Scrape-Off-Layer Current (SOLC) as a *Dynamic* Source of Error Field

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Topics

- Introduction: Dynamic Source of Error Field
- SOLC-generated Error Field Can:
  - Be Significant Relative to Equilibrium Field
  - Contribute to "Badness of Fit"
  - Mislead Tokamak Control through Bad Input
- Summary

SOLC Is Largely Neglected…

Consider, however:

•SOLC flows in immediate proximity of plasma, and can total many kA - "Why ignore?"

•SOLC is in general non-axisymmetric - "Yes, it's an *error field.*"

•SOLC is *dynamic* - *"Comes and goes."*

•Controlling SOLC might lead to improved AT discharges.

Potential Effects of Error Field Generated by SOLC

SOLC
Intrinsic
or
Driven

→ ***Resonant* B-field Normal to Flux Surfaces**

↓ ?

Flux Surface Distortion
MHD Stability

→ **B-field Signal Pollution**

↓ ?

Feedback Control
Tokamak Operation
Equilibrium Reconstruction

↓ ?

MHD Control

Dynamic Nature Distinguishes SOLC Error Field

SOLC error field is 'dynamic' in many ways:

•Exists in some discharges but not in others.

•Phase-locks to mode rotation - spinning plasma will not prevent resonant-field penetration.

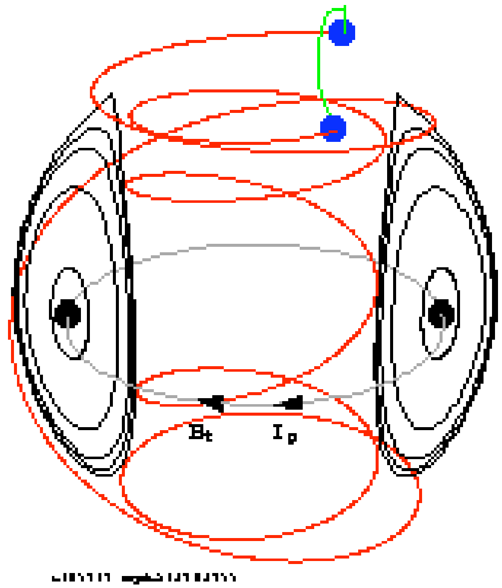
•Responds to mode growth.

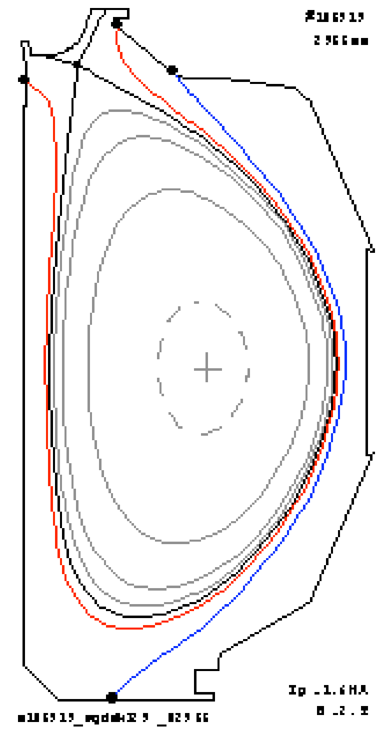
•Responds to equilibrium boundary changes.

The dynamic nature of SOLC error field may be interesting, troubling, and potentially useful, all at the same time.

SOLC Flows Just Outside Separatrix

Line Current Model of SOL Current





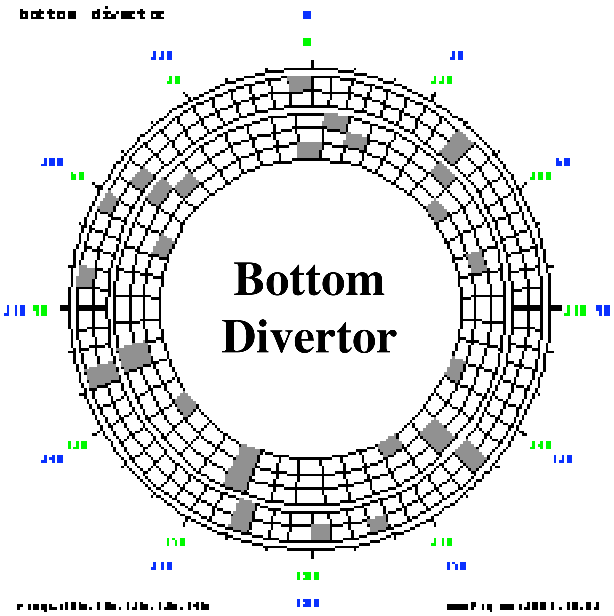
SOLC path topology can change dramatically for small shift in location - see red and blue paths in the figure to the right.

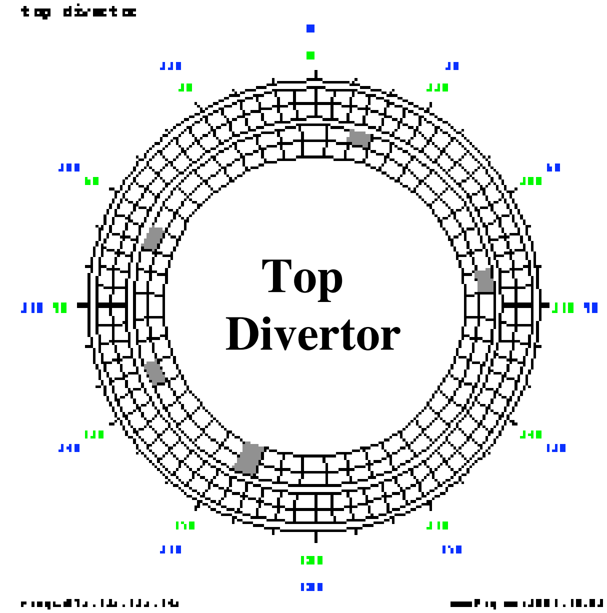
The simplest model SOLC flows along an open field line and closes its circuit through tokamak structure.

