Integrated Transport Modeling of High-Field Tokamak Burning Plasma Devices

Arnold H. Kritz,
T. Onjun, C. Nguyen, P. Zhu, G. Bateman

Lehigh University Physics Department
16 Memorial Drive East, Bethlehem, PA 18015

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Integrated Transport Modeling of High-Field Tokamak Burning Plasma Devices

- **Integrated transport modeling simulations carried out**
  - using theory-based Multi-Mode and empirical Mixed-Bohm/gyro-Bohm transport models
  - BALDUR predictive transport code
  - simulating several high-field tokamak reactor designs with scans over parameter ranges

- **Transport models with very different gyro-radius scaling match experimental data equally well**
  - hence, burning plasma experiment is needed to test validity of core transport models
  - also needed to test bounday condition models e.g., models for the height of H-mode pedestal

Baseline Design Parameters

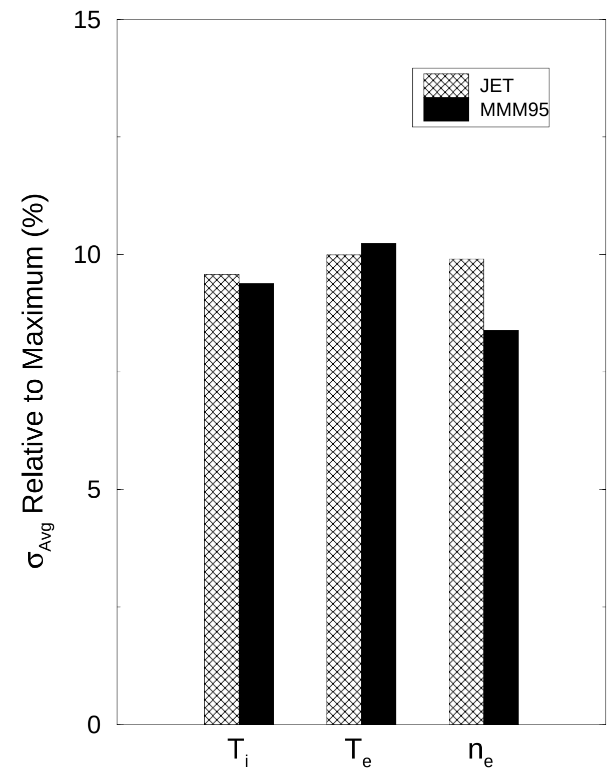
Simulations have been carried out for three high-field tokamak reactor designs: Ignitor, Mazzucator, and FIRE.

Physical Quantity	Symbol	Unit	Ignitor	Mazzucato	FIRE
Major Radius	R	m	1.33	3.92	2.00
Minor Radius	a	m	0.455	1.12	0.525
Elongation	κ		1.80	1.75	1.80
Triangularity	δ		0.40	0.40	0.40
Toroidal Magnetic Field	B_t	Tesla	13	8	10
Plasma Current	I_p	MA	12	12	6.5
Vol. avg. electron density	$< n_e >$	10^{20} m^{-3}	4.7	2.0	4.5
Auxiliary Heating	$P_{\rm aux}$	MW	10	30	22
Alpha Power	P_α	MW	14.1	49.1	12.3
Ohmic Power	P_Ω	MW	5.9	2.3	2.0
Fusion Gain	$Q_{\rm fusion}$		4.5	7.6	2.6
Diagnostic Time	$t_{\rm diag}$	sec	7	20	20

Comparison Between Transport Models

- **Two transport models**
  - Multi-Mode-95 (MMM95) gyro-Bohm scaling
  - Mixed-Bohm/gyro-Bohm (MB/gB) mostly Bohm scaling
- **Match experimental data equally well**
  - 22 H-mode DIII-D and JET
  - 13 L-mode TFTR and DIII-D
- **Can predict different performance**

