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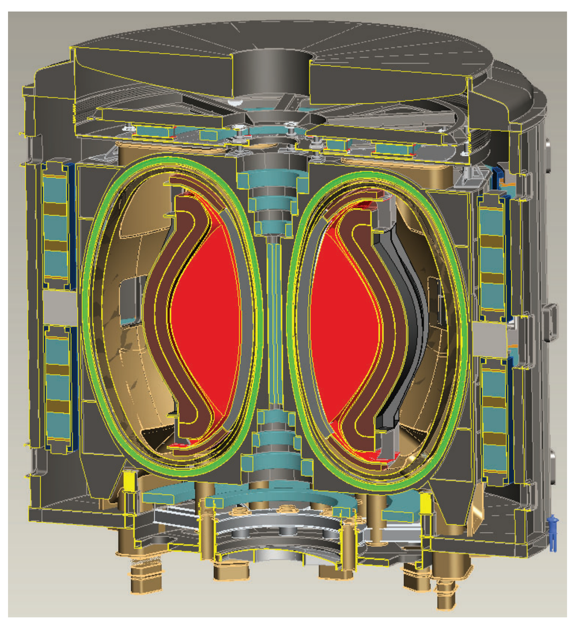
Innovations Needed for Compact Pilot

Emphasis of this poster

- Magnet Technology – Higher B_T and $J_{winding\text{-}pack}$
- Divertors – Liquid metals, long-leg (and combination)
- Confinement – Optimized edge transport barrier
- Aspect Ratio – Lower A → maximize stability, pressure
- Current Drive – Efficient Negative NBI, RF techniques
- Blankets – High thermal efficiency liquid metal

