The Stability of Advanced Operational Regimes on the Tokamak Fusion Test Reactor

E. D. Fredrickson, S. Sabbagh, M. Bell, D. Mansfield

and the TFTR group

Princeton Plasma Physics Laboratory,
Princeton, New Jersey

Outline -

High internal inductance plasmas

Extension of high l_i regime to high current and low q(a)

Disruption characteristics

Reversed Shear Plasmas

Low β - double tearing disruptions and sawteeth

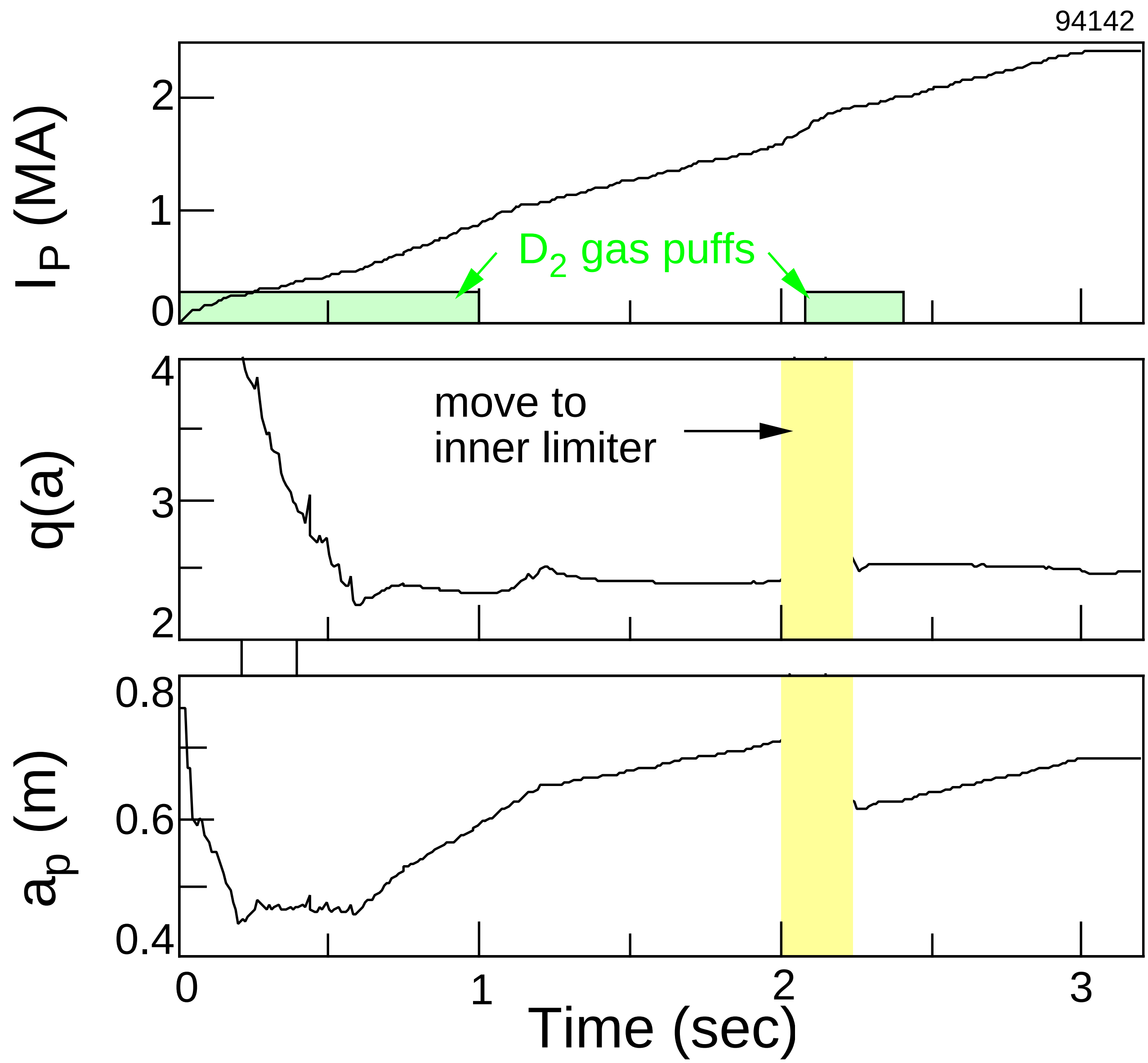
High β - infernal and ballooning modes, neo-classical MHD

Scaling of β-limiting phenomena

disruptions at 2 Tesla

"High li"

Plasma expansion creates "high li at high current (2.3MA), low q(a)



- Need initial q(a) ≅ 2.5 for final q(a) ≅ 4.

- q(a) ≅ 2.5 plasmas quiescent, reproducible, (≅90% success rate over development phase).

Expansion of the plasma raises q(a) from 2.5 to 4, increasing li.