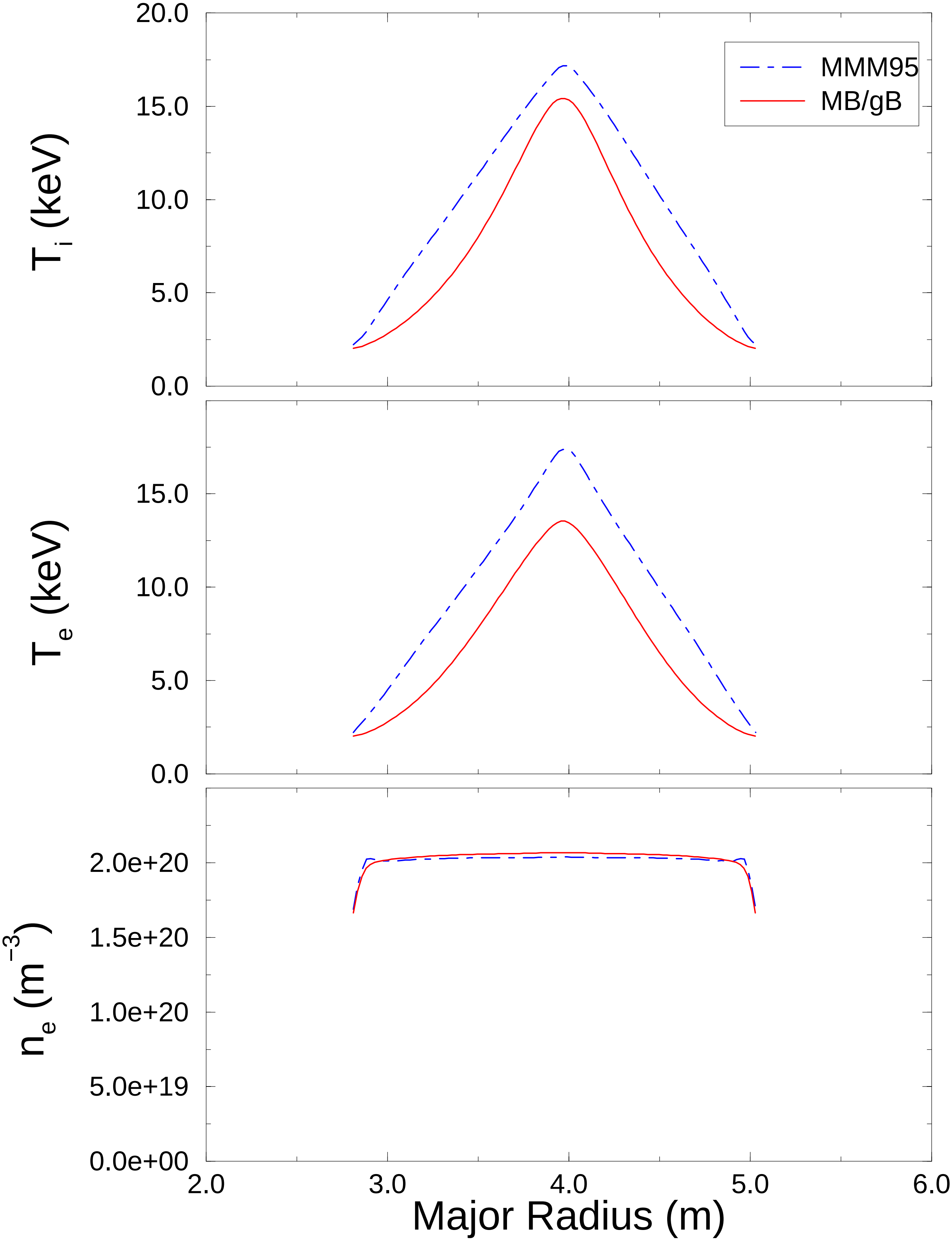
	FIRE	Mazz.	Ignitor
Model	Q	Q	Q
MB/gB	2.7	3.2	2.1
MMM95	2.6	7.6	4.5



Average normalized RMS deviations compared using MMM95 and MB/gB models for 22 H-mode discharges in JET and DIII-D.