Example Pilot Plant: A=2, R_0 = 3m HTS-TF

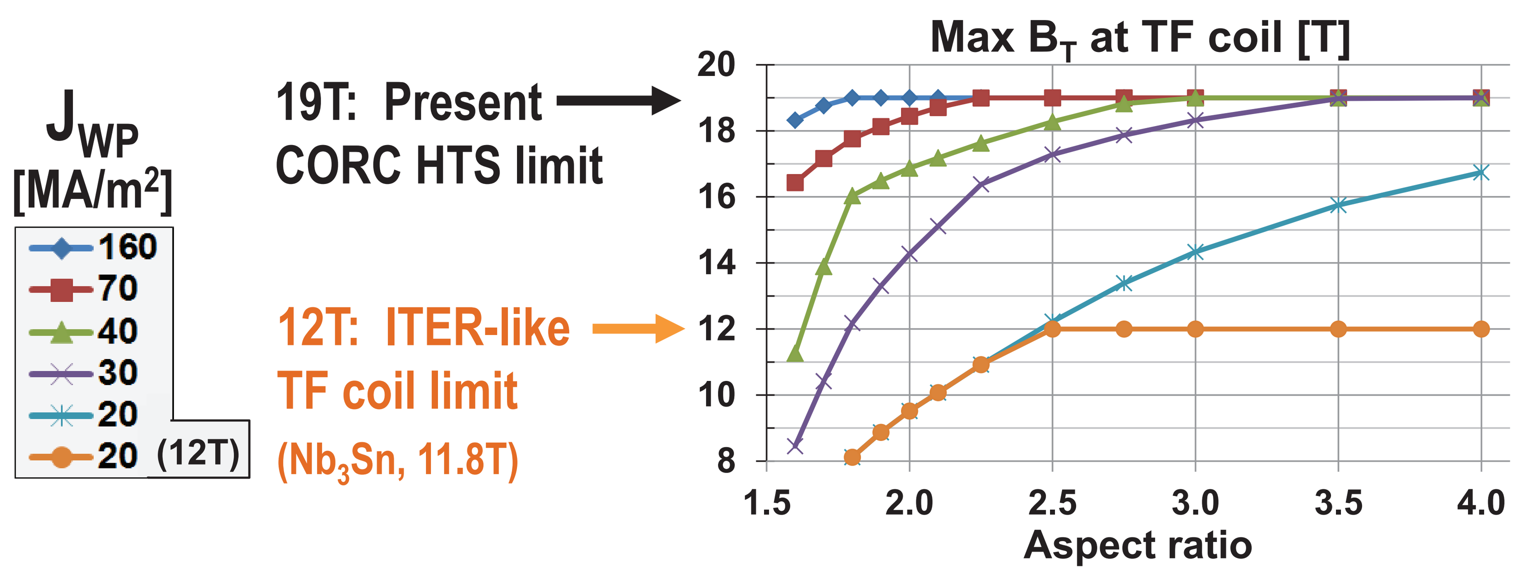


Cryostat volume ~ 1/3 of ITER

B_T = 4T, I_P = 12.5MA	P_{fusion} = 520 MW
κ = 2.5, δ = 0.55	P_{NBI} = 50 MW
β_N = 4.2, β_T = 9%	E_{NBI}=0.5MeV
H_{98} = 1.75, $H_{Petty\text{-}08}$ = 1.3	Q_{DT} = 10.4
f_{gw} = 0.80, f_{BS} = 0.76	
Startup I_P (OH)~2MA	Q_{eng} = 1.35
J_{WP} = 70MA/m²	P_{net} = 73 MW
$B_{T\text{-}max}$ = 17.5T	$\langle W_n \rangle$ = 1.3 MW/m²
No joints in TF	Peak n-flux = 2.4 MW/m²
Vertical maintenance	Peak n-fluence: 7MWy/m²

J. Menard, et al., Nucl. Fusion **56** (2016) 106023

At lower A, high TF winding-pack current density enables access to maximum allowed B_T at coil

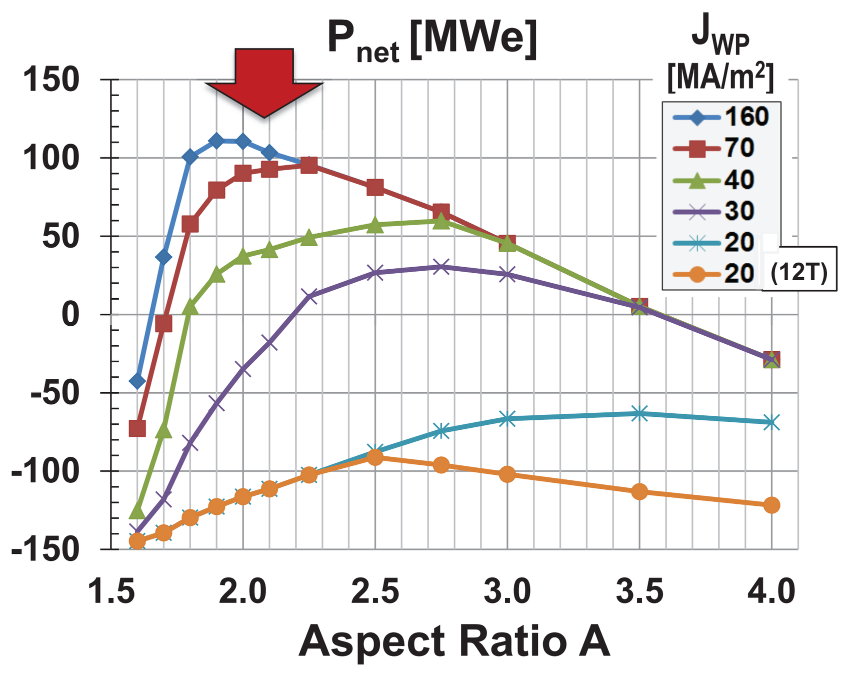


- Coil structure sized to maintain ≤ 0.3% strain on winding pack
- Effective inboard tungsten carbide (WC) neutron shield thickness = 60cm

High current density HTS cable motivates consideration of lower-A tokamak pilot plants