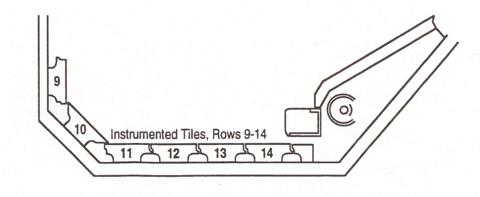
The origin of the SOLC* is not yet fully understood - not a subject of this talk.

*See, e.g., discussion by M. Schaffer and B. Leikind, NF 31(1991)1750.

DIII-D Has Sensor Arrays for Measuring Current through Divertor Tiles







Each of shaded divertor tiles is instrumented with a resistive-element current sensor. (tile representation merely schematic.)

A narrow SOL current channel may escape detection, because less than 10 % of tiles in only selected tile-rings have sensors.

***Schaffer, et al., Poster 3Q21, APS-DPP, 1996, Denver, CO, Nov. 11-15.**

Fast Data Acquisition Allows Study of MHD Details

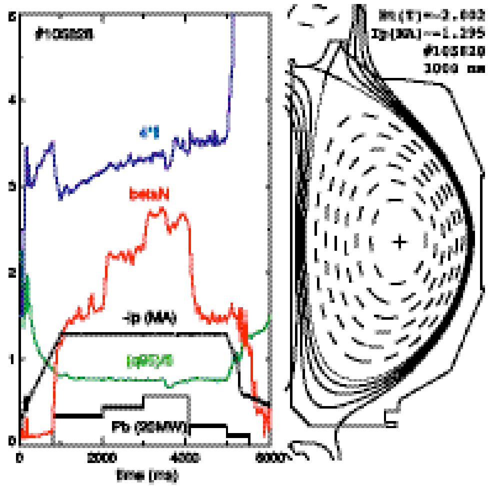
Fast Branch

- 30 Channels.
- 1 MHz Optical Isolator Bandwidth.
- 10/40/200 kHz Selectable Anti-alias Filters.
- Up to 1 MHz (200 kHz Typical) Sampling.
- 5 sec Data Window (at 200 kHz).

Slow Branch

- 48 Channels.
- 15 kHz Optical Isolator Bandwidth.
- 2 kHz (Normal)/20 kHz (Importance) Sampling.
- 8 sec Data Window (at 2 kHz).

SOLC Error Field Detected by Sensors May be Large Enough…

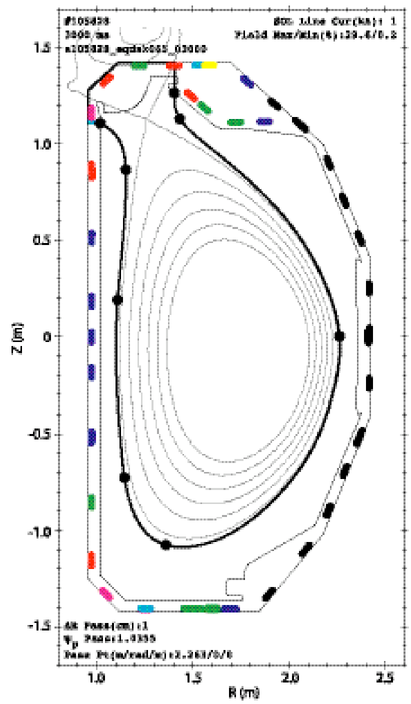


Discharge Summary

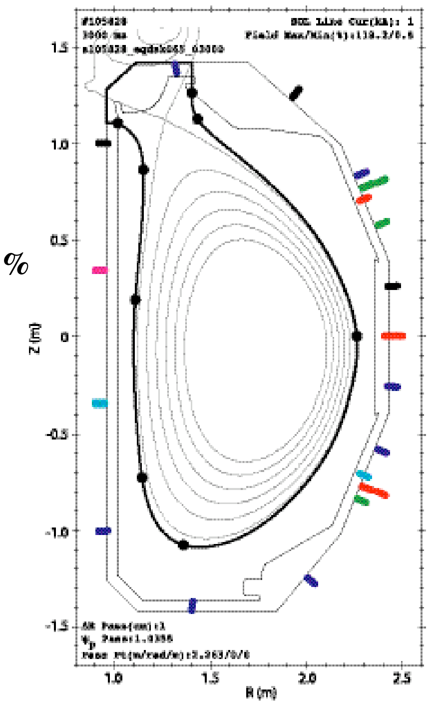
B-field produced by a unit (1 kA) SOL line current is calculated at the locations of magnetic sensors as a percentage of the equilibrium field coupled by them. Current is rotated and peak field is recorded.

Error Field for Unit (1 kA) Line SOLC

Minov Coils < 30%



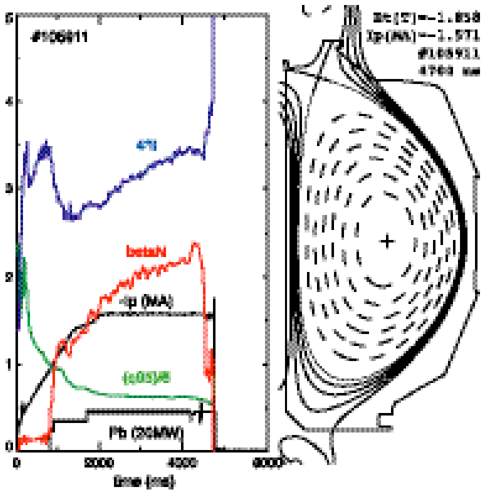
Saddle Loops < 118%



20% < cyan
10% < magenta <20%
5% < yellow <10%
2% < red <5%
1% < green <2%
0.5% < blue <1%
black <0.5%

… to affect tokamak operation, RWM feedback, etc., but…

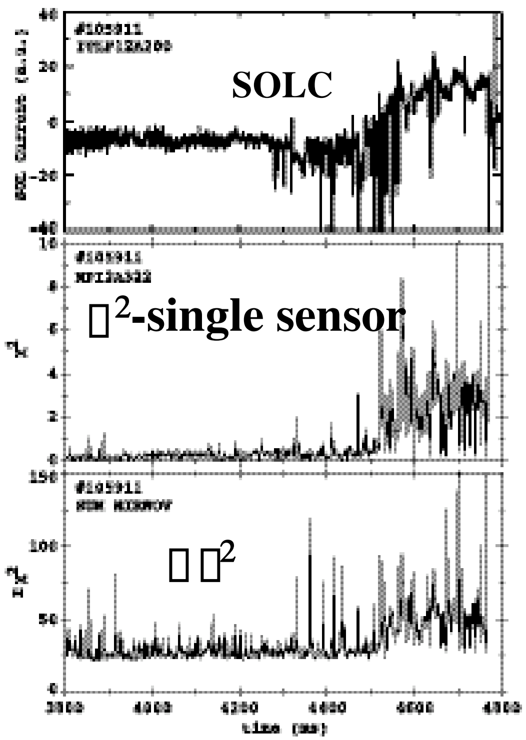
Any Experimental Signs for SOLC Contributing to Bad Fit?