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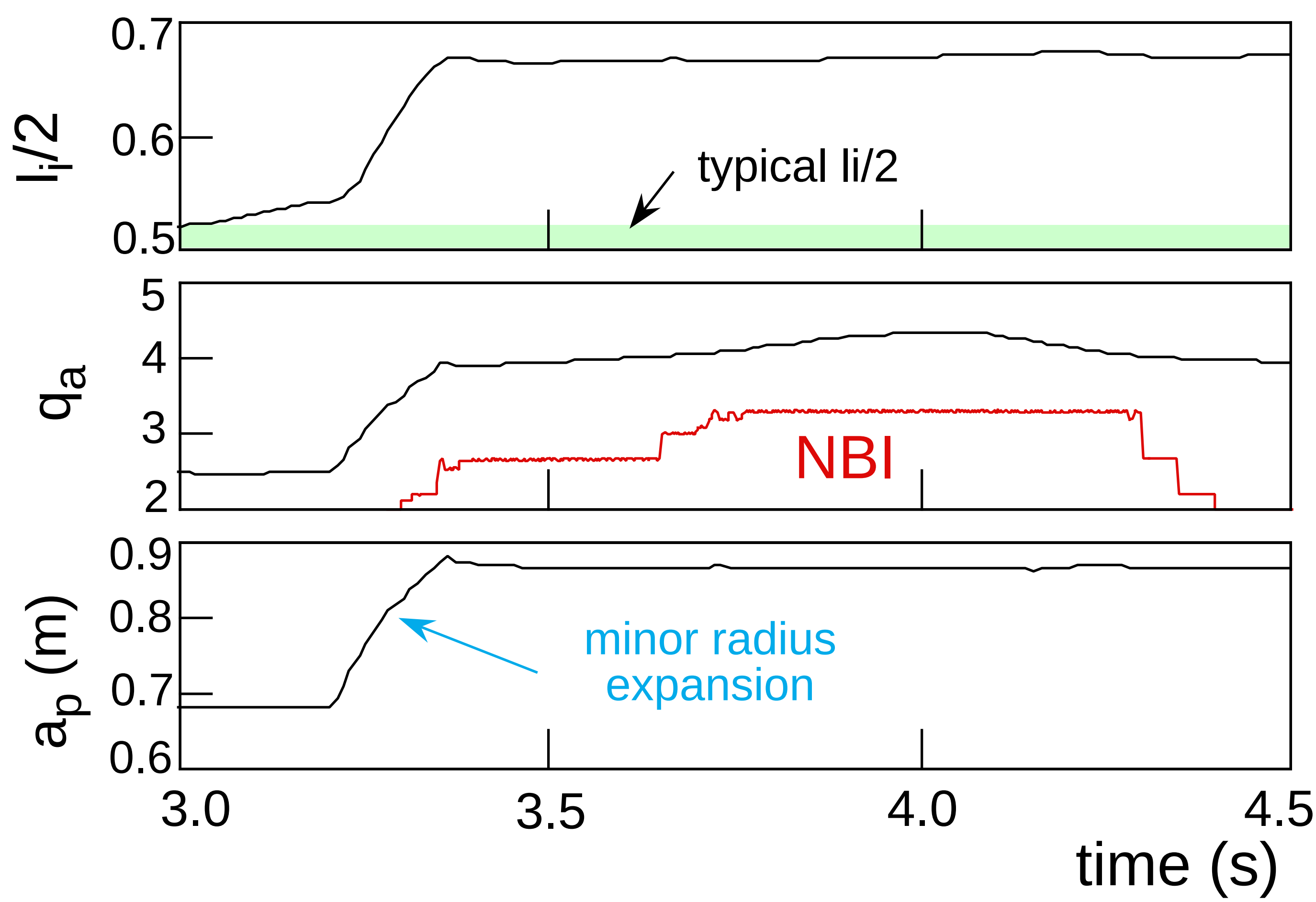
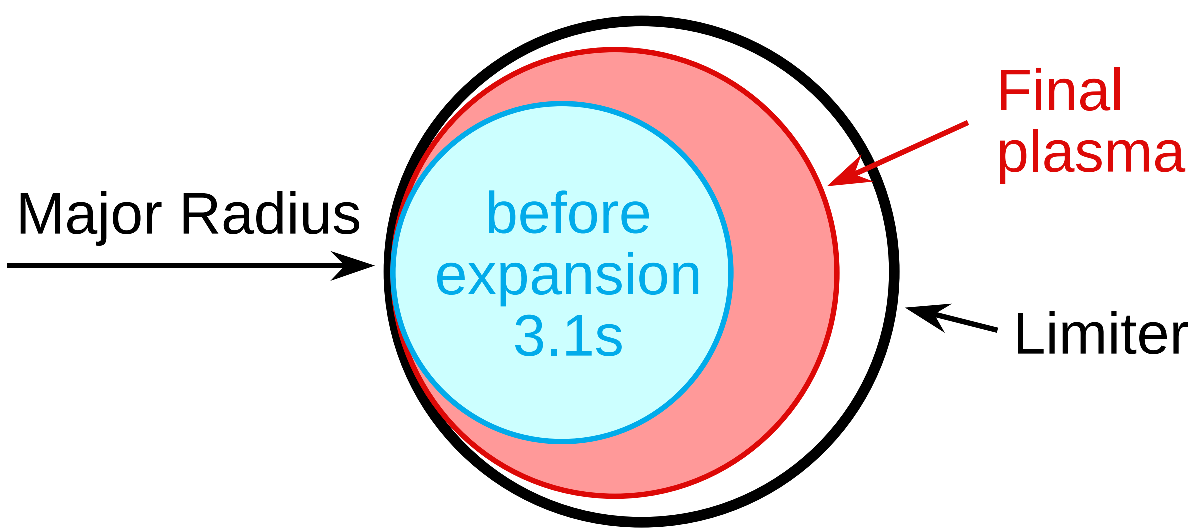
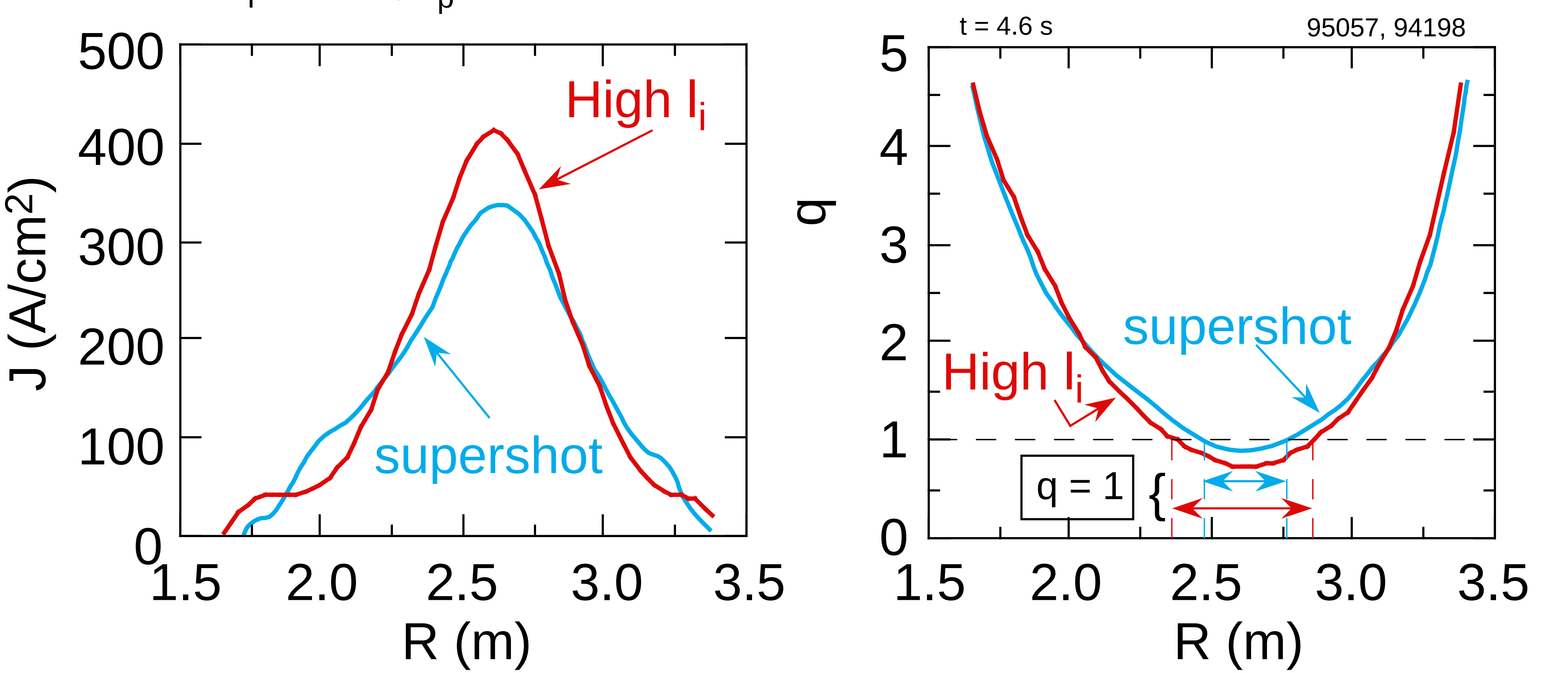




The measured current profile (MSE) is more peaked in high l_i plasmas

B_T = 5.6 T, I_p = 2.3 MA



- n=1 ideal internal kink unstable for q(0) < 1, but is not seen.

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FP&T

β_n increases linearly with l_i at q(a) ≤ 4

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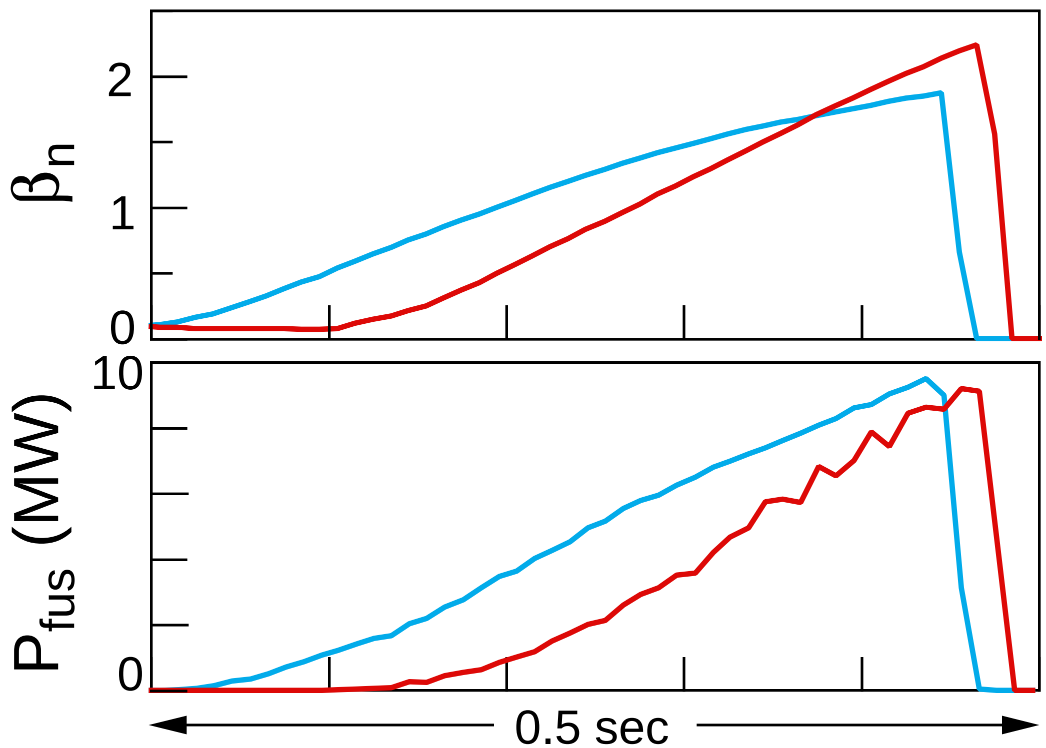
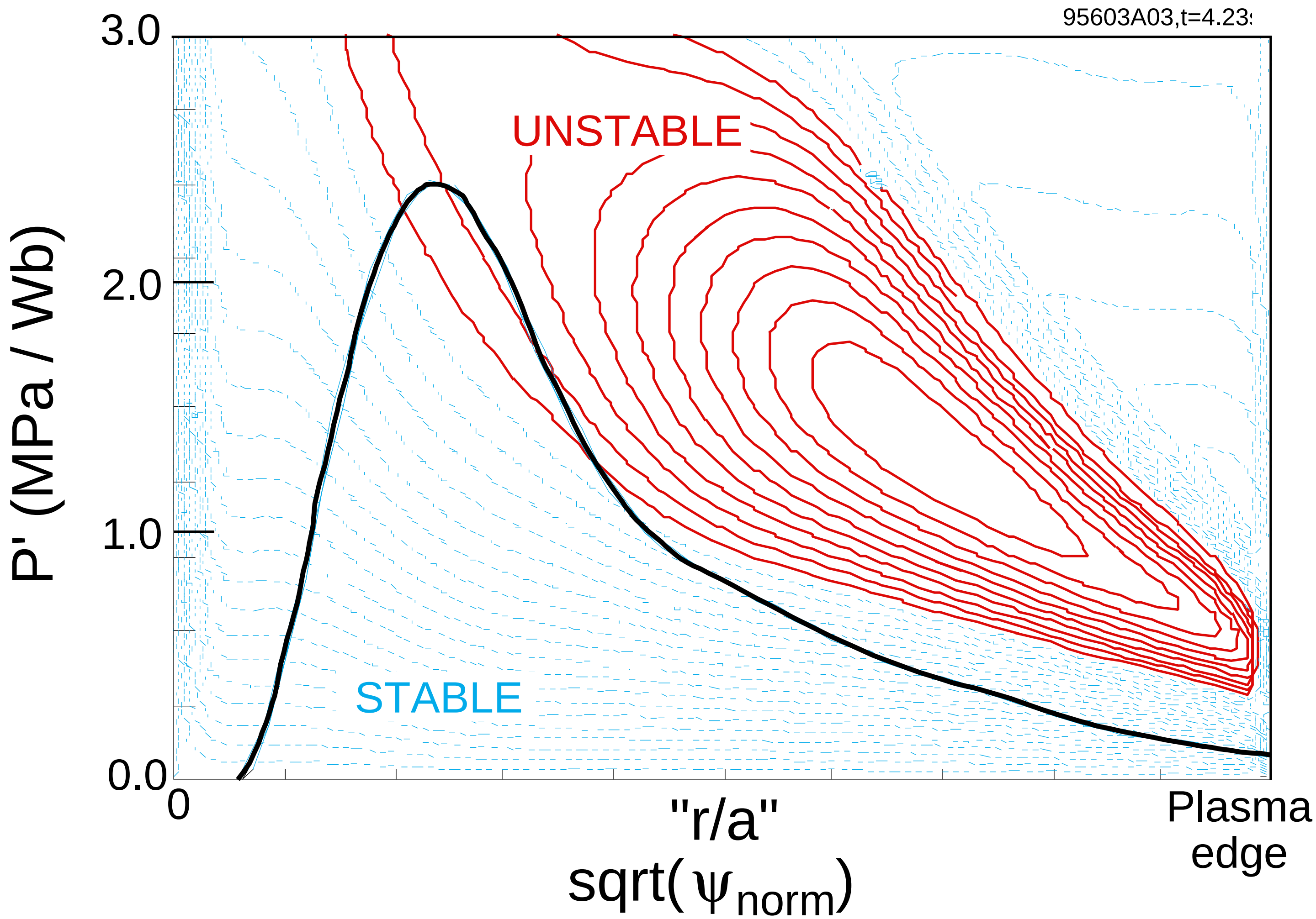