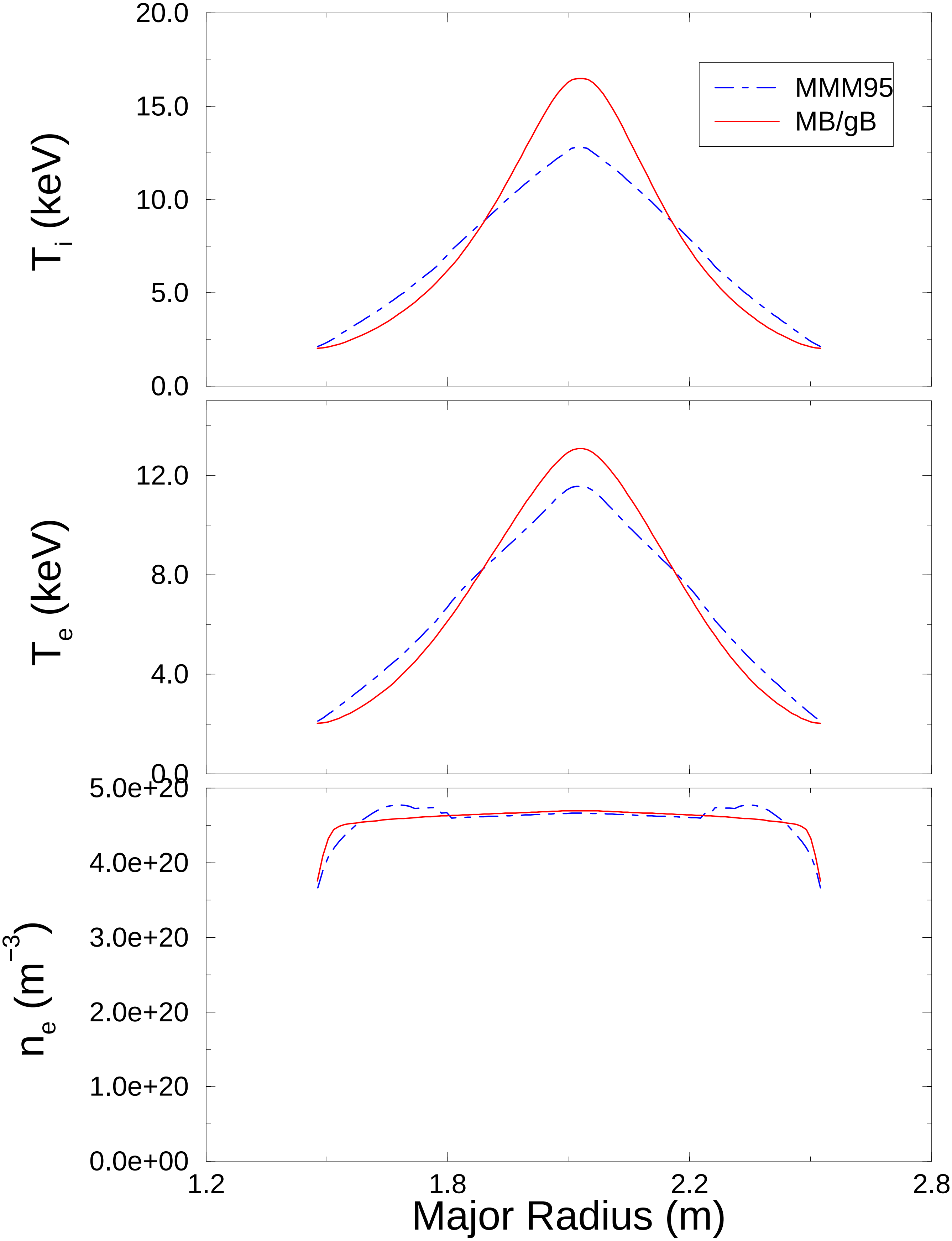
Comparing MMM95 and MB/gB Models

Mazzucato baseline design at 20.0 sec



Comparing MMM95 and MB/gB Models

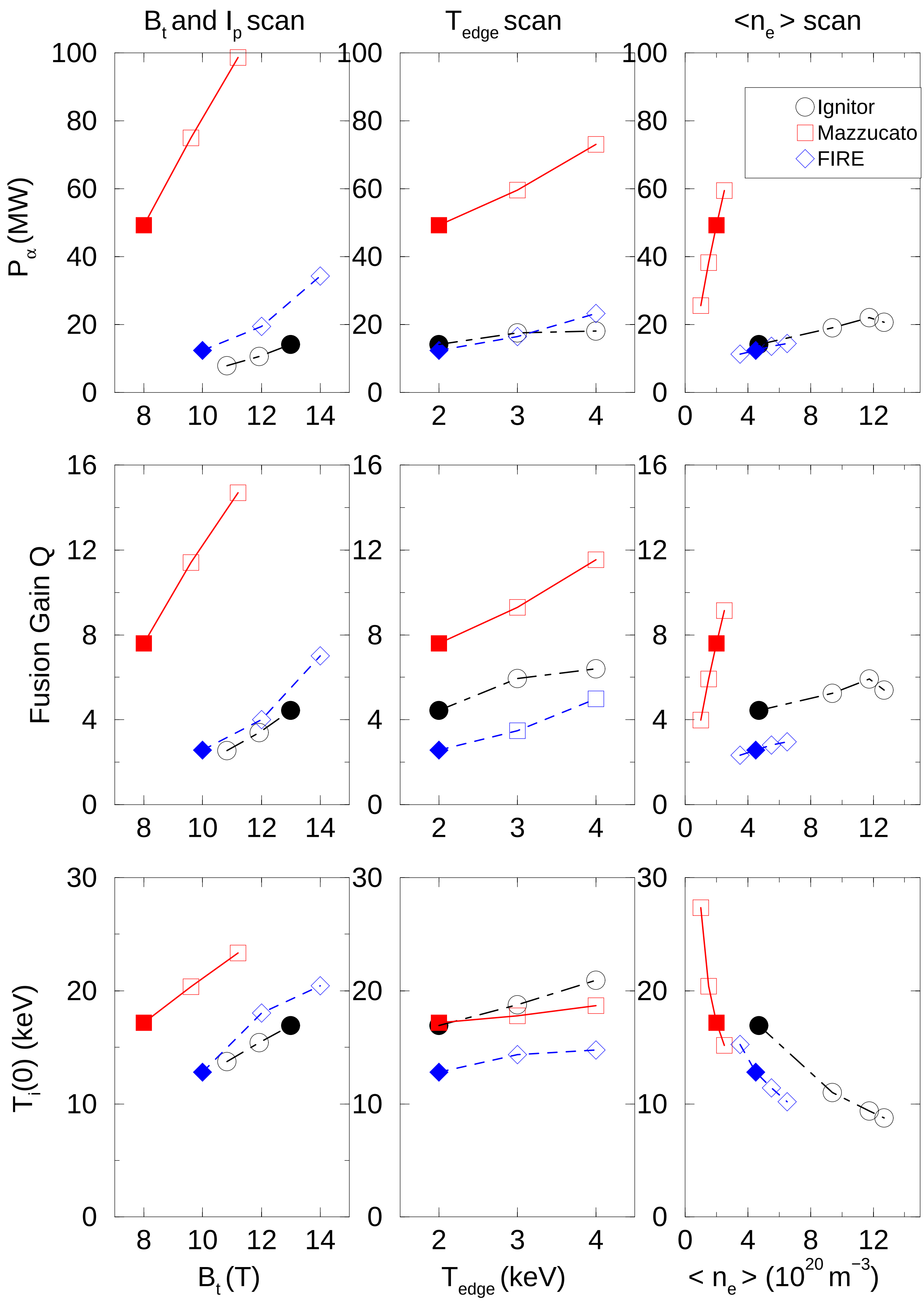
FIRE baseline design at 20.0 sec



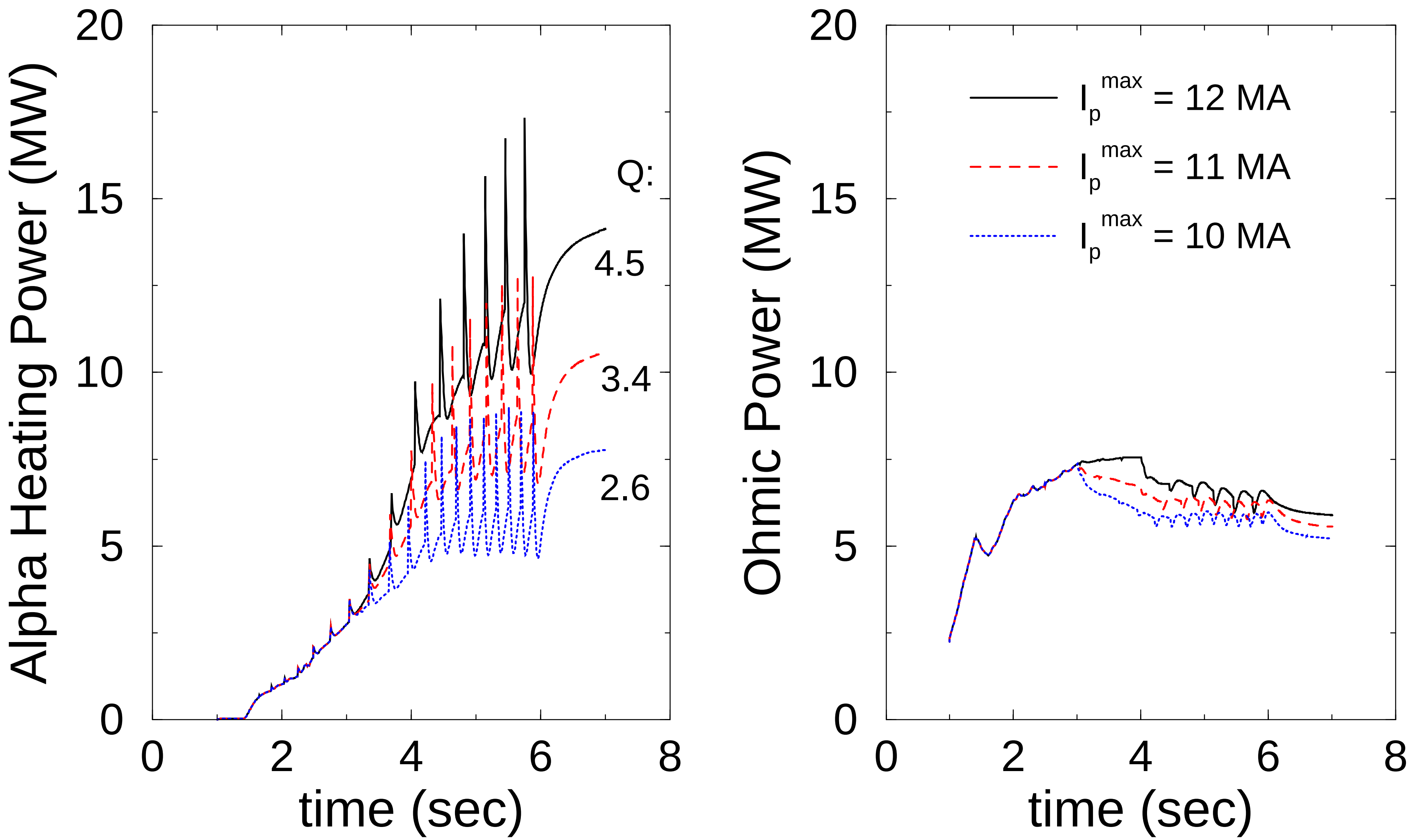
Systematic Scans of Fusion Reactor Simulations

- **Increasing plasma current and toroidal magnetic field has the biggest effect on performance**
  - Magnetic q held fixed
- **Increasing edge temperature (at top of H-mode pedestal) increases performance**
  - Stiff transport models are sensitive to edge temperature
  - Developing a model for H-mode pedestal
- **Increasing plasma density reduces plasma temperature**
  - Net increase in performance up to nearly the Greenwald limit
- **Impurity content**
  - Increasing Z_{eff} degrades performance
- **Pellet injection**
  - Can improve performance