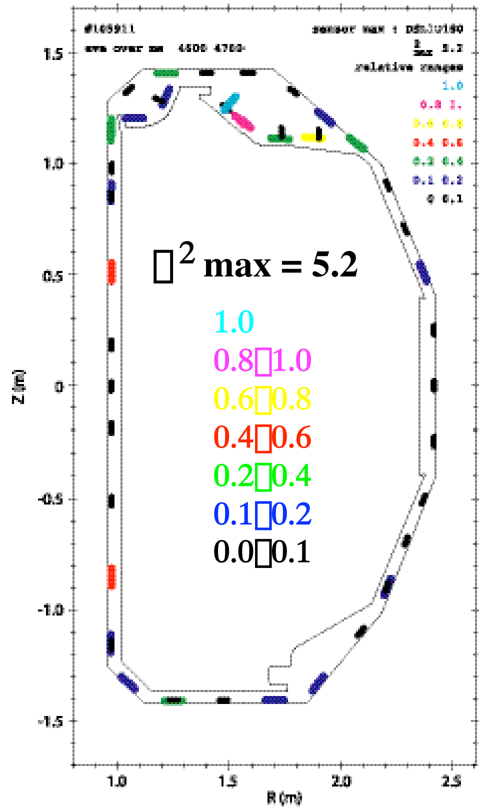
Discharge Summary

"Badness of fit," χ^2, for Mirnov signals used in equilibrium fitting is shown for a single sensor and sum over all sensors in the bottom two panels. It exhibits a marked rise coincident with the rise in SOLC around 4500 ms.

SOLC and "Badness of fit" index χ^2 for Mirnov signals

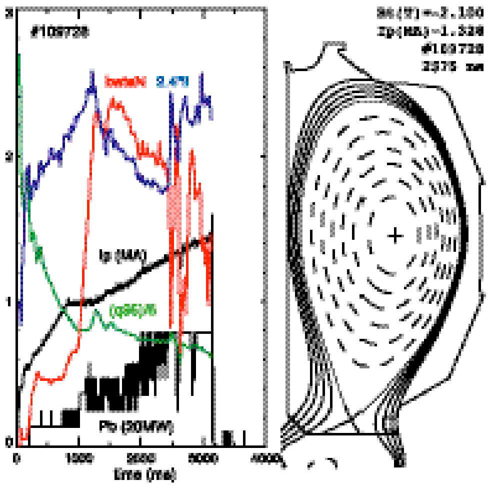


Map of Time-averaged "badness of fit" index χ^2



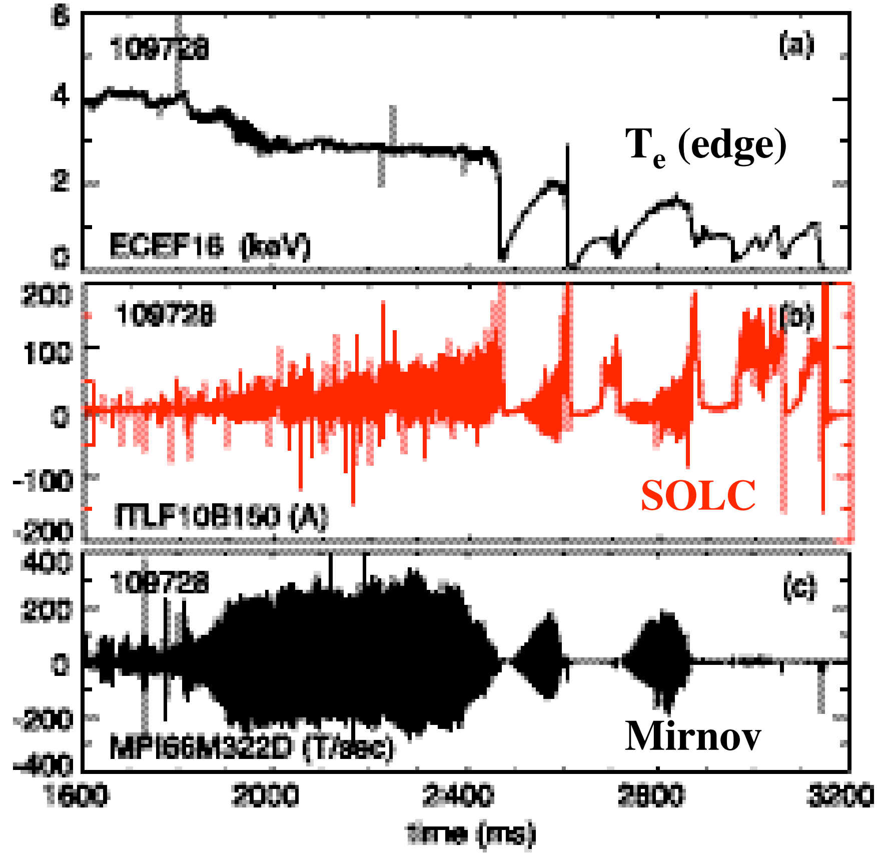
"Badness of fit" index rises concurrently with SOLC.