	High l_i	Supershot
I_P	2 MA	2.5MA
B_T	4.7 T	5.1 T
l_i	1.3	1.0

- Same performance at 2.0 MA, 4.7T as 2.5MA, 5.1T.
- Performance limited by limiter power handling constraints, not stability, at highest currents and fields.

The pressure gradient is near the ideal ballooning stability boundary in the core region prior to disruption.



Disruptions of "High l_i" plasmas have two thermal quenches; similar to disruptions of supershots

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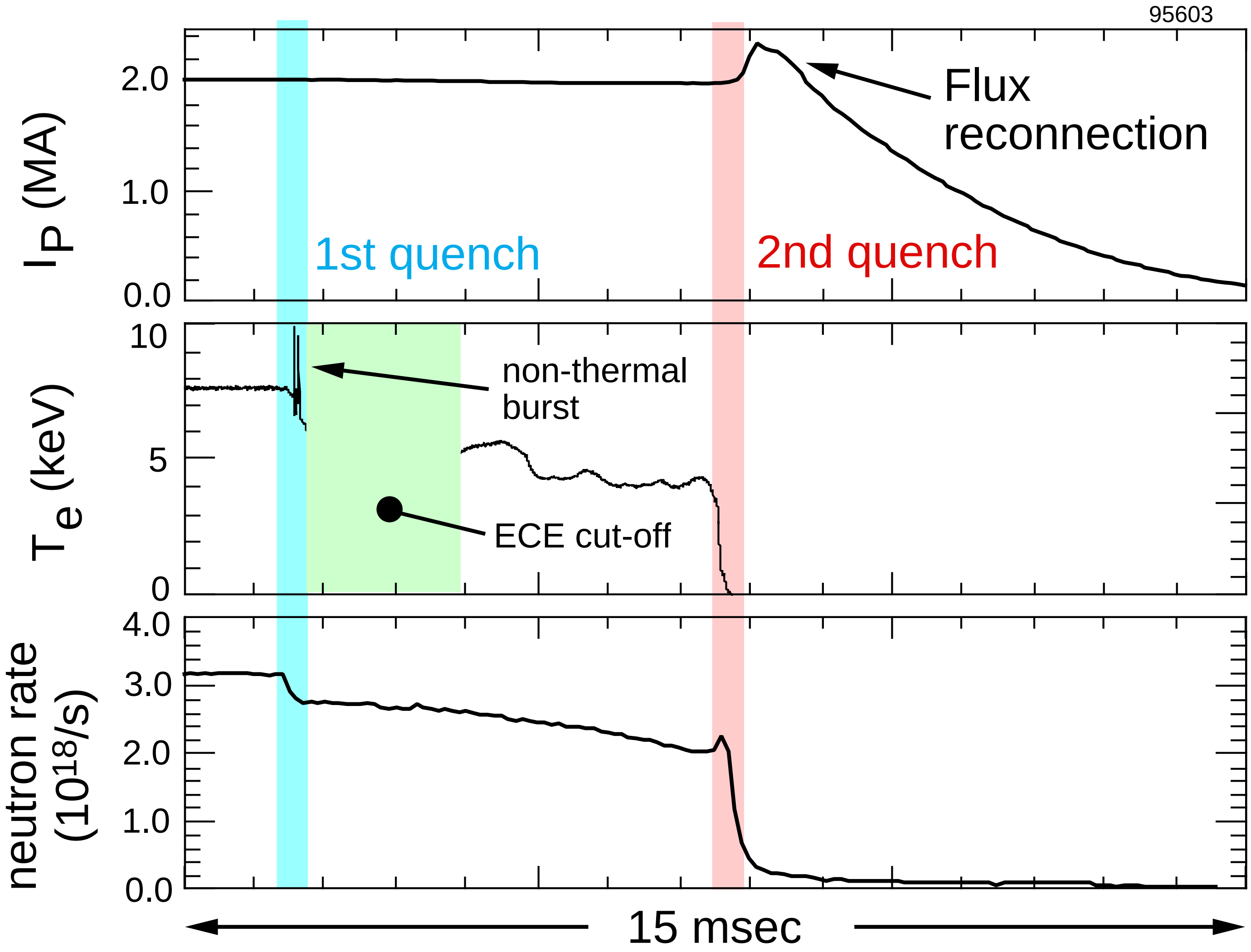
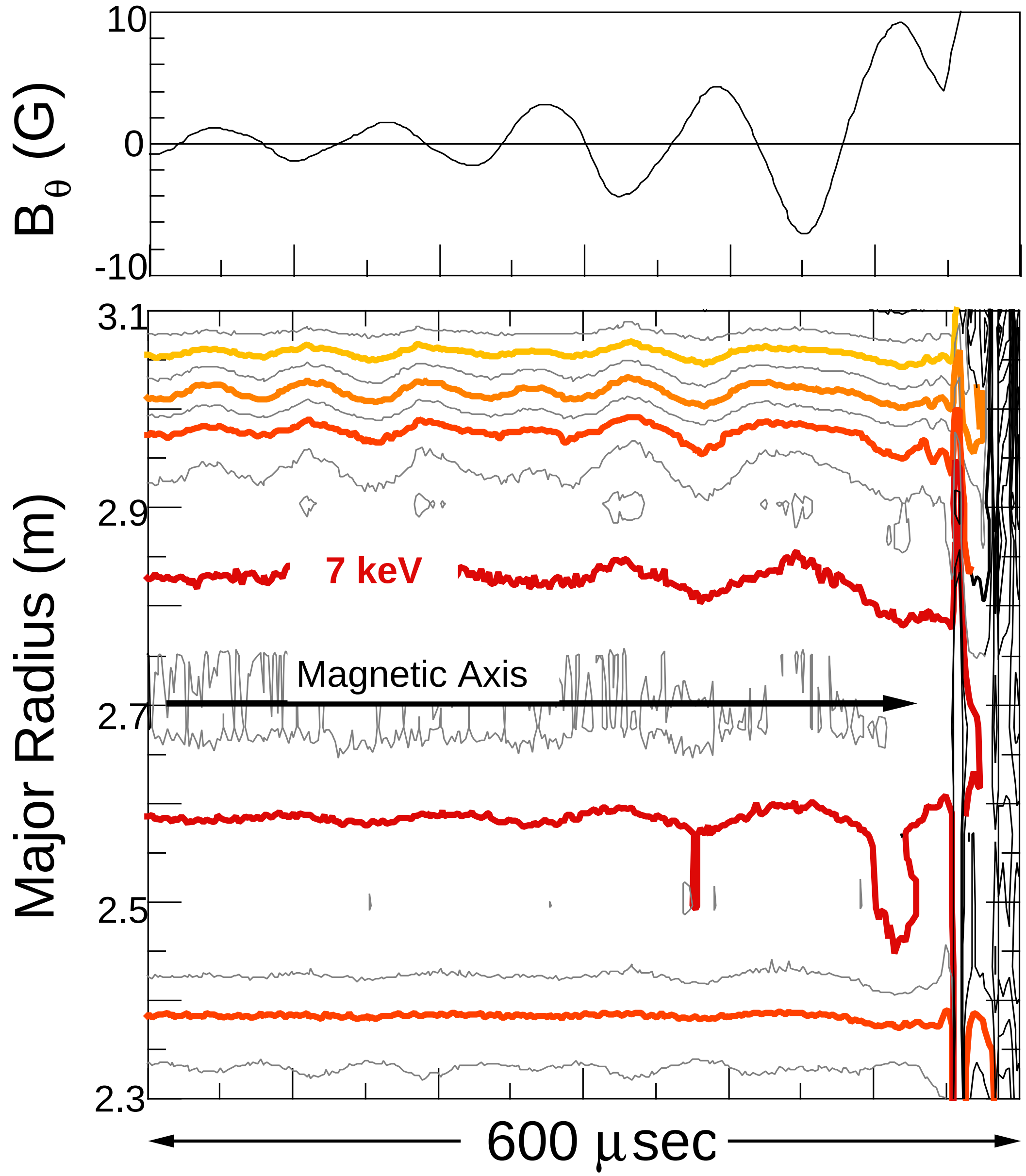


