
$n_{e,ped}/n_{GW}$	0.5-1
pressure <p>	to 400 kPa
PB/R	100-300
τ_R	2 – 3 s
ν_*	~0.2
f_{BS}	60-100%
T_e, T_i	~3-4 keV
Predicted H_{98}	1.2– 1.6

Table 1: Key parameters of SHPD reference design point, determined by multi-dimensional optimization of integrated core (TGLF), pedestal (EPED), heating & current drive, and MHD stability predictions using the IPS-FASTRAN suite.

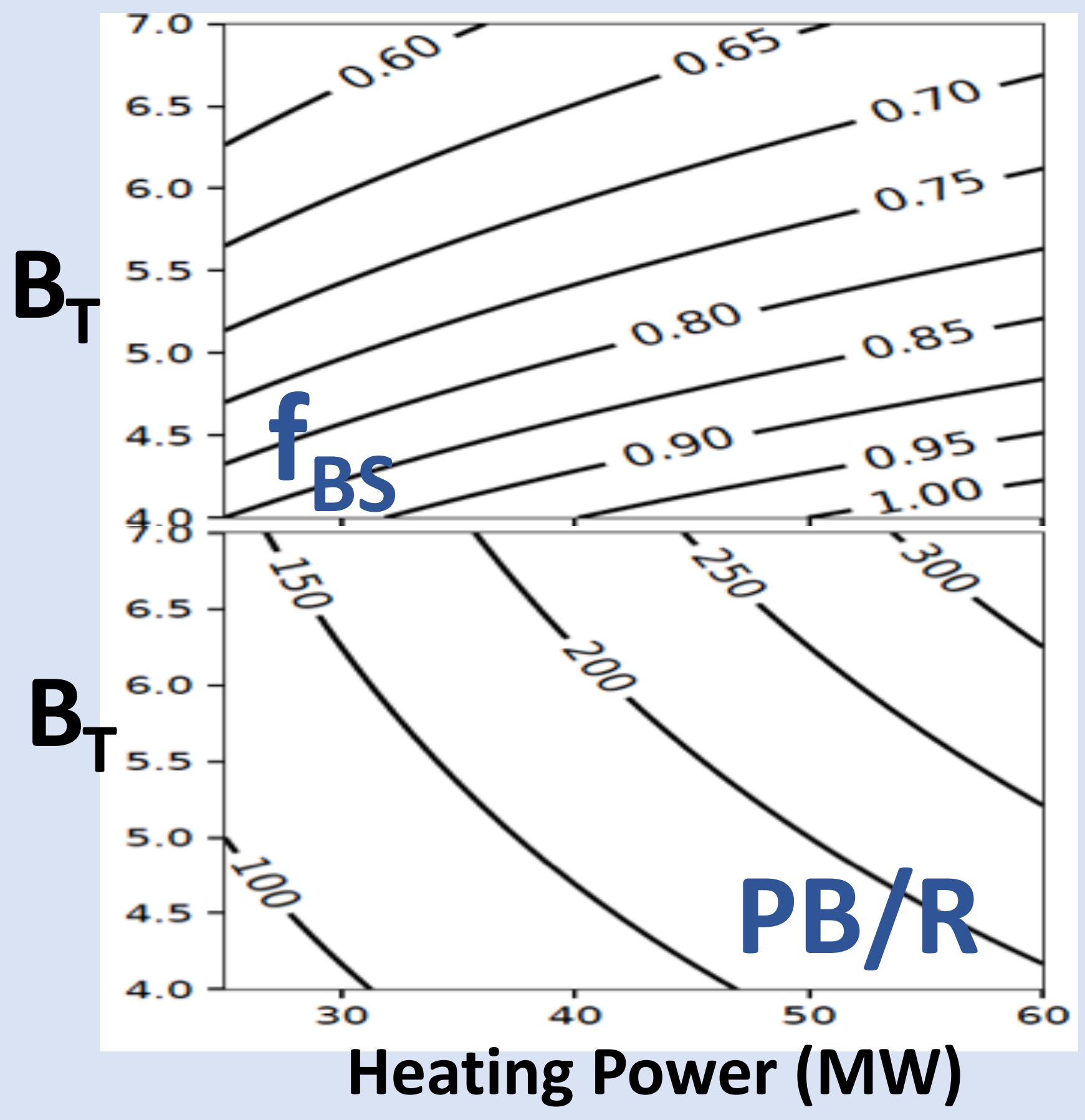

Fig 4: Predicted f_{BS} and PB/R vs B_t and heating power for SHPD at q_{95}=8..

CONCLUSION AND FUTURE WORK

- A reference design point is developed for an SHPD tokamak to address key physics missions enabling a low capital cost fusion pilot plant capable of sustained operation with high fusion power density (i.e. high pressure) and low recirculating power (i.e. high bootstrap fraction).
- Predictions with self-consistent integrated transport, current drive, pedestal, and equilibrium simulations indicate a modest scale, strongly shaped SHPD tokamak with R/a~2.5 can meet key SHPD challenges,
- The device is intended to be flexible, well diagnosed, and allow personnel access, to facilitate comprehensive model validation and physics exploration in pilot plant relevant regimes.
- Ongoing work: detailed divertor, PFC, H&CD design, systems engineering

ACKNOWLEDGEMENTS

- This work was funded by the U.S. DOE under DE-FC02-04ER54698, DE-AC05-00OR22725, DE-SC0017992, DE-FG02-95ER54309, DE-AC52-07NA27344, and DE-AC02-09CH11466, and by GA internal funds. See paper for references