



Error field/Locked mode scaling experiment on Alcator C-Mod

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B-field scaling of locked mode error field threshold



- Scaling of B_{err}/B_T locking threshold is needed to extrapolate to burning plasma and reactor regimes

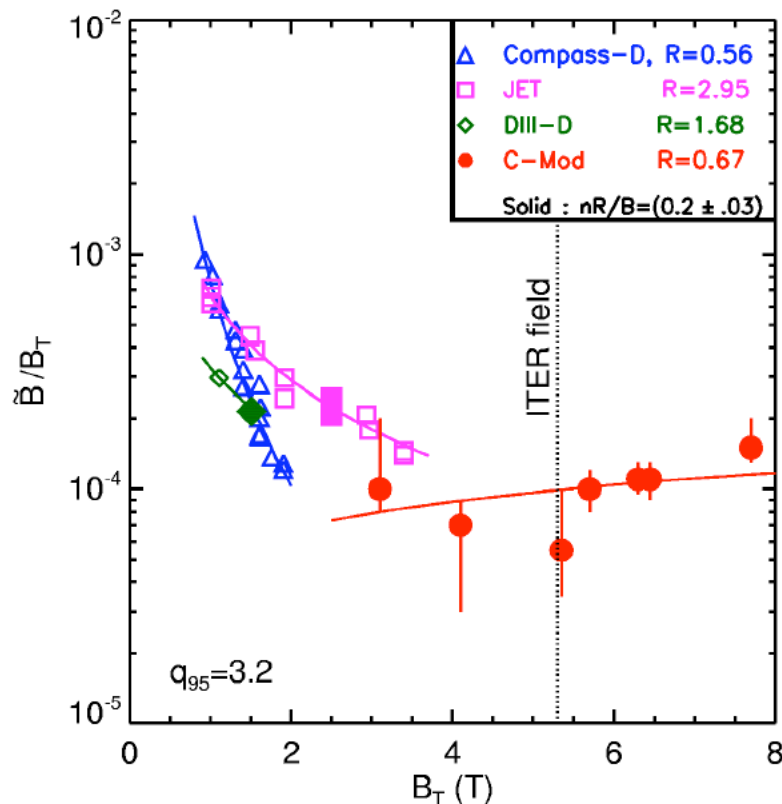
$$\frac{B_{\text{pen}}}{B_T} \propto n^{\alpha_n} B^{\alpha_B} q^{\alpha_q} R^{\alpha_R}$$

- It is well-established that $\alpha_n=1$
- From dimensionless scaling constraints,