The disruption precursor in "high l_i" plasmas is an ideal internal kink mode



- Evidence for ballooning modes is not seen here.
- The n=1 kink has a strong internal component.
- The growth times are slower than "ideal"; $\tau_{Alfvén} < 1\ \mu sec$

Stability in Reversed Shear

Plasmas with reversed shear are susceptible to resistive instabilities in the low β phase, ideal modes with high β

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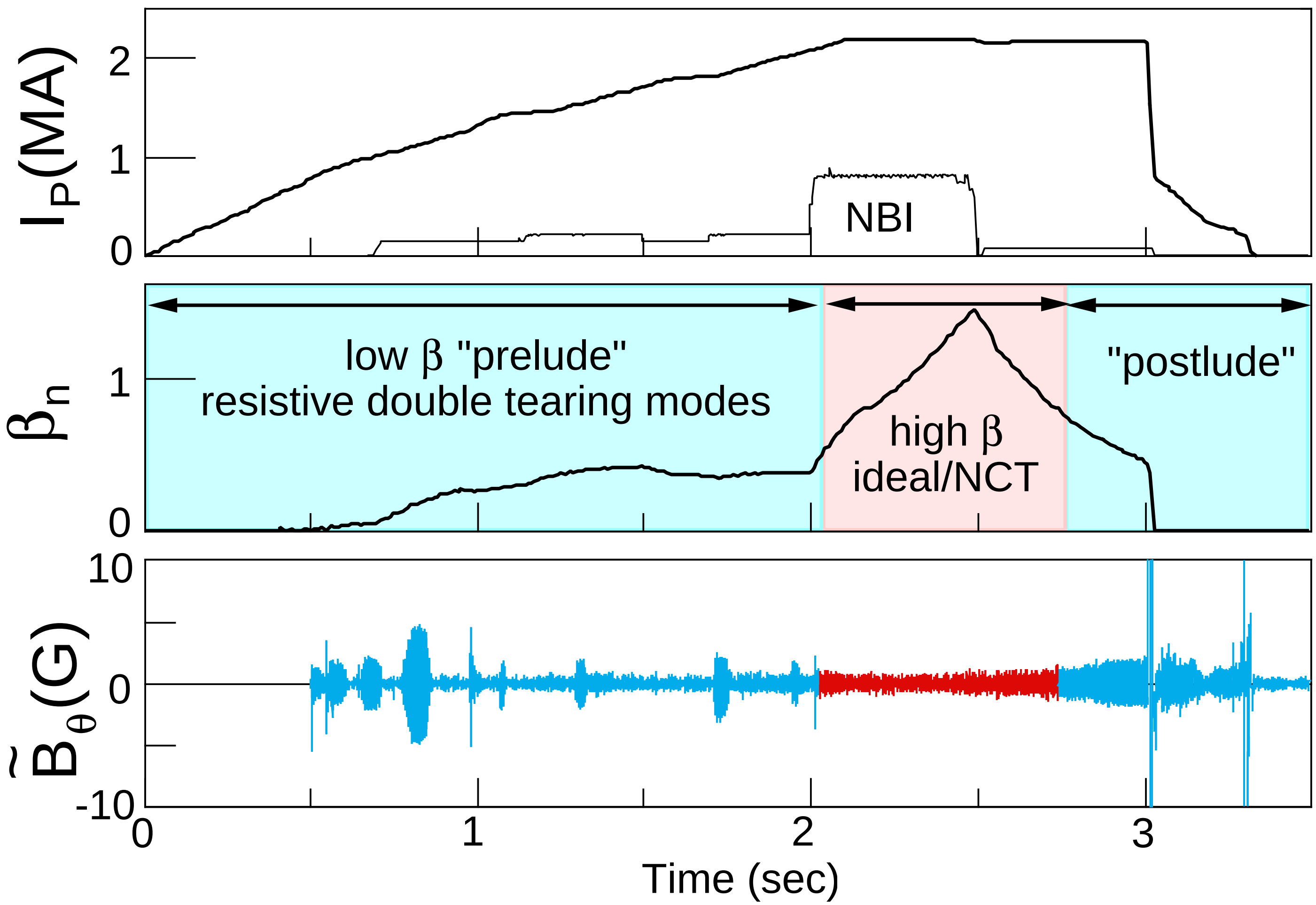
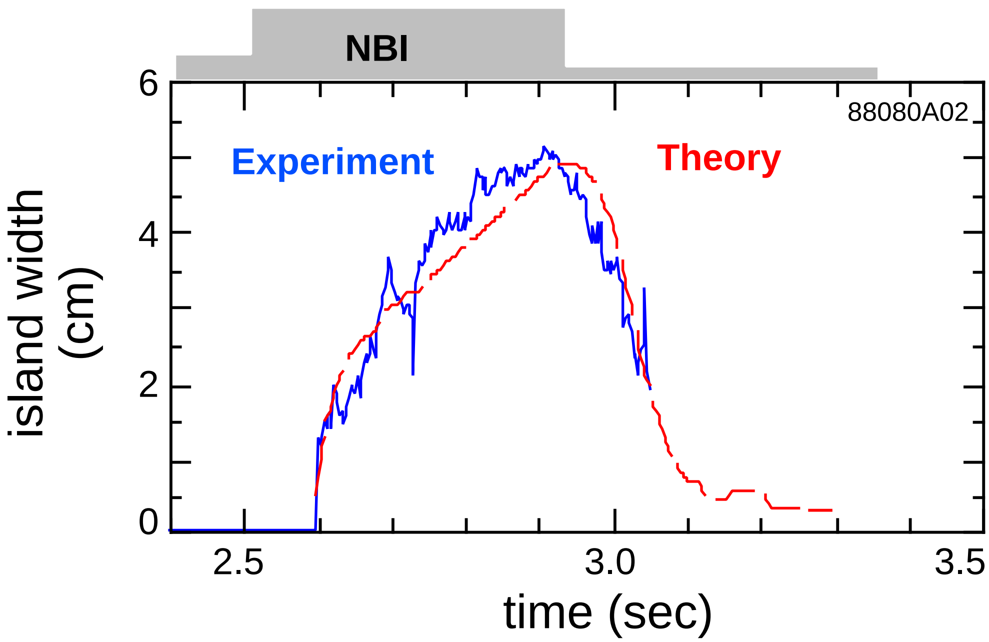
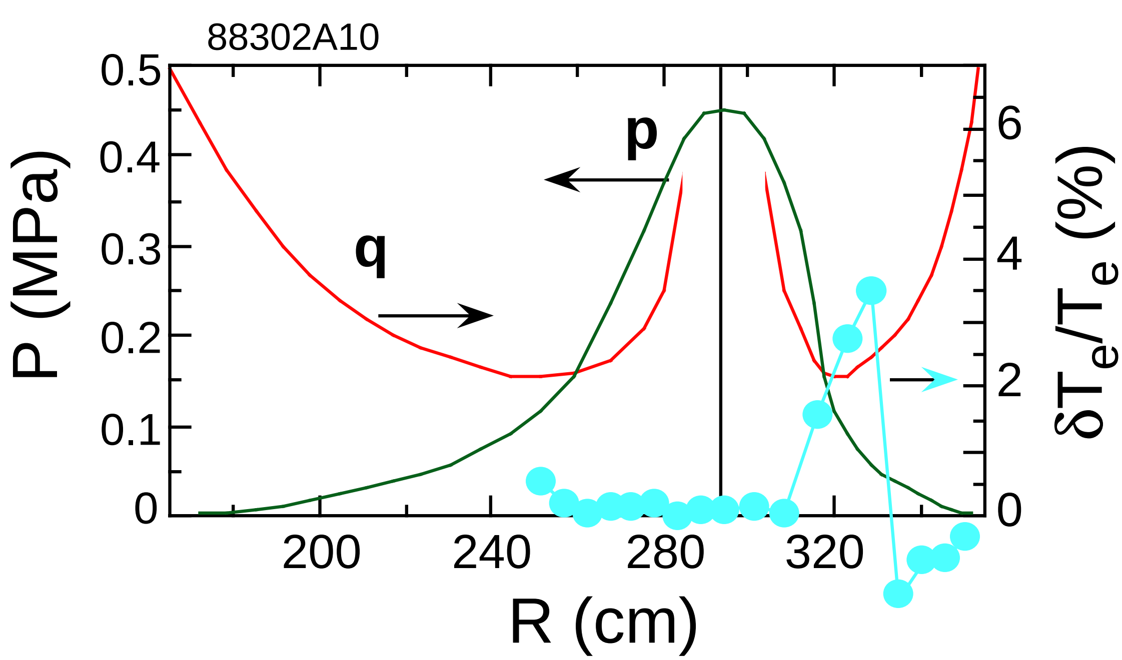