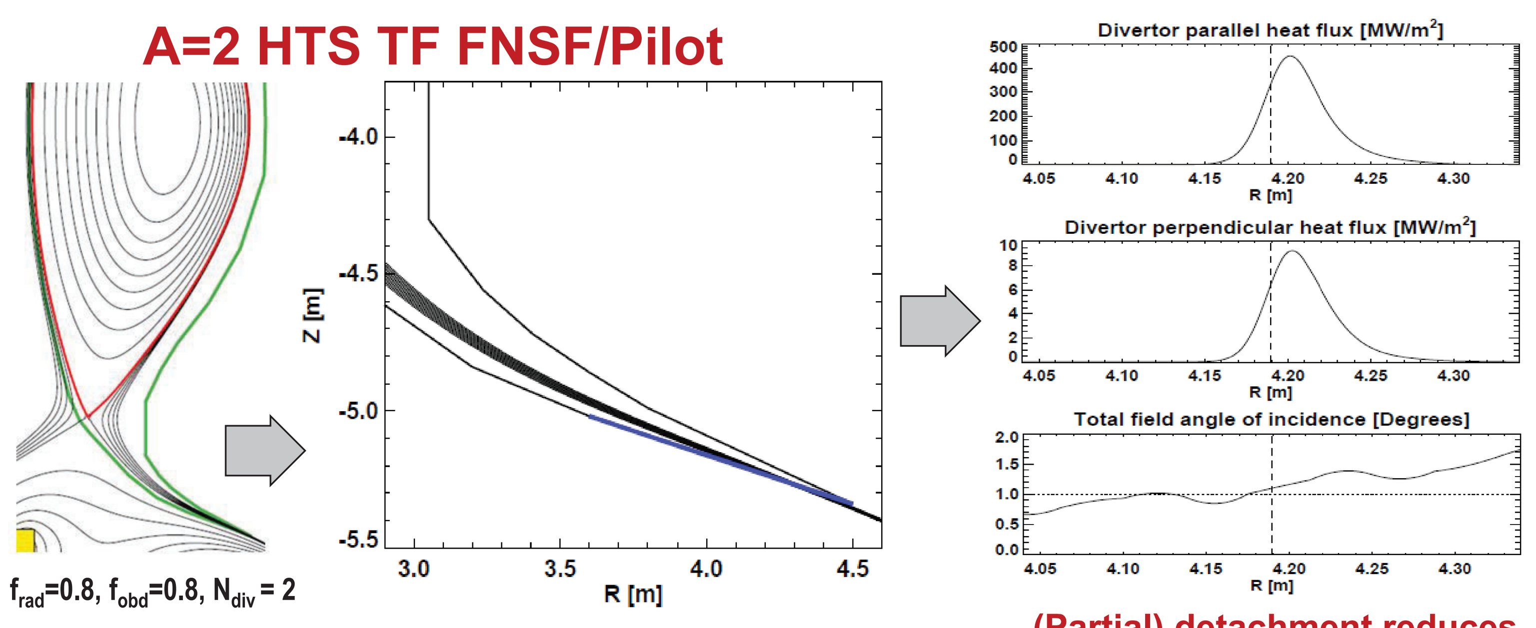
- ITER-like TF constraints:
  - J_{WP}=20MA/m², B_{max} ≤ 12T
  - P_{fusion} ≤ 130MW, P_{net} < -90MW
- J_{WP} ~ 30MA/m², B_{max} ≤ 19T
  - P_{fusion} ~ 400MW
  - Small P_{net} at A=2.2-3.5
- J_{WP} ≥ 70MA/m², B_{max} ≤ 19T
  - P_{fusion} ~500-600MW
  - P_{net} = 80-100MW at A=1.9-2.3