BALDUR Simulations using the MMM95 Model



Ignitor Current Scan



Model Being Developed for Height of Pedestal at the Edge of H-mode Plasmas

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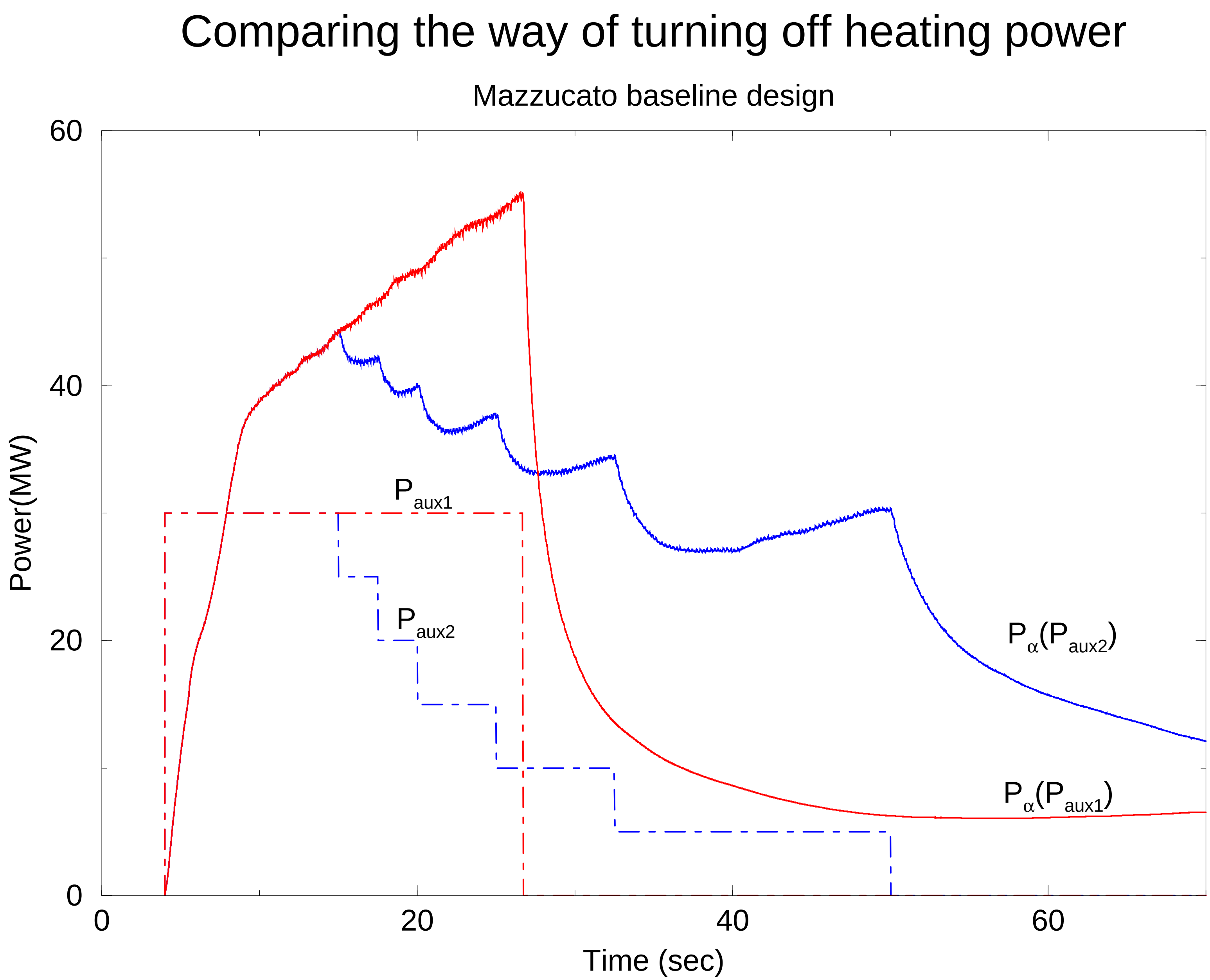
- **Predictive boundary conditions needed for simulations**
  - **Plasma boundary consists of scrape-off-layer and pedestal**
- **Pedestal temperature decreases with increasing density relative to Greenwald density**
  - **Reduced pedestal temperature also reduces core temperature predicted by stiff transport models**
  - **This effect partly offsets increase of fusion power with density**
- **Increasing plasma current increases Greenwald density**
  - **Allows higher plasma density for same pedestal temperature which further increases plasma performance**



Comparing the way of turning off heating power
Mazzucato baseline design
Power(MW)
Time (sec)
0
20
40
60
0
20
40
60
P_{aux1}
P_{aux2}
$P_{\alpha}(P_{aux2})$
$P_{\alpha}(P_{aux1})$

Physics Issues in Reactor Simulations

- **Different transport models extrapolate in different ways to fusion reactors**
  - **Several different models match experimental data equally well**
  - **Issues of stiffness and scaling**
- **Sawtooth oscillations can be very broad**
  - $r_{\mathrm{mix}}/a \geq 0.6$ **observed in simulations**
  - **Can be reduced by using current drive or current ramping**
  - **Might have a big impact on fast alpha particles**
- **Fusion power depends on time history of auxiliary power**
  - **Rapidly turning off auxiliary heating power produces a rapid decay of alpha heating power** $P_\alpha(t)$
  - **Slow reduction in auxiliary power yields slow** $P_\alpha(t)$ **decay**