Neoclassical tearing modes are seen in high β phase



- Modes are localized in normal shear region



β-limit disruptions of reversed shear plasmas also have two thermal quenches

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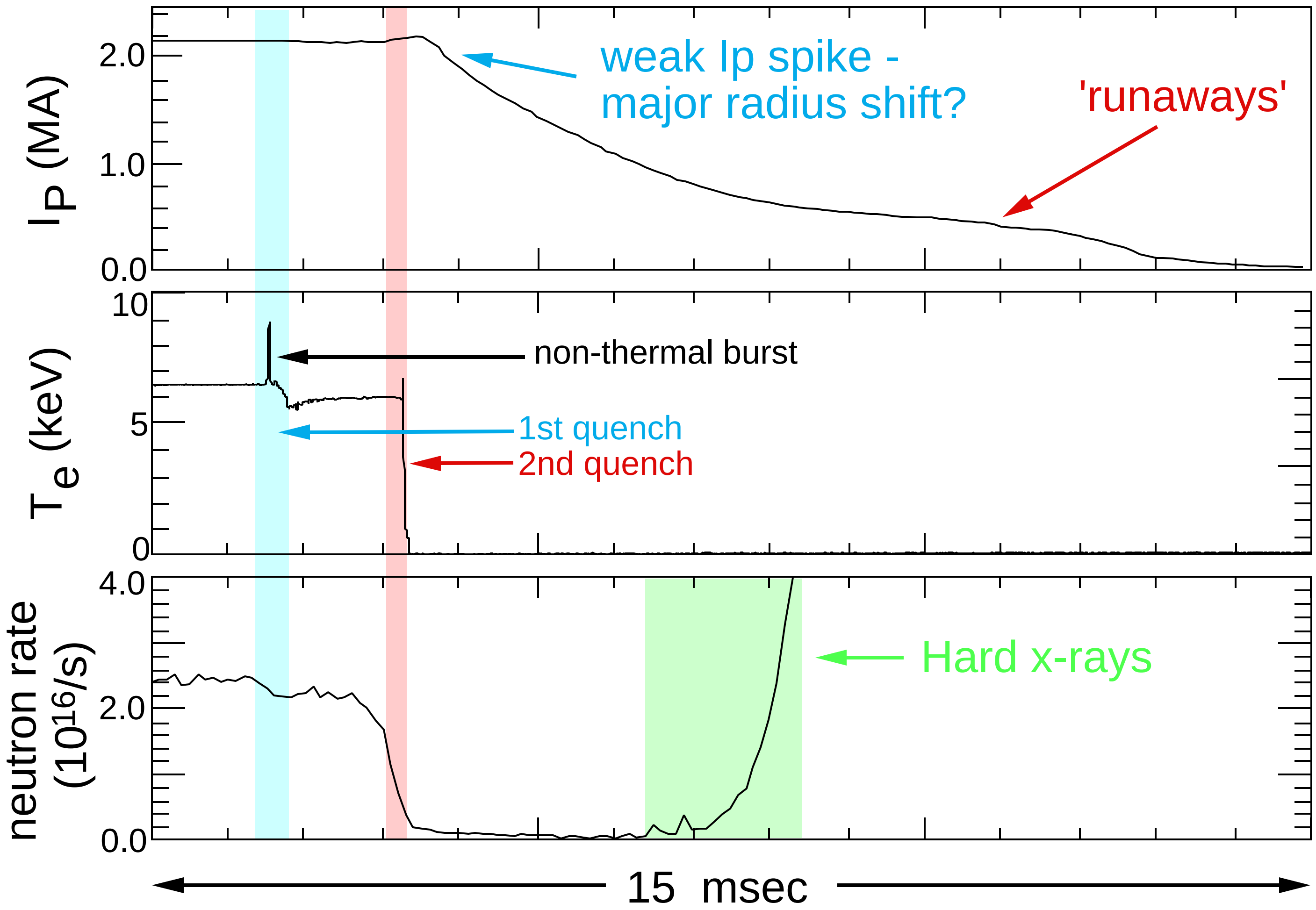