$$\alpha_R = 2\alpha_n + \frac{5}{4}\alpha_B$$

- Therefore knowledge of α_B also determines the scaling with machine size

Scaling with B (and thus R) has significant uncertainty



- B-field scalings of threshold among various tokamaks show large disparity

C-Mod: $\alpha_B = -0.6 \pm 0.6$

JET: $\alpha_B = -1.2$

DIII-D: $\alpha_B = -0.96$

Compass-D $\alpha_B = -2.9$

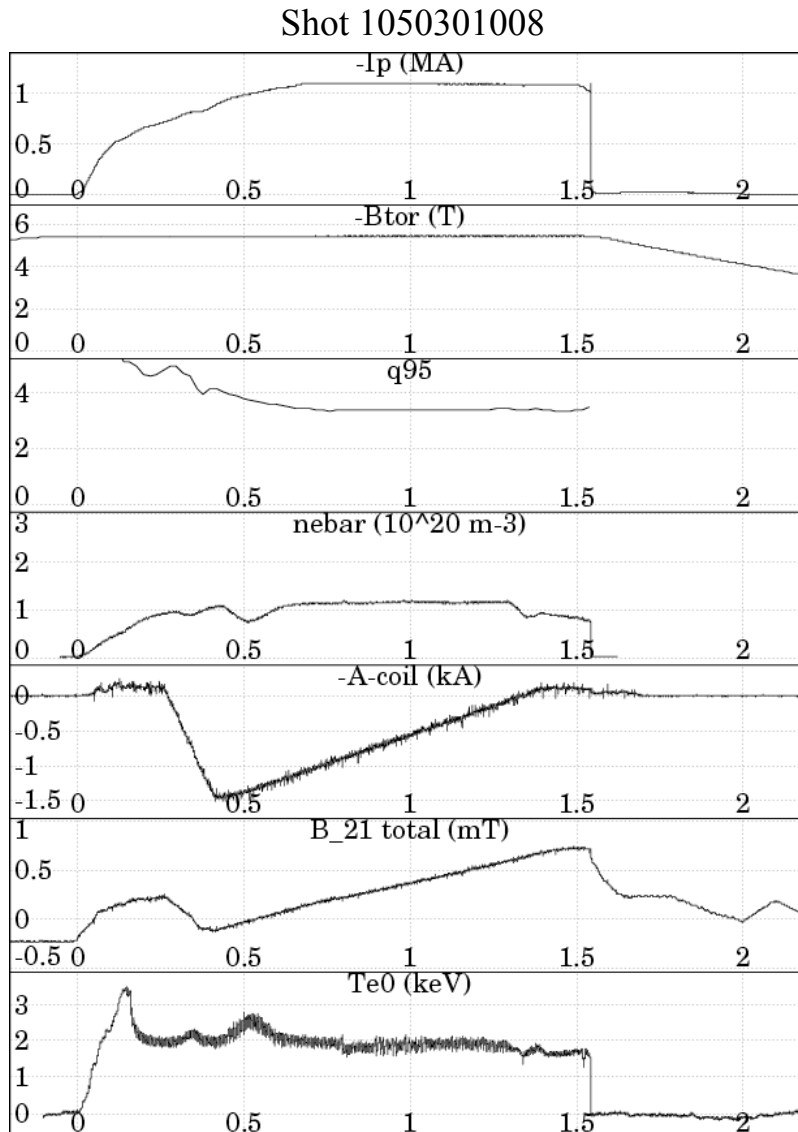
- Restricting dataset selection to same normalized density (n/n_M or n/n_G) reduces disparity somewhat, but error bars are still large

Locked mode size/field scaling experiment

Alcator
C-Mod

- Do a systematic, controlled parameter scan on C-Mod to clarify the B-field threshold dependence.
 - Fixed plasma shape
 - Fixed q_{95} (ITER value is 3.1) drops this parameter from scaling law
 - Fixed n/n_G (ITER ohmic target plasma = 0.17)
 - Vary B_T (with $I_p \propto B_T$ and $n \propto I_p \propto B_T$) shot-to-shot
 - During flattop, ramp B_{err} slowly to find locking threshold
- Determine α_B more accurately, and thus α_R

