Profile Effects on DT Fusion Performance

- For pure thermalized DT near optimum temperature (~15keV)

  $<\sigma v> \sim T^2 \;\Rightarrow\; P_{fusion} = E_{DT} \int n_D\, n_T <\sigma v> dV \propto \int n^2 T^2 dV \propto \int p^2 dV$

- For $P_\alpha << P_{aux}$ (no self heating)

  $P_{aux} = P_{loss} = 3 <nT>/\tau_E$ *[< > ⇒ volume average]*

  $\Rightarrow\; Q \equiv P_{fusion}/P_{aux} \propto [<n^2T^2>/<nT>]\,\tau_E$

  - This is often approximated either as

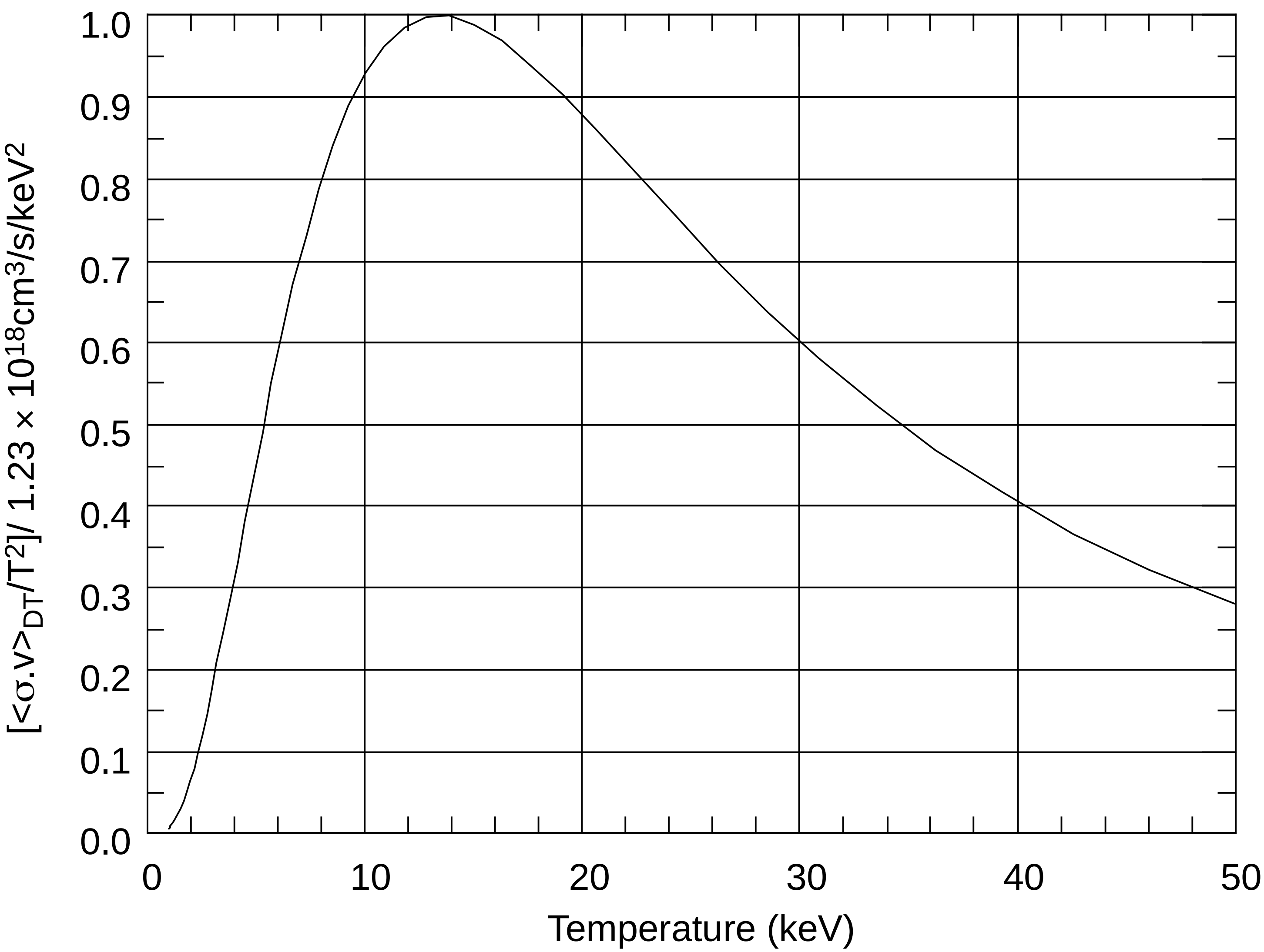
    $\mathbf{Q \propto n_e(0) \cdot T_i(0) \cdot \tau_E}$

    or

    $\mathbf{Q \propto \beta_T \cdot \tau_E \cdot B_T^2}$

- In real world
  - Edge temperature must be well below optimum fusion temperature
    - Edge can contribute to $<nT>$ while not generating much P_{fusion}
  - $<n^2T^2> \neq <nT>^2$