Disruption precursor located near q_{min}

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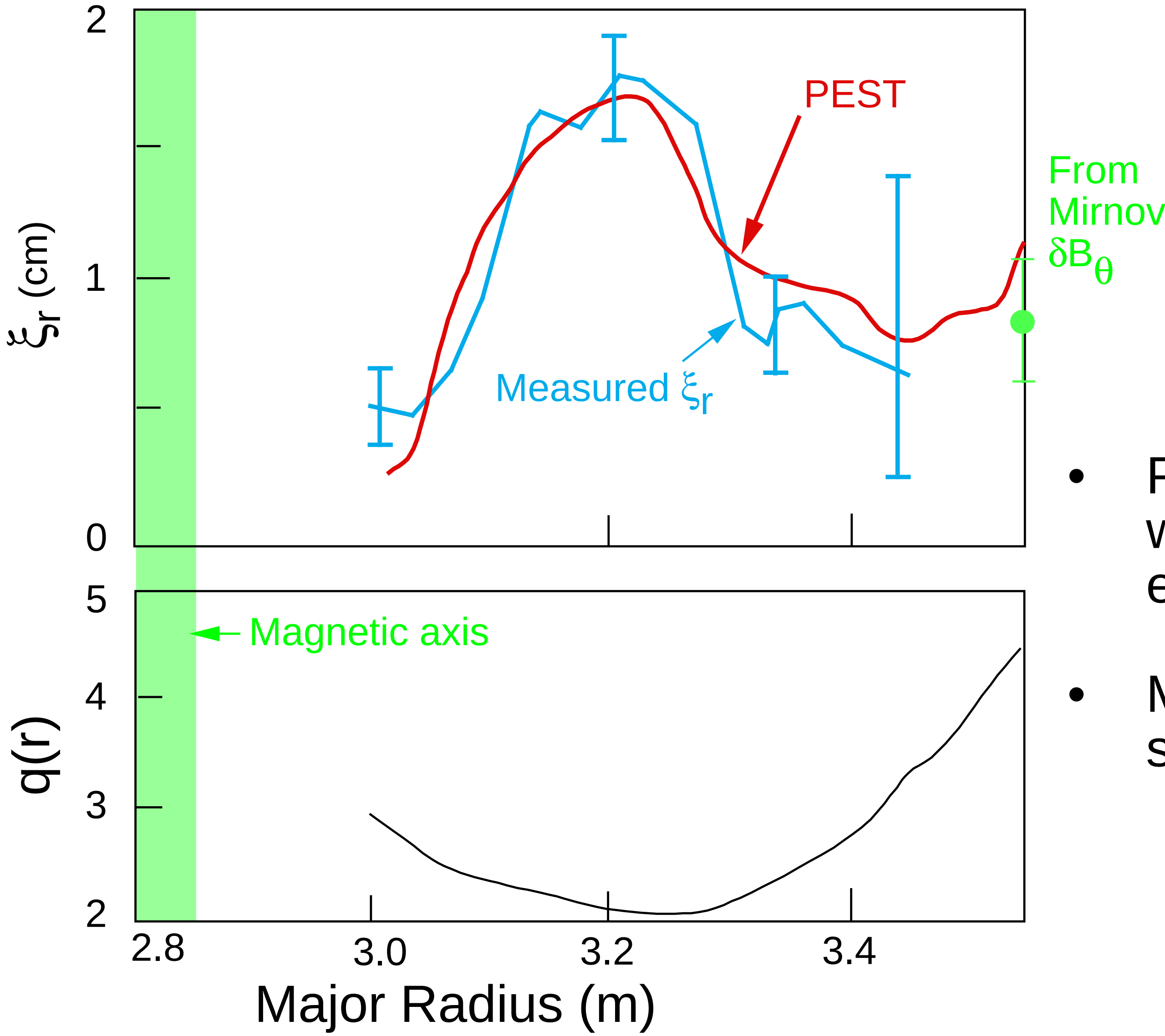
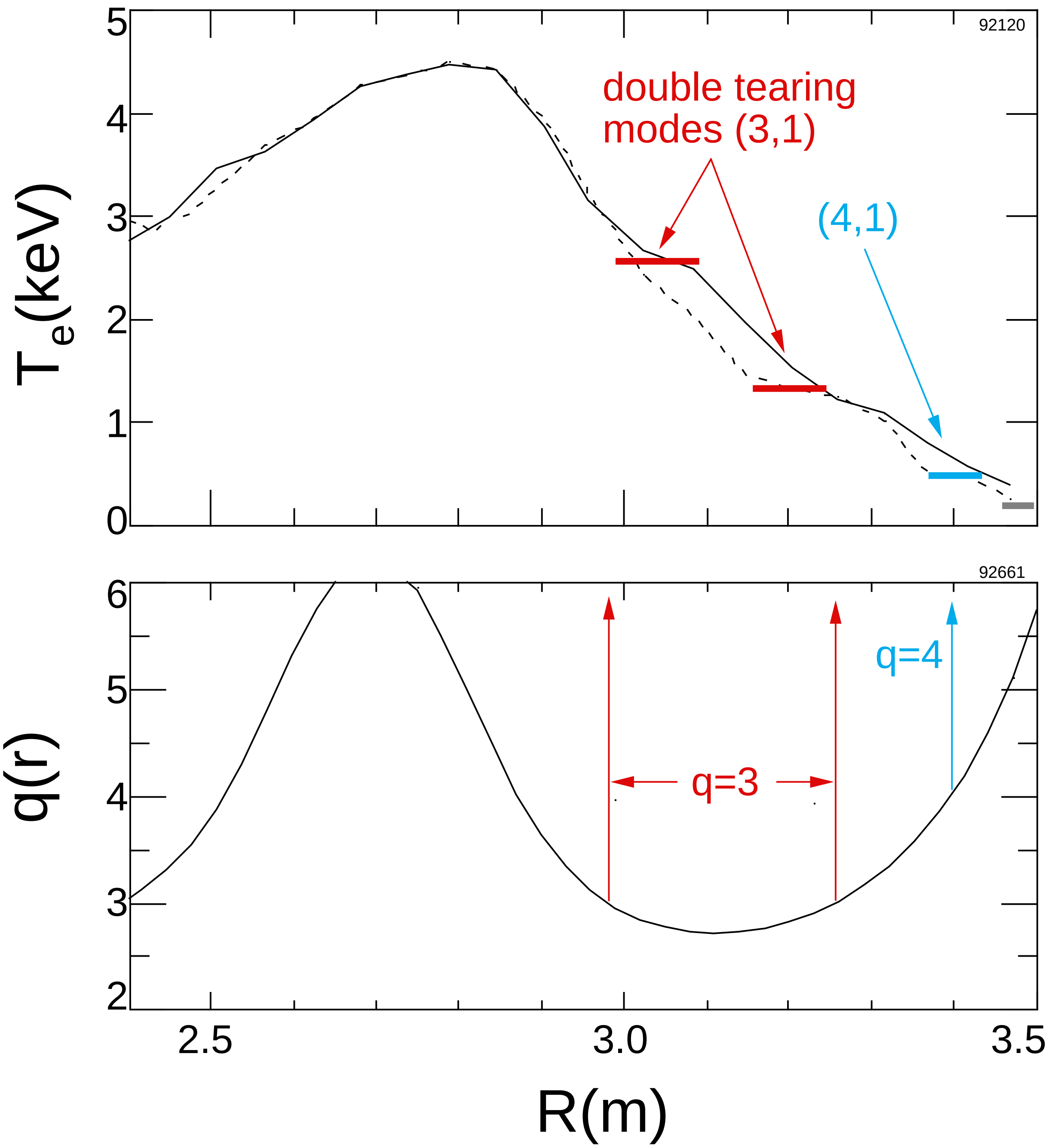


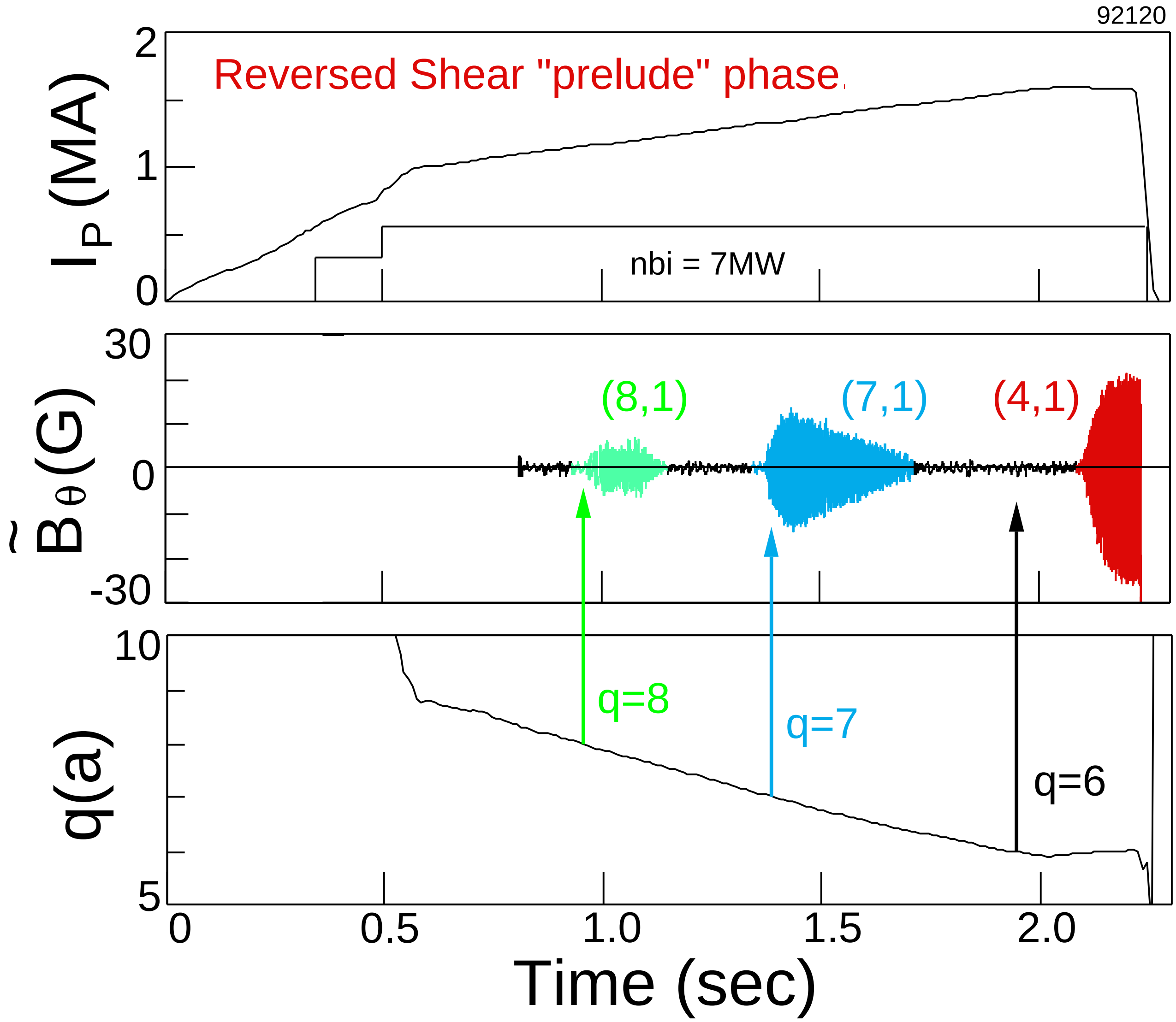
- Poloidal coupling agrees with PEST Infernal eigenmode structure.
- Mode is localized in weak shear region

