Motivation for Building a High-Field Tokamak Burning Plasma Experiment

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A Few of the Reasons to Build a High-Field Tokamak Reactor

$B \sim$ 12 tesla, $R \sim$ 1.75 m, cost $\sim$ $ 1 B

1. **Test physics of alpha heating**
2. **Test gyro-radius scaling of confinement**
3. **Test the scaling of H-mode (onset and pedestal height)**
4. **Can Internal Transport Barriers be produced in reactors?**
5. **Does strong electron heating produce particle pinches?**
6. **Test effect of large sawtooth oscillations on reactor performance**
7. **Test divertors at high heat loads**
8. **What will $\langle Z_{\rm eff} \rangle$ be in fusion reactors?**
9. **Public proof of ignition**

Test Physics of Alpha Heating

- **Fast alphas may degrade or enhance performance**
  - **Fast alphas might drive new instabilities (such as TAE modes)**
  - **The electron heating from fast alphas might cause particle pinches $\longrightarrow$ more peaked density profiles**
- **Fast alphas may be ejected by sawtooth oscillations or they may stabilize sawtooth oscillations**
  - **Very broad sawtooth mixing radius in fusion reactors**
- **High field tokamak reactor designs have:**
  - **high plasma density**
    $\longrightarrow$ short slowing down time for fast alphas
    but high source rate
  - **moderate size and high energy density**
    $\longrightarrow$ short confinement times

Gyro-Radius Scaling

The normalized gyro-radius is defined as

$$\rho_* \equiv \rho_s/a = (2T_e M_i)/(eB_T a) = 4.57 \times 10^{-3} \frac{\sqrt{T_e[\mathbf{keV}]\; M_i[\mathbf{AMU}]}}{B_T[\mathbf{tesla}]\; a[\mathbf{m}]}$$

In present-day tokamaks, $3.7 < \rho_*(0) \times 10^3 < 12.8$

In fusion reactor designs with $T_e(0) = 20$ **keV**

Design	a[m]	B_T[tesla]	$\rho_*(0) \times 10^3$
ITER-EDA	2.8	5.7	2.0
ITER-FEAT	2.0	5.3	3.0
Mazzucato	1.1	8.0	3.2
BPX (1991)	0.8	9.0	4.5
Ignitor	0.455	13.0	5.5
FIRE	0.525	10.0	6.2

Transport Barriers

- Need to test scaling relations for H-mode
  - Conditions needed to produce and maintain H-mode
  - Height of temperature and density pedestal which has a strong effect on core confinement
  - Control ELMs
  - Models are being developed for H-mode pedestal
- Internal Transport Barriers (ITBs) for enhanced confinement
  - It may be possible to produce Internal Transport Barriers in fusion reactors
  - It has been shown in C-mod that ICRF can drive significant plasma velocity and flow shear
  - Can use current ramp to produce reversed magnetic shear (which helps produce ITBs)