Possible Signs for Loss of Control due to SOLC Pollution



Discharge Summary

Thermal Collapses



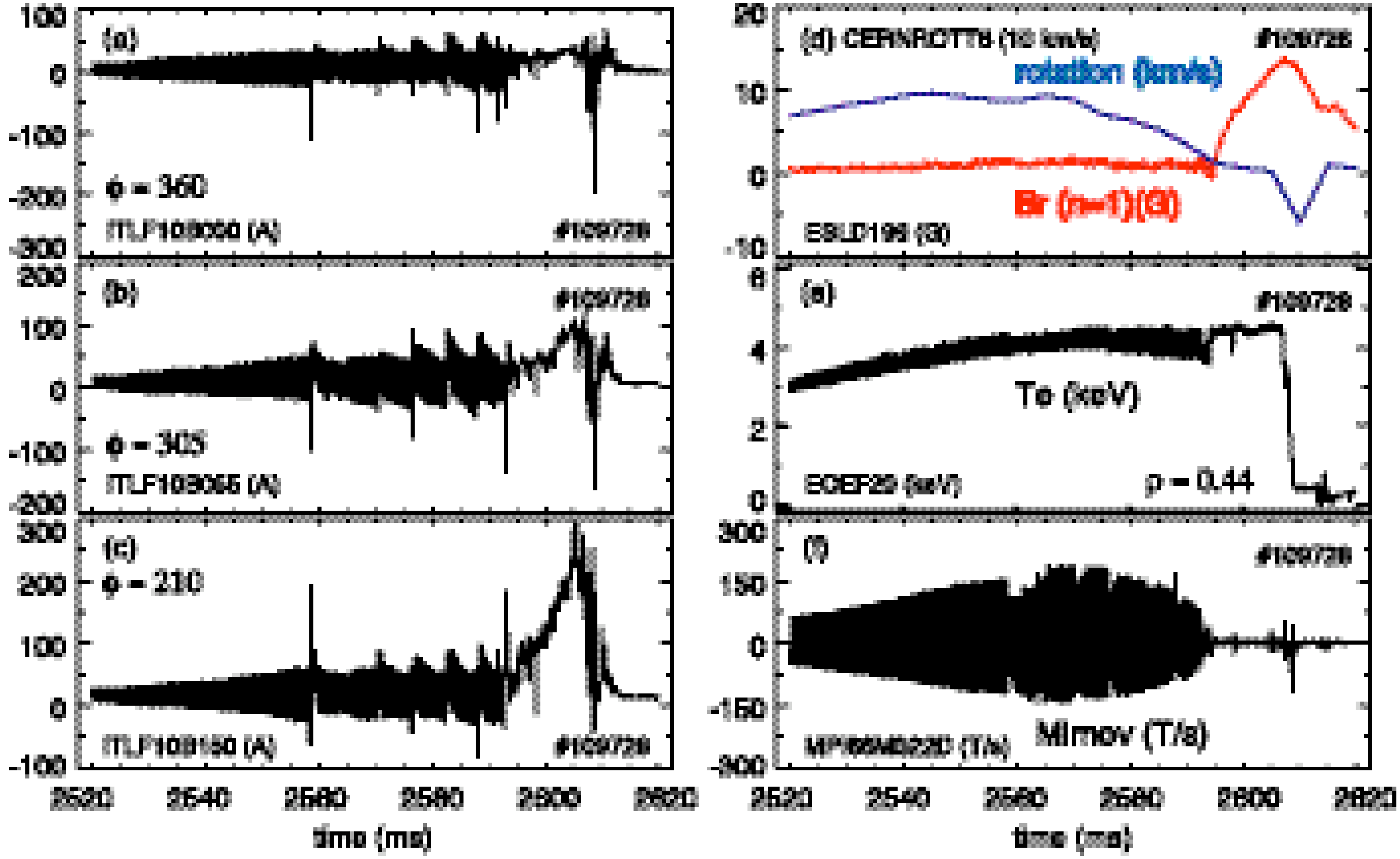
Possible Causes of Thermal Collapse

(1) RWM?
(2) Locked growing tearing mode islands?
(3) Limiter interaction due to pollution of magnetic signals?

Rotation Slow-down, Mode-Locking, Growth, Thermal Collapse

SOL Current (A) | **Other Parameters**

SOLC Sensor Toroidal Array



SOLC is non-axisymmetric and grows prior to thermal collapse.

SOLC, B-dot, and Te Oscillations Phase-Locked

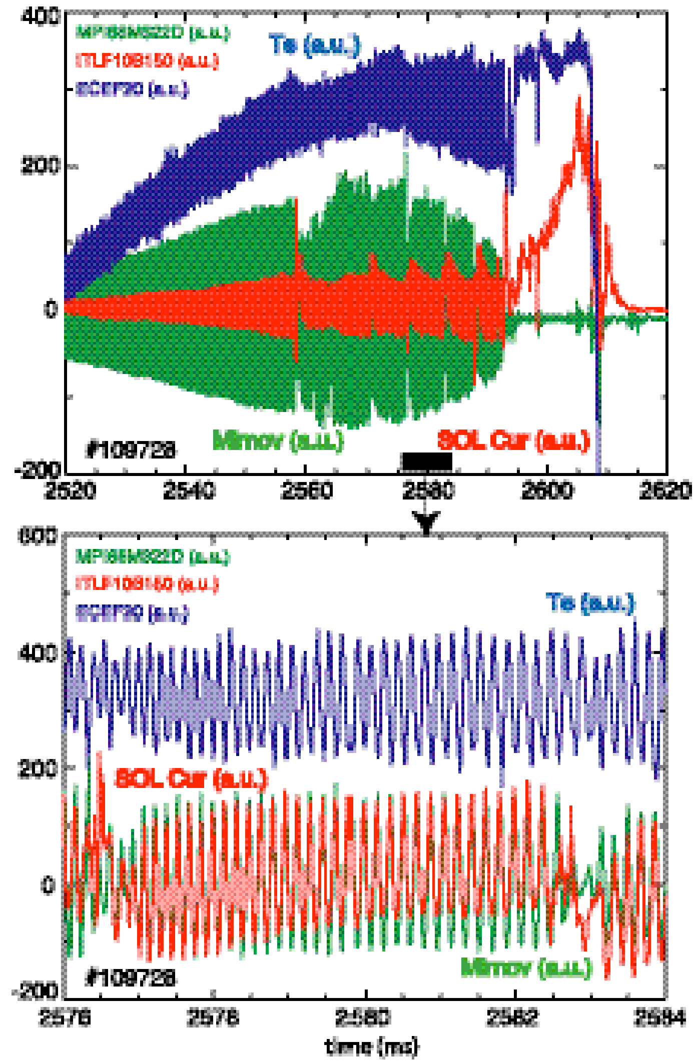
Total current may reach several kA in the close proximity of the plasma - large enough to be of concern in the MHD stability physics.