Disruption precursor has double tearing



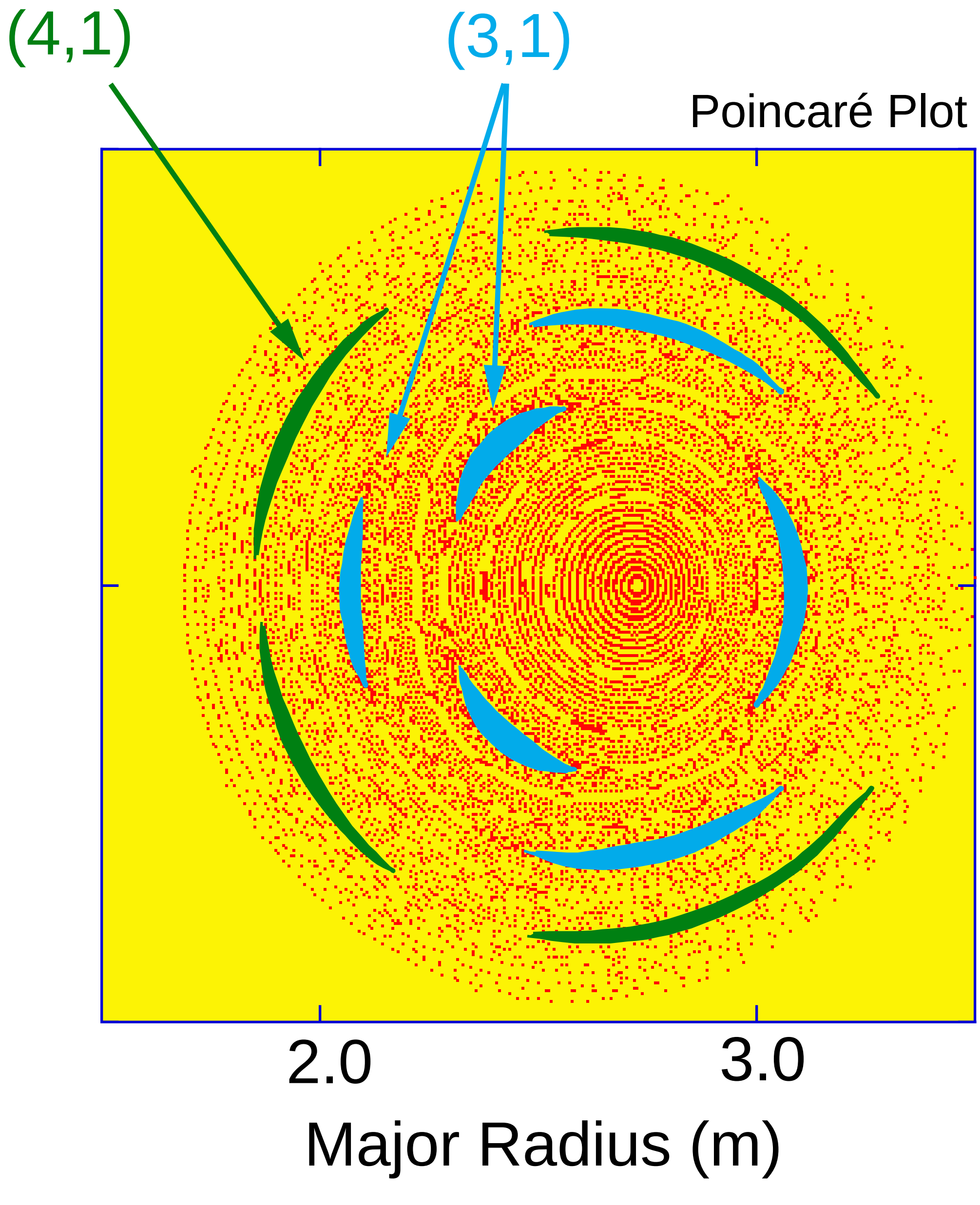
- Double tearing modes are localized between rational surfaces.

Double tearing modes can cause disruptions at low β



- Double tearing not seen in high β phase.
- The stabilizing neoclassical terms in the reverse shear region are weaker at low β.

Linear simulation of the (3,1) double tearing mode predicts the observed coupling to (4,1)



- Phasing of the coupled modes is as observed.

β-limit scaling experiments

The β-limit is soft at low field, with a slow collapse and a locked mode .

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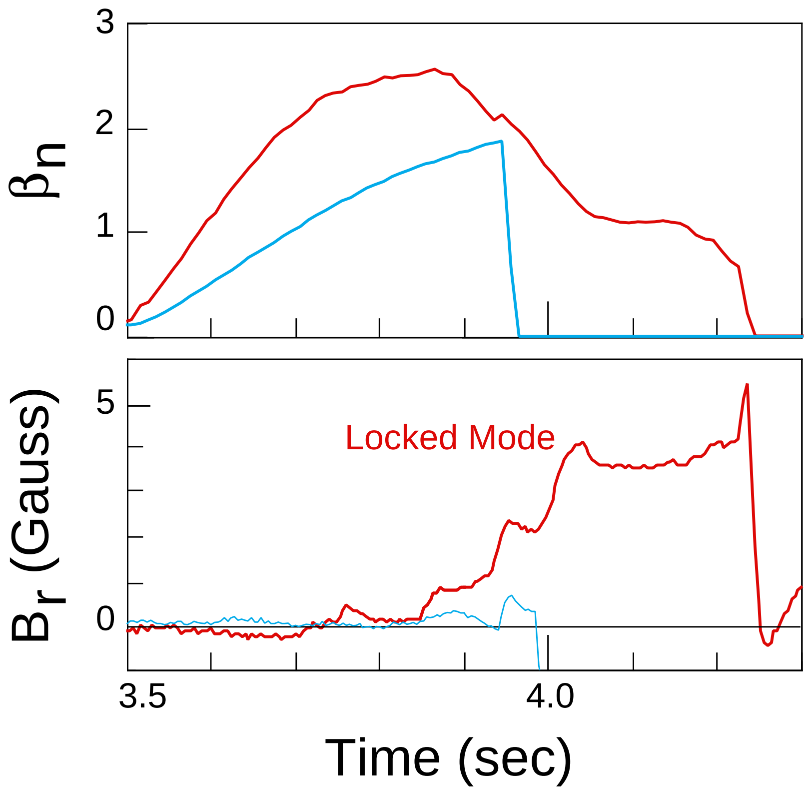
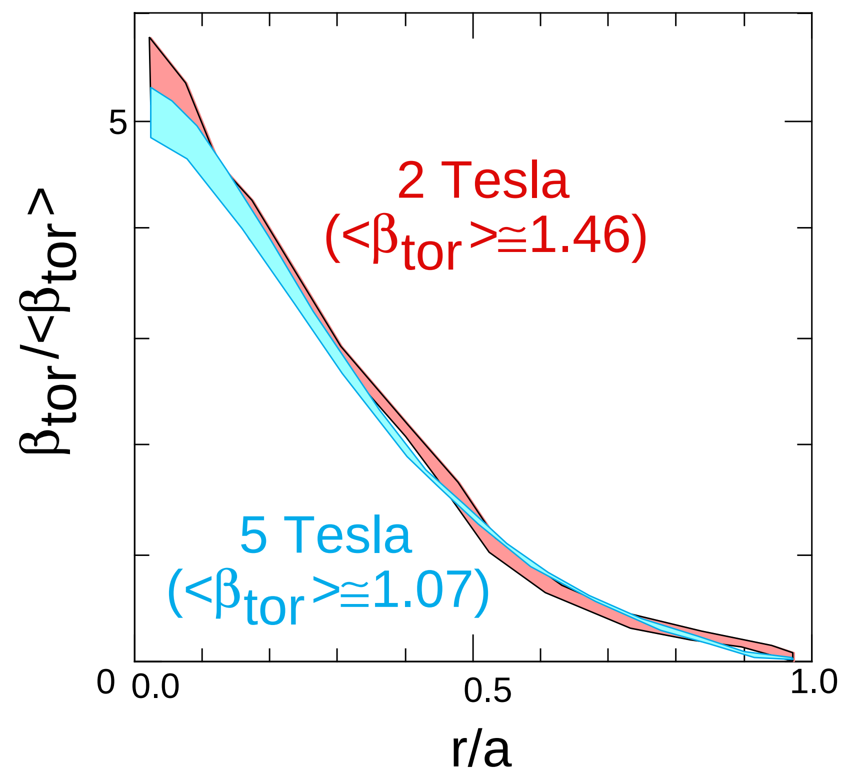
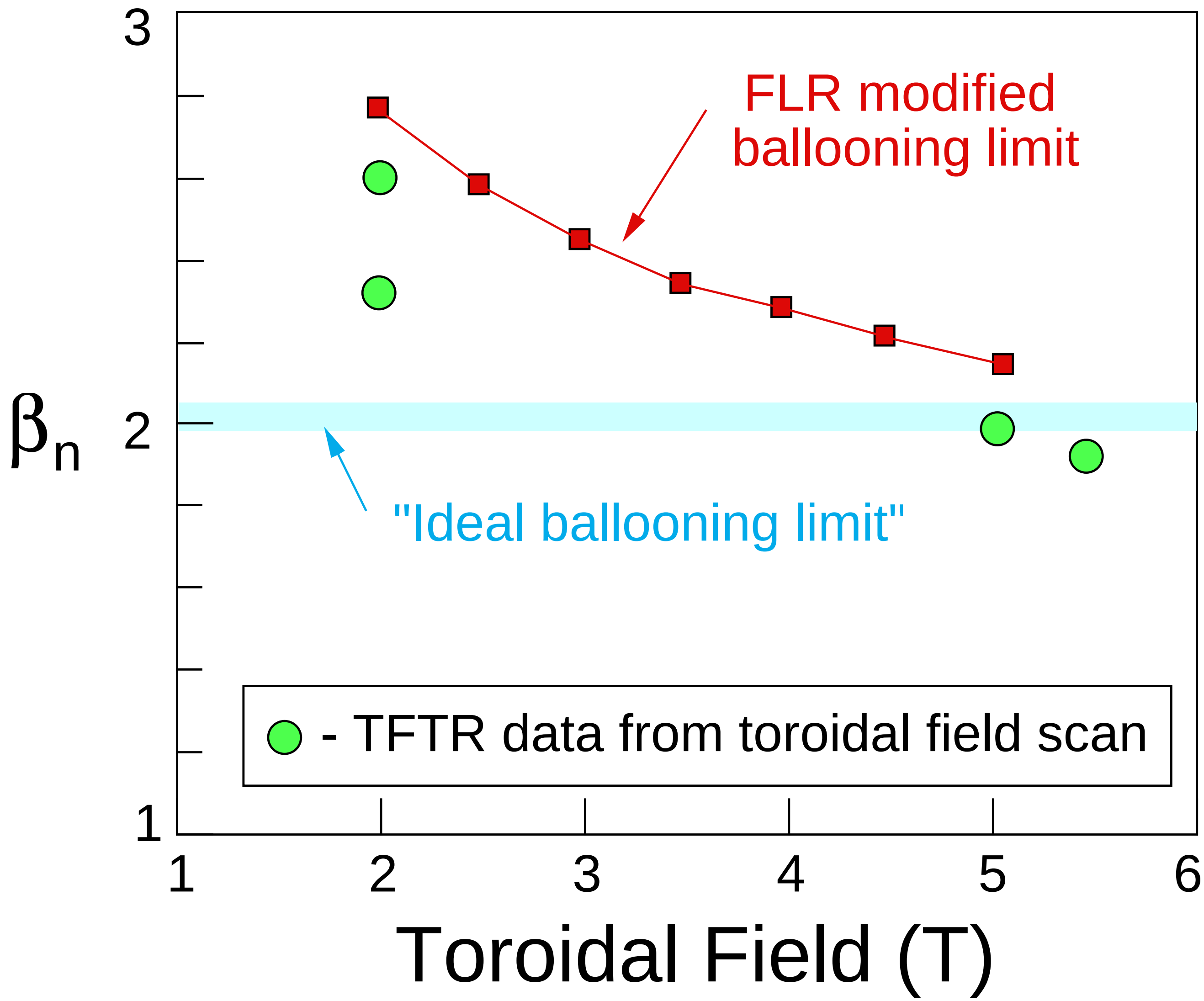