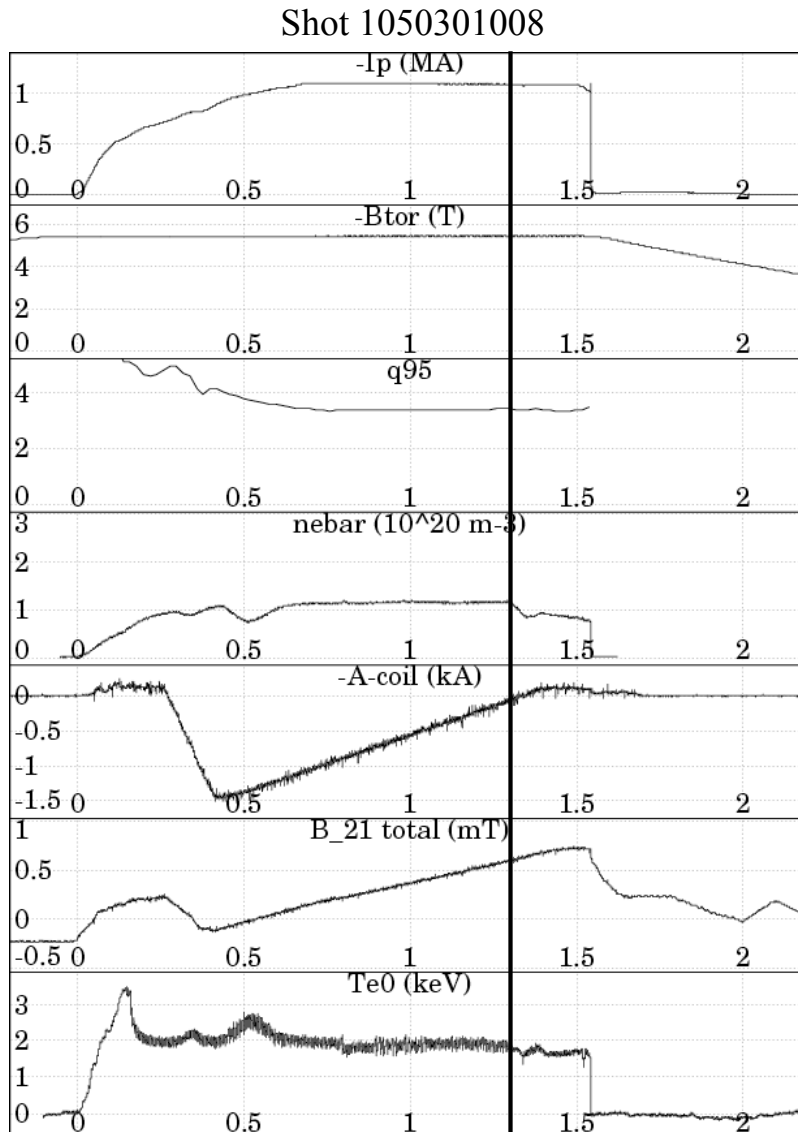
Example of shot from locked mode run



In flat-top of discharge, the applied error field (A-coil current) is ramped to find the threshold for mode locking.

Intrinsic error fields calculated as in S. Wolfe, PoP **12** (2005)

Example of shot from locked mode run



Locking indicators are:

- cessation of sawtoothing
- slight drop in density
- n=1 magnetic signature

Disruption often follows

Plasma parameters for this experiment



Shot #	Time (s)	Btor (T)	Ip (MA)	nebar (10 ²⁰ m ⁻³)	q95	n/nG	Total B21 (mT) at threshold
1050301011	1.38	3.11	0.60	0.70	3.47	0.17	0.39
1050301013	1.465	3.11	0.59	0.77	3.49	0.20	0.48
1050301015	1.40	4.07	0.80	0.95	3.46	0.18	0.52
1050301008	1.30	5.40	1.09	1.12	3.41	0.16	0.61
1050301019	1.365	5.96	1.21	1.29	3.35	0.16	0.71
1050301025	1.36	6.91	1.41	1.46	3.37	0.16	0.83