SOLC Not Driven by RWM during Oscillating Phase (f ~ 6 kHz).

SOLC Not Driven by B-dot during Locked Phase (B-dot ~ 0).

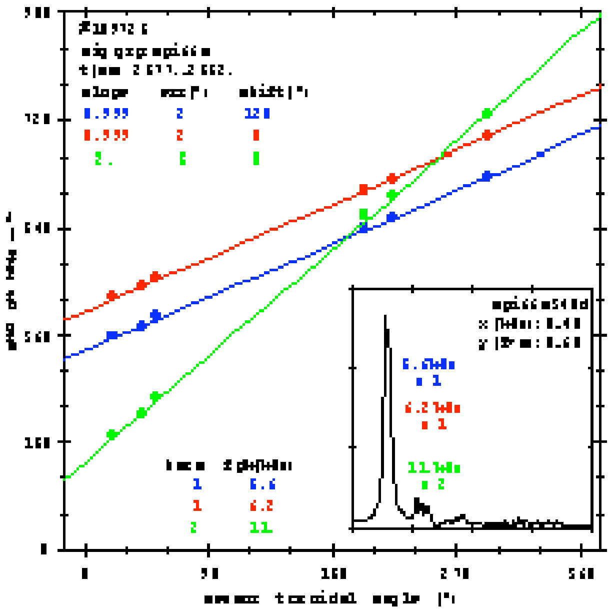
Oscillations in Mirnov and Te are dominantly kink-like, *not* tearing modes (NTMs).

These magnetic perturbations may not be of MHD instability origin (hypothesis).

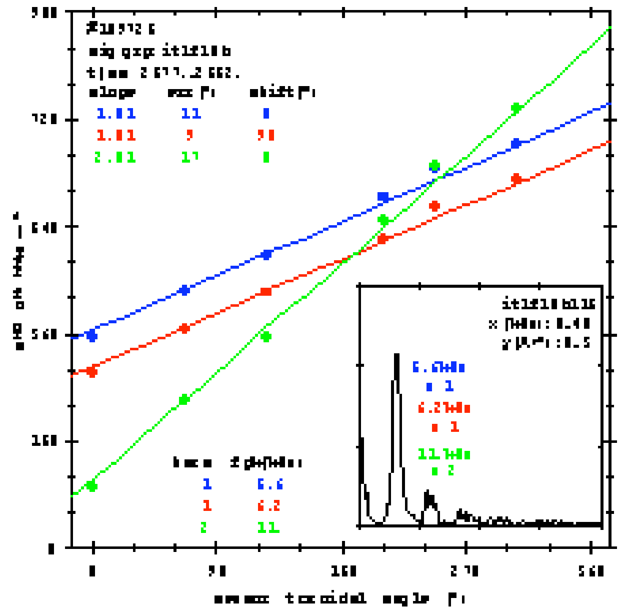


Frequency Spectrum and Toroidal Structure Similar for SOL Current and B-dot

Mirnov Signal



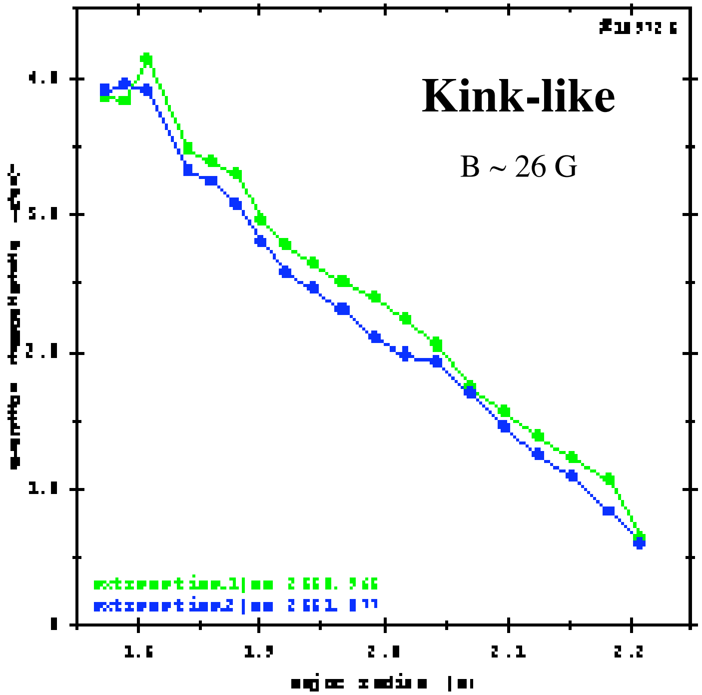
SOL Current

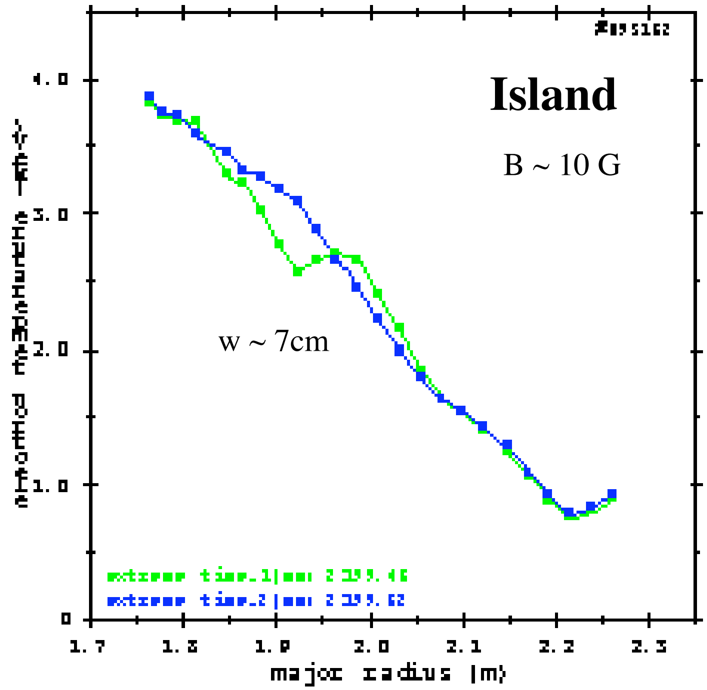


SOLC may have generated the magnetic perturbations and accompanying Te fluctuations.