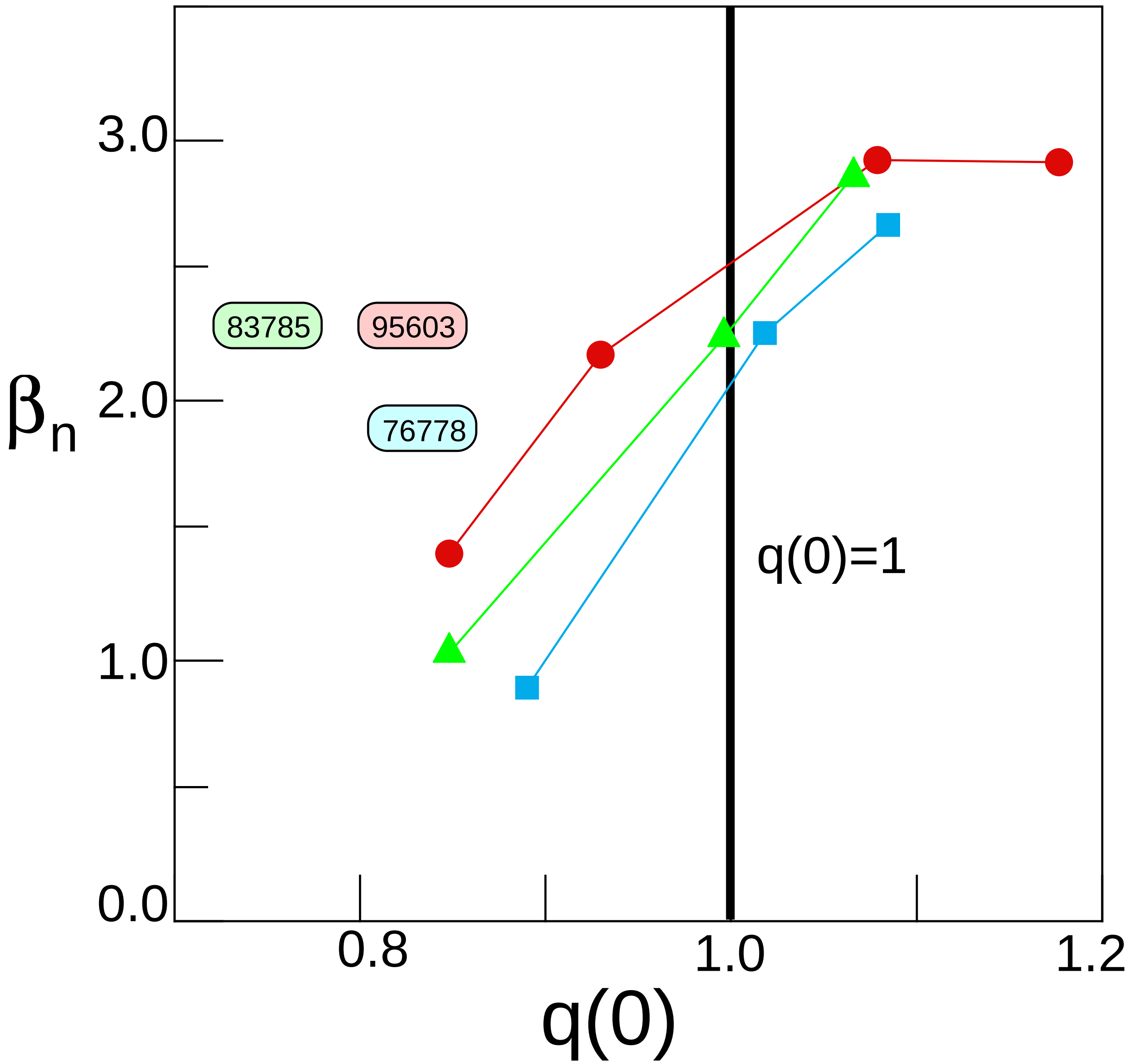
- The pressure (and current) profile shapes are similar.

- The high-n β-limit uncertain, profiles not accurate low-n β-limit uncertain with q(0) < 1.

"Finite Larmor Radius" effects modify the ballooning stability boundary



PEST n=1 stability calculations show proper trend, but with "q(0) = 1".



76778 - supershot
2.5MA, 5T

83785 - supershot
1.0MA, 2 T

95603 - "High li"
2.0MA, 4.7T

J. Manickam

Summary

- We have made detailed comparisons of experimentally observed MHD and theoretical models.

- Good agreement between theory in some cases:
  - high field disruptions (ERS/SS/High li)
  - double tearing disruptions,
  - neoclassical tearing modes amplitudes

- Progress in theory is still required to explain:
  - Disruption scaling with toroidal field.
  - Stability of $n=1$ kink with $q(0)<1$.
  - Neoclassical tearing mode existence.
  - Lack of resistive interchange modes.