$m = 1$ MODE EFFECTS ON IGNITION AND BURNING

- Most existing experiments operate in the regime of the resistive MHD 1/1 mode.

  BPX's will operate on the border or in the ideal MHD unstable regime.

  - Mode and sawtooth behavior cannot be extrapolated directly from most present experiments to BPX's.

- Ideal MHD unstable 1/1 modes are driven by the pressure gradient.

  - Resistivity increases the mode growth rate and marginal stability threshold, below a characteristic pressure or mode growth rate for given plasma configuration.

- Electrostatic effects allow the temperature crash without redistribution of the current, so that $q_o < 1$ remains fixed in time.

  - Sawtooth period is no longer directly linked to a current diffusion time (unlike the BPX predictions shown so far!).

  - Electrostatic component is important when, eg, ω_{*i} is large,

SAWTOOTH PREDICTIONS

- **There is no model to predict sawtooth period that can be reliably extrapolated to burning plasmas.**
- **Sawtooth observations show many apparently random departures from strict periodicity of crashes.**
- **Porcelli model is "cartoon" physics.**
  Simple form, easily presented and implemented in codes, BUT
  It does not describe the real $m = 1$ physics.
  - **Does not describe reconnection process.**
  - **Large approximations are made in calculating the various terms. These disguise the evaluation of the real physical effects.**
    Difficult to tell what is physics and what is artifact.
  - **For the critical parameter, the ideal MHD free energy δW, both the marginal stability condition and its value above marginal stability are very roughly approximated.**
    $\delta W_{MHD} \propto \epsilon_1^2(\beta_{p1}^2 - \beta_{p,crit}^2)$ is the $a/R \rightarrow 0$, circular, low β_p Bussac form.
    More generally, $\delta W_{MHD} \simeq k_0 + k_1\beta_{p1} + k_2\beta_{p1}^2$.

- Neglects many important non-ideal MHD effects.
- Neglects nonlinear effects, which are expected to be important at very low mode amplitude. Stabilizing or destabilizing?

• Ideal MHD 1/1 mode stability with free boundary:

  - No-wall dependence of the ideal MHD stability boundary is a toroidal mode coupling effect. Difference between wall and no-wall growth rates is reduced by higher edge $q_\psi > 3$ (Bondeson, et al).
  - Ignitor has the most conducting wall closest to the plasma (2.7 cm thick stainless steel vacuum vessel very close to the plasma boundary).

• Sawtooth predictions depend strongly on
1) the crash model and
2) the plasma reheat (transport, etc).

• Tests so far on present experiments are all in the resistive/current-diffusion regime, where q_o rises significantly during the crash.
No large scale calibrations against observed sawtooth size/period yet.

- **Applications to burning experiments so far appear to show that they are also in the resistive/current-diffusion regime BECAUSE q_o is assumed to rise during the crash.**
  - **Does not agree with present experiments at high β_p, where q_o remains fixed (eg, JET).**
  - **This regime depends on different parts of the model — NOT YET TESTED.**

IGNITOR PREDICTIONS

- **Ignitor sawtooth predictions from the model are determined by the thermal transport assumptions, not by the sawtooth model!**
  - **Poor control of the initial current ramp leads to low $T_o \sim 5$ keV at the end of the ramp and correspondingly large $q = 1$ radius.**
    $\rightarrow$ Large β_{p1} within $q \leq 1$ is more MHD unstable.
    $\rightarrow$ Large crash radius and even larger mixing radius.
  - **Controlled by interaction of current/density/plasma size and shape programming and transport assumptions, including edge values,**
    Time-dependent.
    Difficult to balance properly.
    The reference Ignitor papers (Coppi et al, Physica Scripta (1992) and Sugiyama et al, Nucl. Fusion (1992)) were the first to recognize the importance of these factors, including the programming of current ramp phase, for ignition.
    Effect of sawteeth period on heating to ignition shown earlier in Coppi and Sugiyama, Comm. Plasma Phys. (1986).
  - **Many simulations since have confirmed that it is possible to program the**

current ramp phase properly.

- Assumed electron thermal transport model (Coppi-Tang) was not intended for OH regimes.

  Also, it is too strongly constrained to be realistic near ignition.

  Enforces a temperature profile that was fit to circular ohmic TFTR discharges.

- The assessment predicts that Ignitor sawteeth are determined by ideal MHD unstable conditions, while FIRE and ITER are 'resistive', despite Ignitor's lower β_{p1} and higher q_a.