Scaling law to be fitted

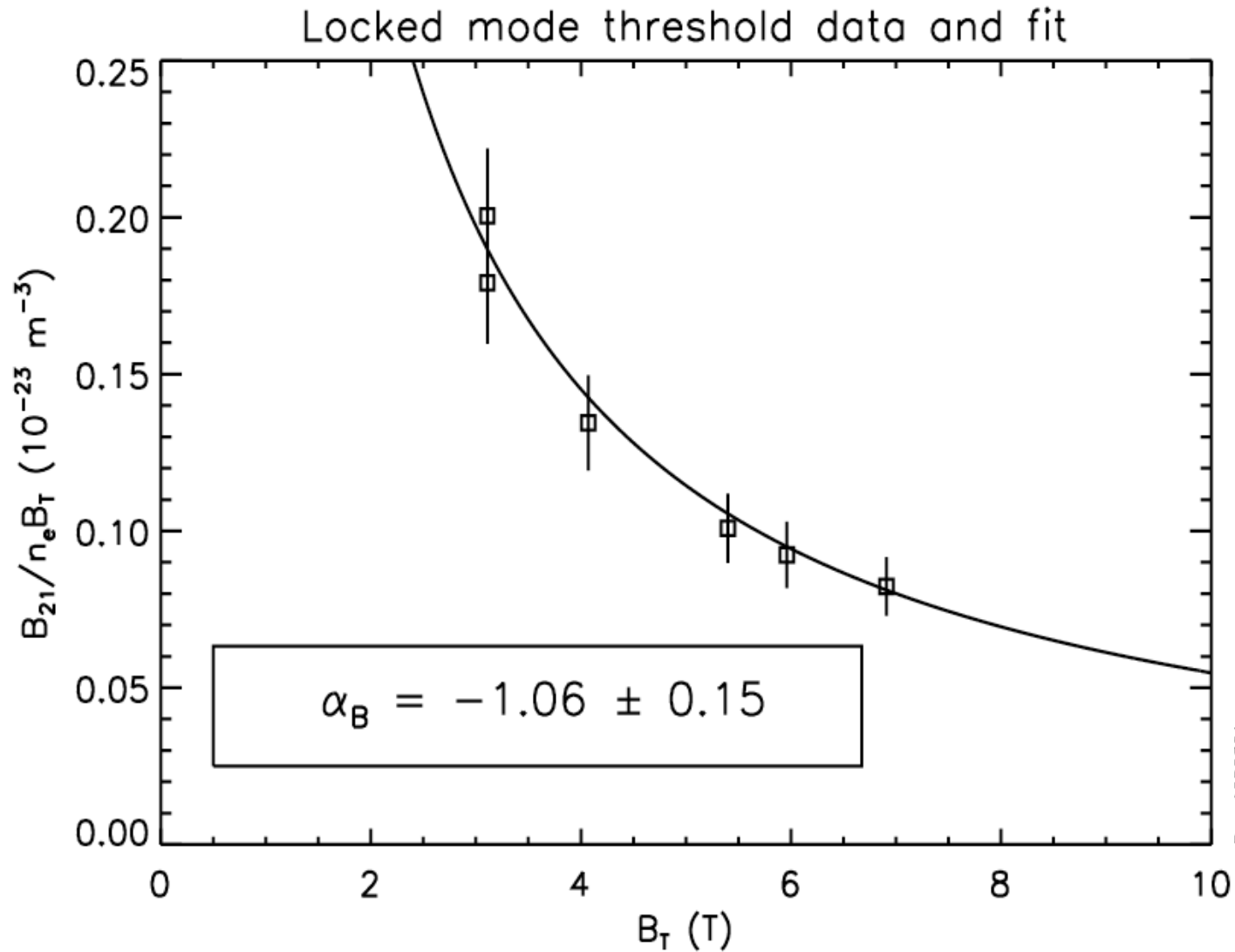
$$\frac{B_{pen}}{B_T} \propto n^{\alpha_n} B^{\alpha_B} q^{\alpha_q} R^{\alpha_R}$$

Since q is held constant, and R is fixed, and $\alpha_n=1$,

$$\frac{B_{21}}{n_e B_T} \propto B_T^{\alpha_B} \Rightarrow c B_T^{\alpha_B}$$

Fit c and α_B to dataset

Locked mode threshold data and fit



Result

$$\alpha_R = 2\alpha_n + 1.25\alpha_B = 0.68 \pm 0.19$$

Implies threshold $\tilde{B}_{21}/B \approx 0.9 \times 10^{-4}$ at ohmic density ($2 \times 10^{19} \text{ m}^{-3}$) of ITER target plasma

Caveats:

- Applied error fields were not dominant. Determination of intrinsic error fields relies on model and empirical data
- The universally observed linear density dependence of the locking threshold, which was relied on in this analysis, is not supported by theory.

Additional comment



Recent JET/C-Mod dimensionless identity experiments (same ρ^* , v^* , q_ψ , β) have been carried out, and these datasets can also be analyzed to get the B-field exponent (α_B).

- JET shape
- higher densities
- different applied error field structure

These give a very different value: $\alpha_B = -2.0$ to -2.9

The reason for this discrepancy is not understood, but is being investigated. This work includes an 8 T run (discrepancy is primarily at high field), varying the sidebands and toroidal phase of the applied error field, and further testing of the model of the intrinsic error fields.