A ~ 2 attractive at high J_{WP}



Long-leg / Super-X aids heat flux reduction

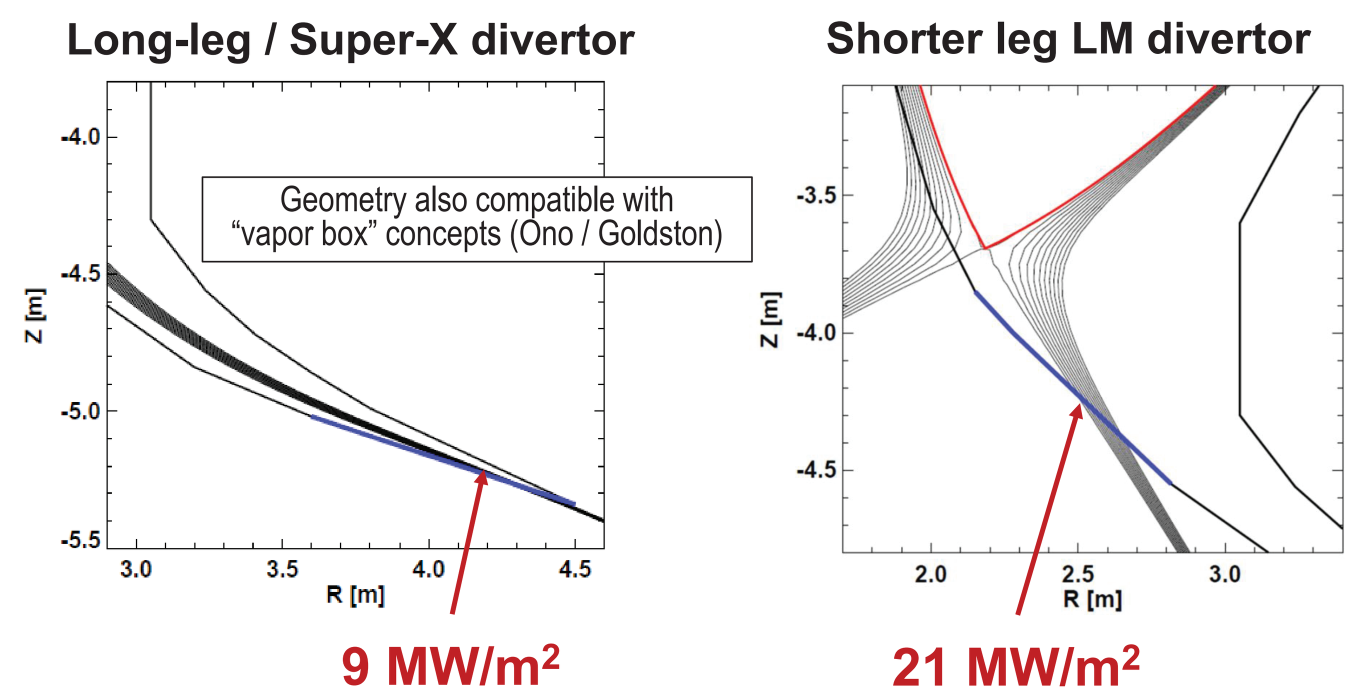
A=2 HTS TF FNSF/Pilot



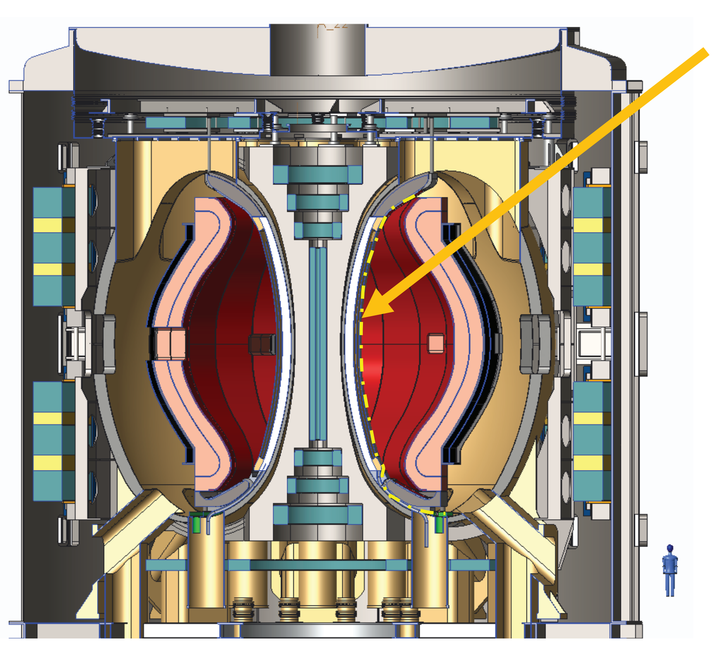
λ_q ~ 1mm, assume S ≈ λ_q (closed divertor)
T. Eich, et al., Nucl. Fusion **53** (2013) 093031

(Partial) detachment reduces peak $q_\perp$ by further factor of 2-4

Another option: use fast-flowing Liquid Metal (LM) divertor for high heat-flux mitigation



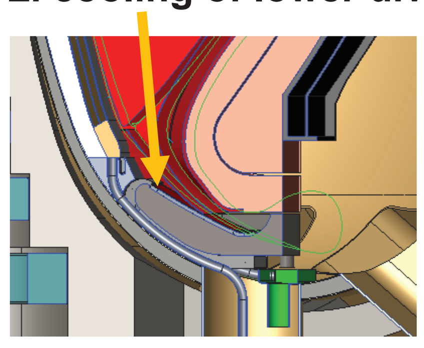
Low-A HTS design with Li flow on divertor and inboard surfaces



Double null liquid metal divertor system

Li flows from upper divertor down the inboard wall, exiting just after the lower inboard divertor.