Temperature Dependence of DT Reactivity



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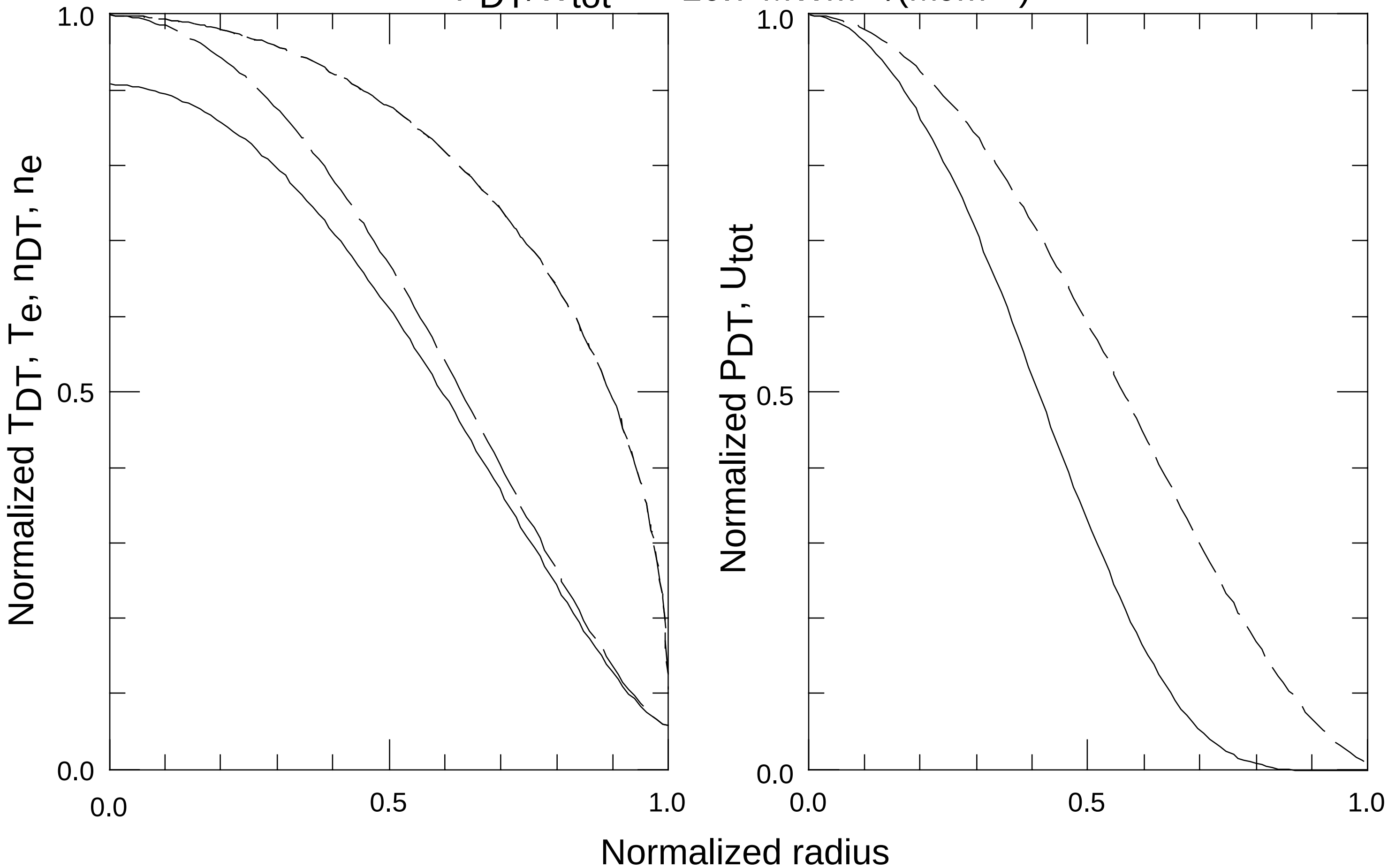
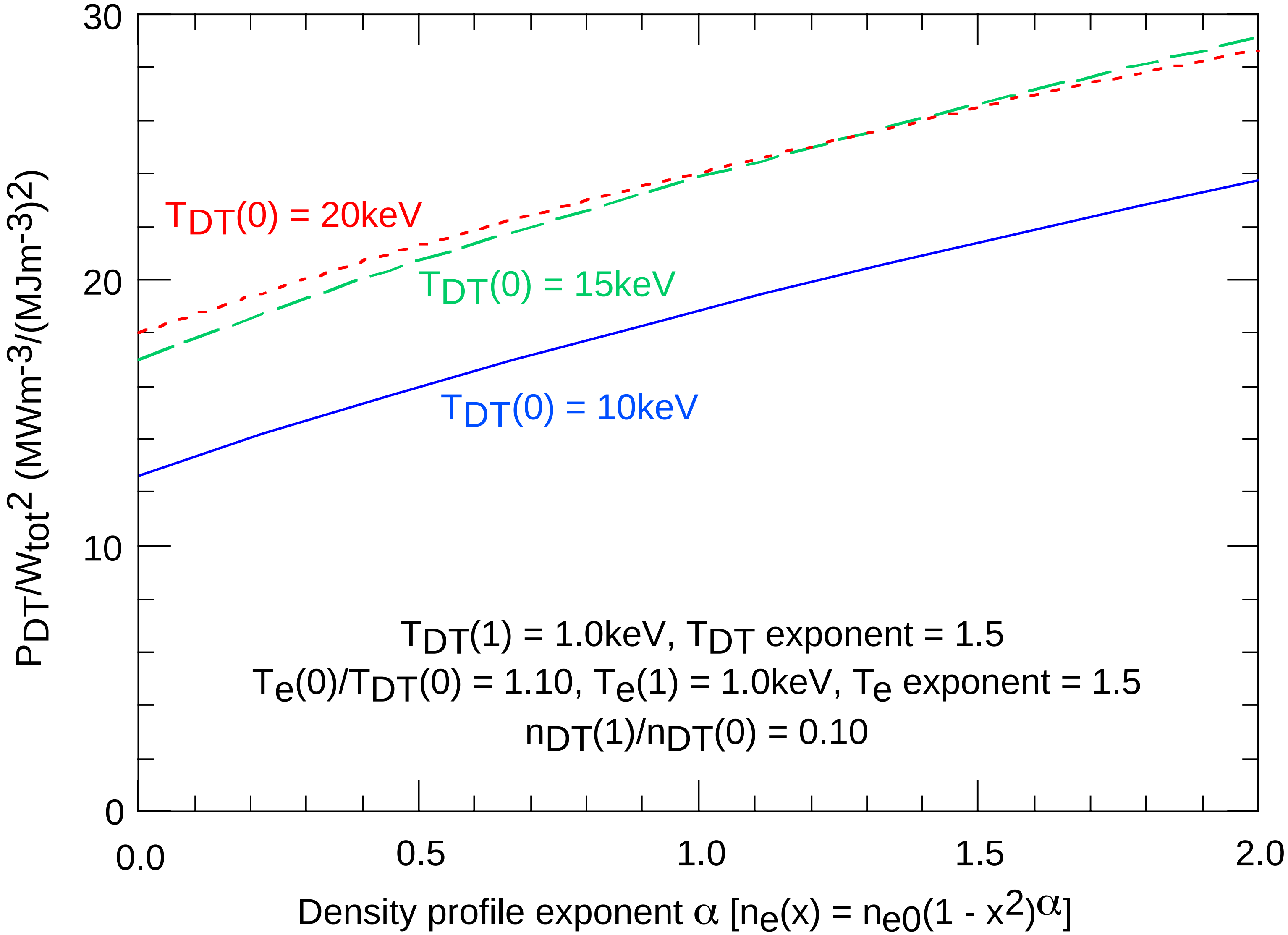
Fusion Power Profile with Realistic Edge