Compare Te Radial Profile with Tearing Mode Island

Profiles at Extreme-Phase Times during a Cycle of Oscillations





- **Delta-Te global**
- **No phase reversal**
- **Large flux surface excursion**

- **Delta-Te localized around a rational surface**
- **Phase reversal.**

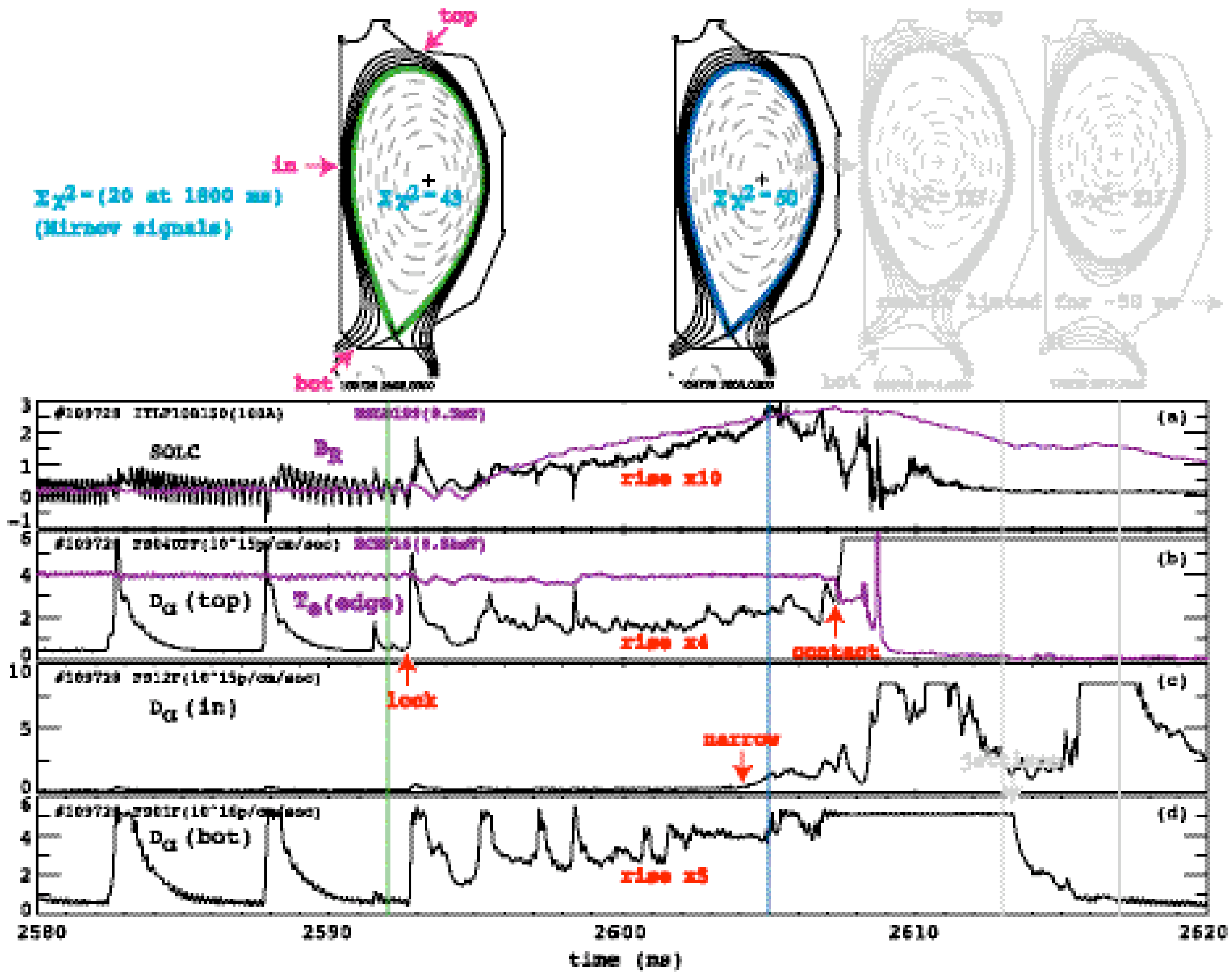
Is SOLC large enough to cause flux surface distortion and produce these oscillations?

Fitting Result Inconsistent with Growing Limiter Interaction

Fitting (EFIT) says "configuration not changing," while rising D_α signals indicating otherwise and SOLC growing strongly.