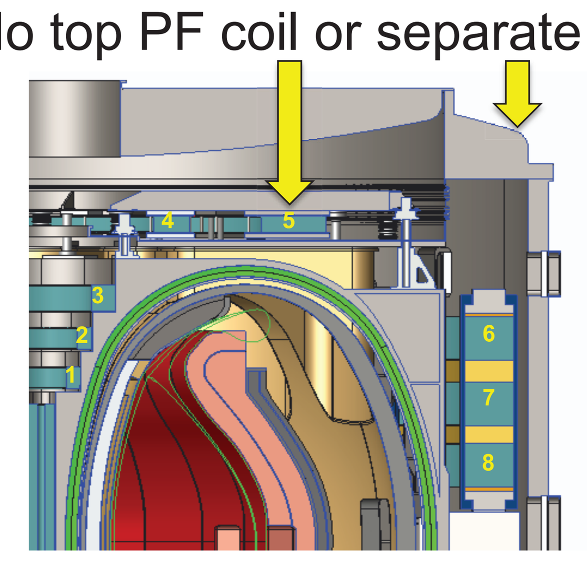
Separate Li cooling of lower divertor

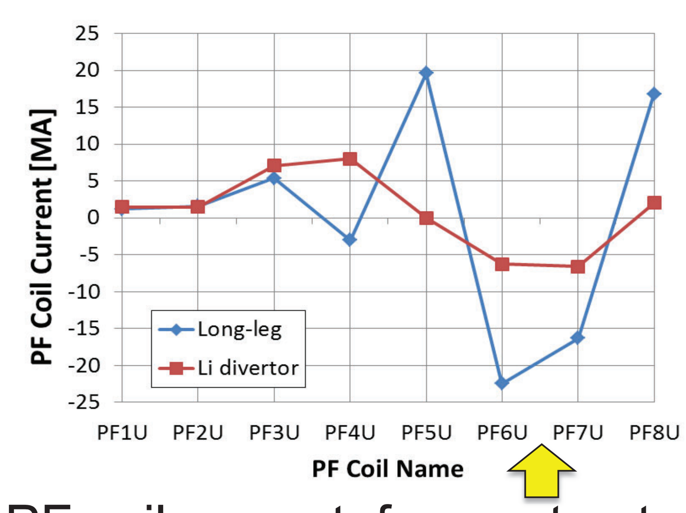


LM thickness = 5-10 mm, flow speed ~5-10 m/s

Benefits of shorter-leg liquid metal divertor:

- No top PF coil or separate cryo-stat → simplified maintenance

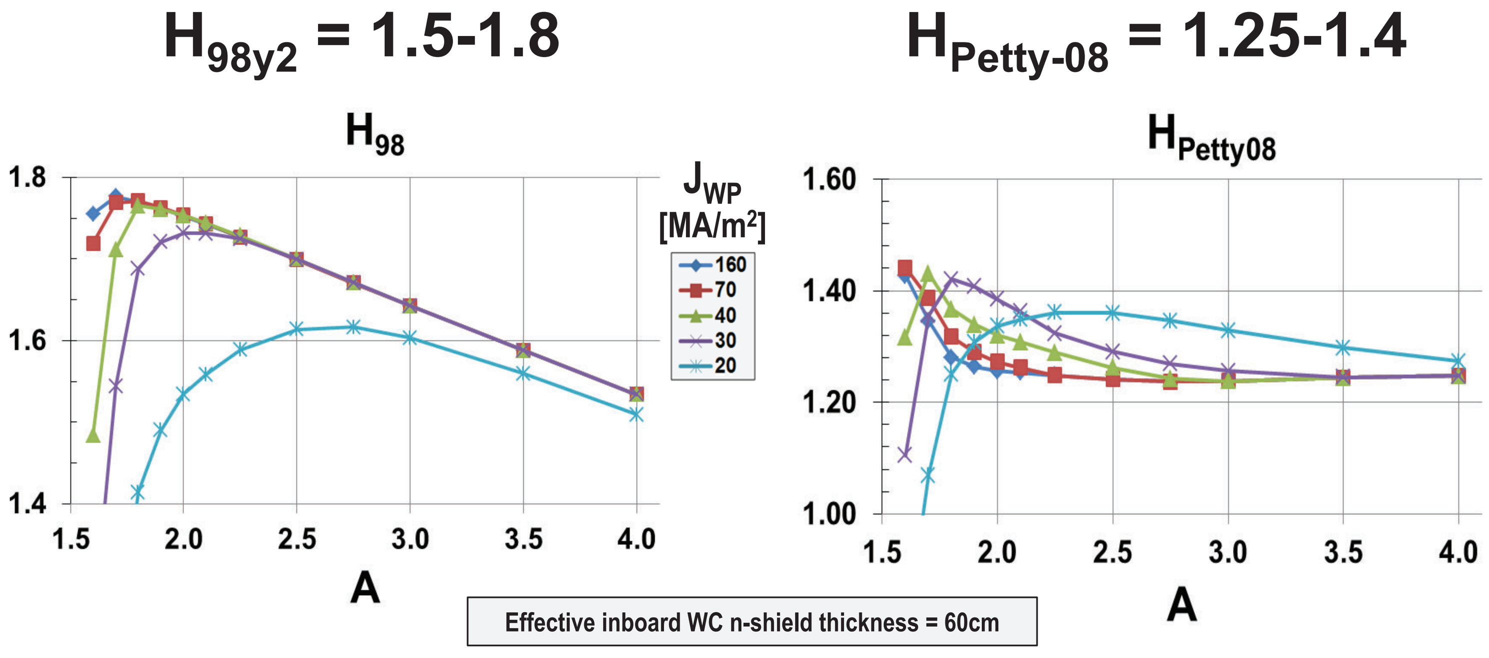




- Significantly reduce outboard PF coil current, force, structure
- If liquid lithium, wall pumping could help increase H-factor

R=3m Pilot Plants require elevated H values

H_{98y2} = 1.5-1.8 $H_{Petty\text{-}08}$ = 1.25-1.4

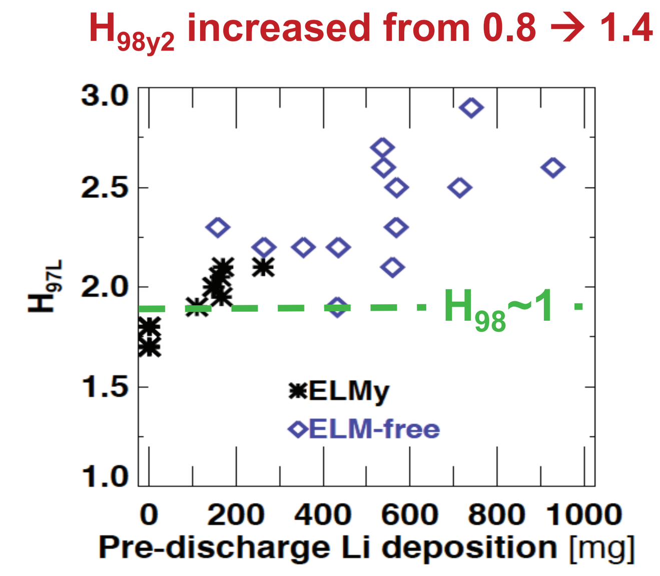


Effective inboard WC n-shield thickness = 60cm

Li (solid and liquid) PFCs can increase confinement

NSTX (wider → higher pedestals)

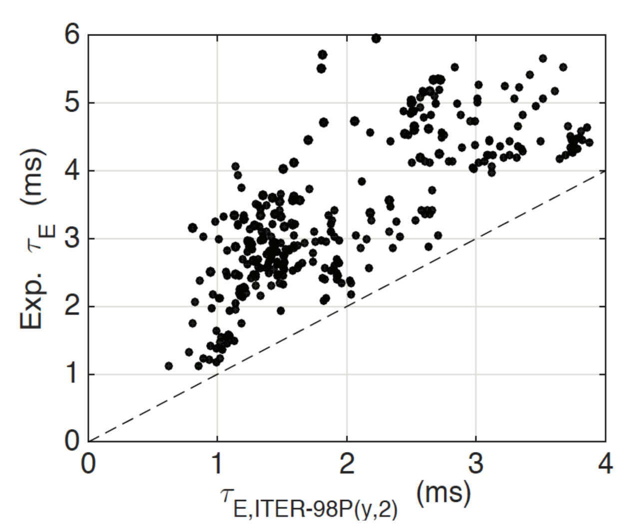
H_{98y2} increased from 0.8 → 1.4



D.P. Boyle, et al., J. Nucl. Mater. 438 (2013) S979

LTX (flatter → higher T profiles)

2-4x improvement over ITER98P(y,2)



J.C. Schmitt, et al., Phys. Plasmas 22 (2015) 056112