$T_i(0) = 15.0$keV, $T_i(1) = 1.0$keV, T_i exponent = 1.5
$T_e(0) = 16.5$keV, $T_e(1) = 1.0$keV, T_e exponent = 1.5
$n_{DT}(1)/n_{DT}(0) = 0.10$, n_{DT} exponent= 0.5
$P_{DT}/W_{tot}^2 = 20.7$ $MWm^{-3}/(MJm^{-3})^2$



Peaked Profiles Demand Lower β



Confinement is the Issue for Tokamaks

Central values	ITER[1]	TFTR	JET[2]	JT-60U[3]
Plasma composition	DT	DT	DT	D
Mode	ELMy H-mode	Supershot	Hot-ion ELM-free H-mode	Reversed-shear High-β_P
n_e [$10^{20}m^{-3}$]	1.3	1.02	0.42	0.85
n_{DT} [$10^{20}m^{-3}$]	0.8	0.60	0.35	0.48 (n_i)
n_{He} [$10^{20}m^{-3}$]	0.2	0.002		
T_I [keV]	19	40	28	16
T_e [keV]	21	13	14	7
Z_{eff}	1.8	1.8	2.1	3.2
p_{tot} [MPa]	0.8	0.75	0.37	0.22
P_α [MWm^{-3}] (source)	0.5	0.45	0.14	
P_{aux} [MWm^{-3}]	0	3.4	0.8	0.3

- Tokamaks have confined plasma with pressure needed for ignition
  - Higher β is only an advantage if required $\langle n^2T^2 \rangle$ is achieved
- All confinement improvements are not created equal
  - In particular, dW/dt doesn't make fusion power