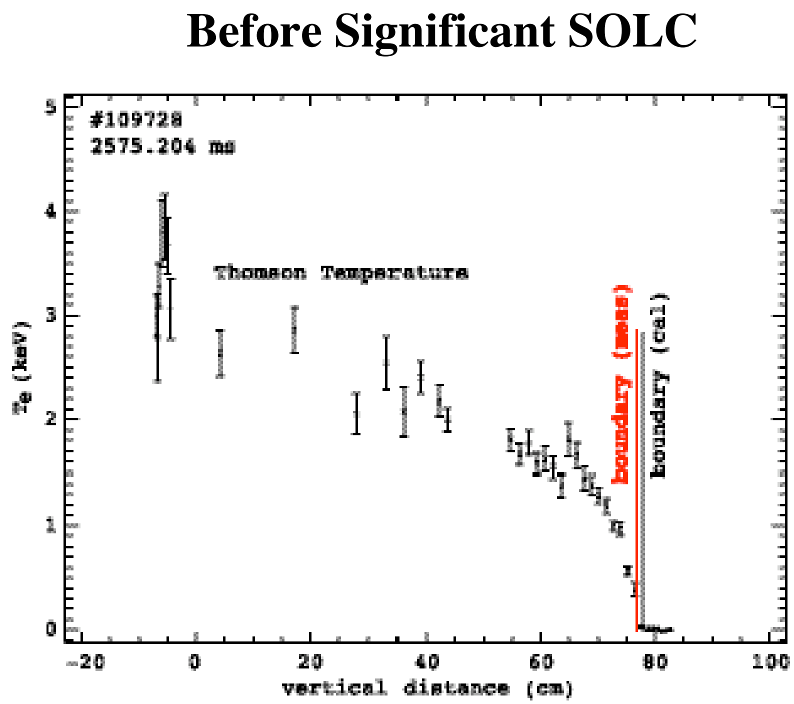
Magnetic signals polluted by SOLC may have played a role in creating discrepancy.

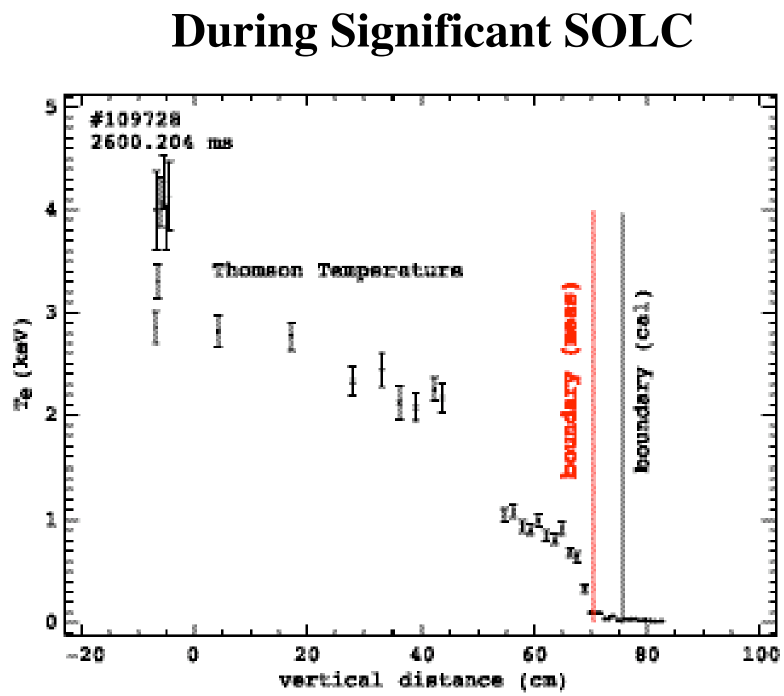
"Badness of fit" index, χ^2, rose during SOLC activity - both oscillating and secular growth periods.



Did control smash plasma against limiter because of bad input?

Computed Boundary Inconsistent with TS Measurement

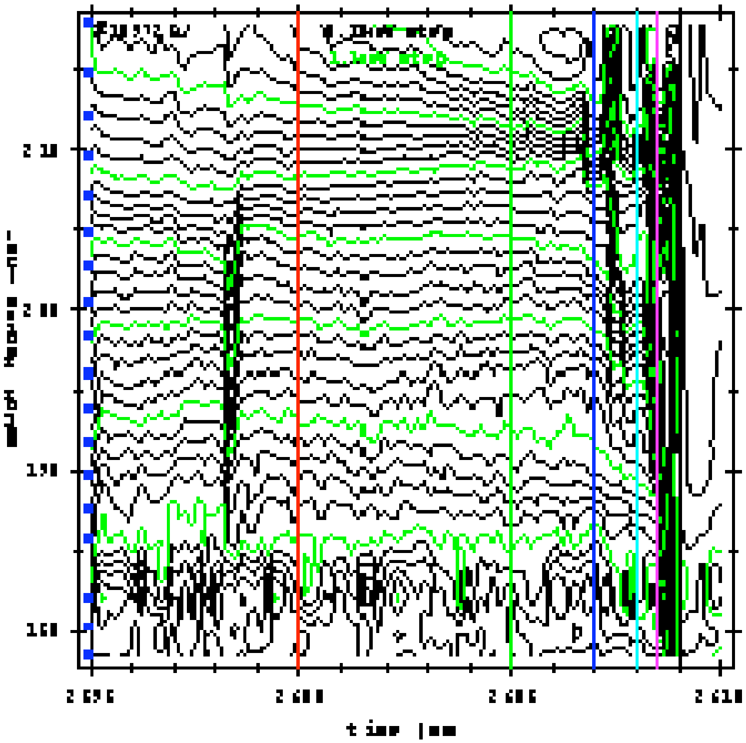




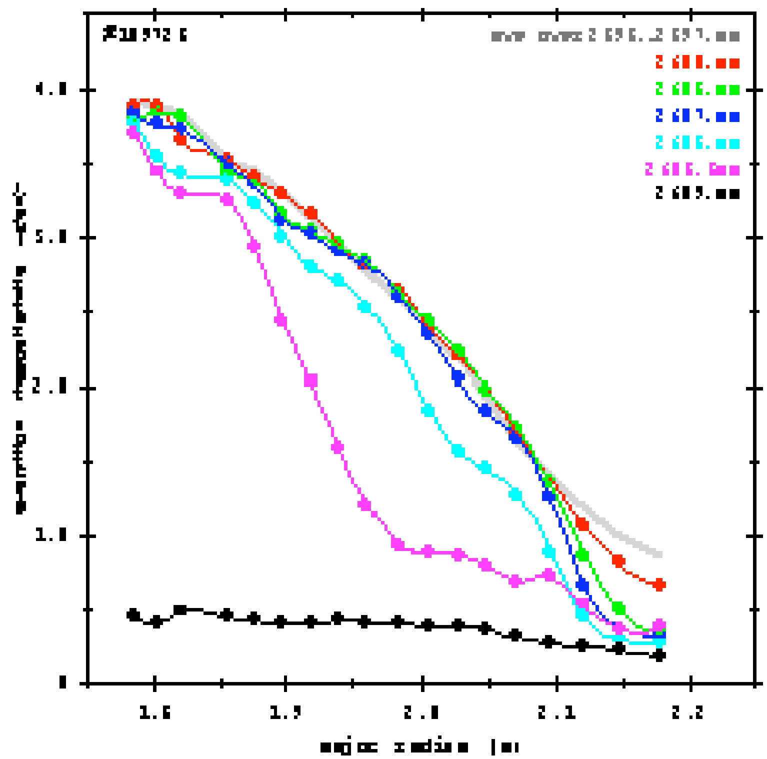
Measured plasma boundary was *lower* than calculated one at the major radius of the Thomson Scattering (TS) as demonstrated here. But plasma moved *upward* (or elongated) during significant SOLC as evidenced from strong interaction with top limiter. Plasma must have also moved *inward* in order to be compatible with both observations (plasma surface may have helically distorted also - see E. Fredrickson, this workshop).