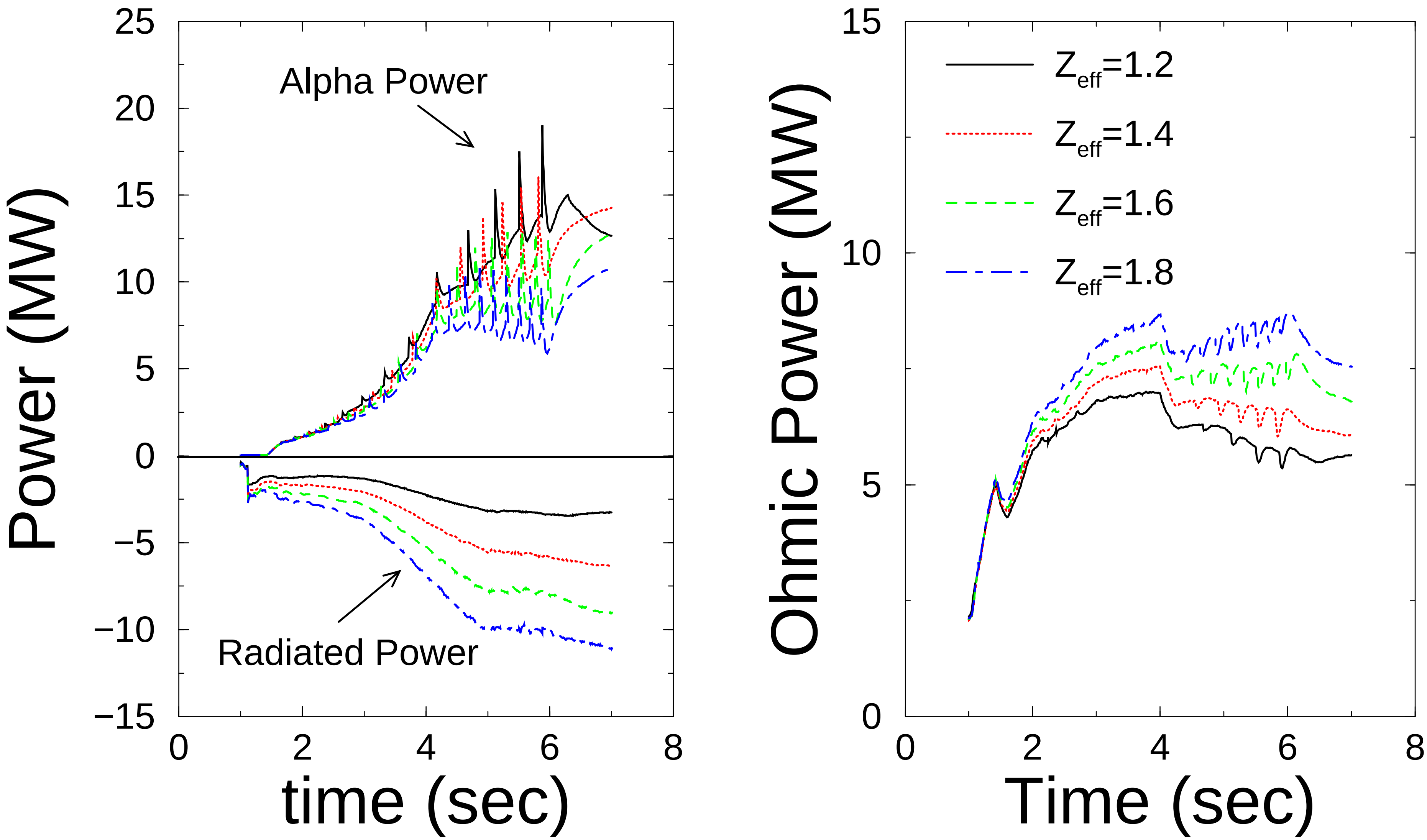
Particle Pinches

- **Peaked hydrogenic density profiles enhance fusion reactor performance**
  - **The reason is simple: more fuel in hotest part of plasma**
- **Peaked helium and impurity profiles degrade performance**
  - **Low Z impurities dilute fuel**
- **There is theoretical evidence that strong electron heating can produce particle pinches**
- **There is experimental evidence that RF heating can produce peaked density profile under some conditions**

Large Sawtooth Oscillations

- In most fusion reactor designs, sawteeth are very broad ($r_{\mathrm{mix}}/a \approx 60\%$ or more) and large amplitude
  - Reason: reactor designs push parameter limits: high elongation and high current (low magnetic q)
- Sawteeth may have large effect on fast alphas, fusion heating, and confinement
  - We do not know if fast alphas will be ejected by giant sawteeth
  - Simulations show pulse of fusion heating with each sawtooth crash
- Sawteeth can be delayed or avoided ($q_{\mathrm{axis}} > 1$)
  - Use current ramp to transiently keep $q_{\mathrm{axis}} > 1$
  - Use current drive and bootstrap current for long pulse
  - Fast alphas may help stabilize sawteeth

Ignitor Impurity Scan



Test Divertors at High Heat Loads

- At sufficiently high density, divertors can radiate away most of the heat flux from the plasma
  - This reduces heat flux to divertor plate
  - But the high edge density may adversely affect confinement
- Test divertors in pulsed mode before going to steady state

What will $\langle Z_{\rm eff} \rangle$ be in fusion reactors?

- High impurity content ($\langle Z_{\rm eff} \rangle$) degrades fusion reactor performance
  - No way to extrapolate $\langle Z_{\rm eff} \rangle$ to fusion reactors