Axi-symmetric or Helical Collapse ?

Te Contour Plot



Te Radial Profiles



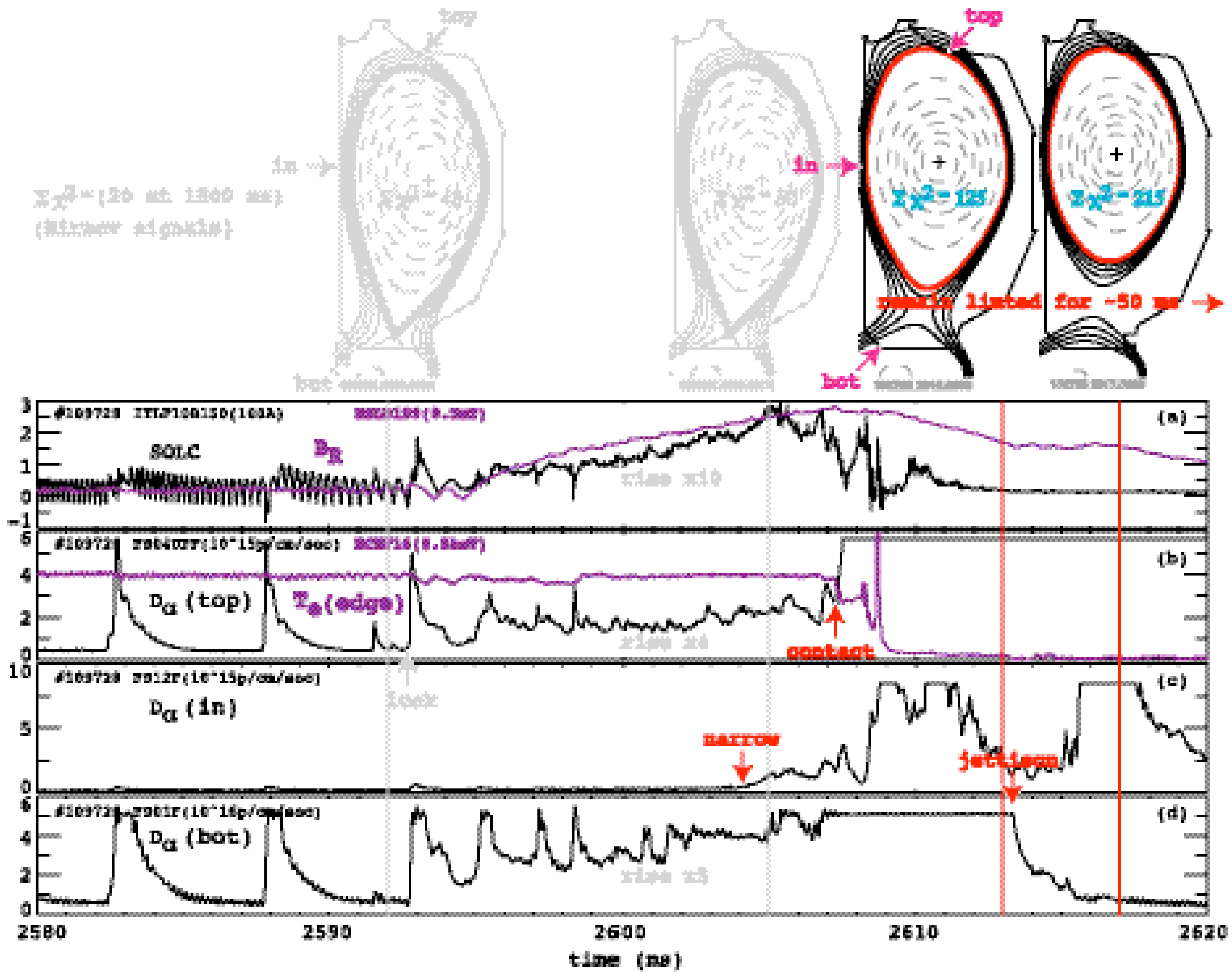
Collapsing Te edge profile is consistent with limiter contact, but a second ECE view is needed for reaching a definitive conclusion.

Collision with Limiter May Have Caused Collapse

Failure by the control to regain a divertor shape for over 60 ms suggests persistence of intrusion of extraneous signals.

Failure of the "badness of fit" index to return to normal values after the collapse also suggests the presence of non-axisymmetric field.

Undetected SOLC around limter plasma (or locked mode) may be sources of B-radial signal after the collapse.



Did control "think" discharge stayed in a divertor configuration?

Summary

Magnetic field generated by Scrape-Off Layer Current (SOLC) was investigated computationally and experimentally as a dynamic source of error field in DIII-D.

(1) Calculations based on a rotating line current model for SOLC shows that peak SOLC-generated error field is a significant fraction of the equilibrium field at the location of magnetic sensors, ranging up to 30 % for Mirnov and 118 % for saddle loops.

(2) "Badness of fit" index, χ^2, between Mirnov signals measured and inferred from a fitted equilibrium as a function of time is correlated with SOLC, suggesting that SOLC-generated error field may play a role in degrading tokamak operation and equilibrium reconstruction.

(3) Experimental evidence was obtained suggestive of SOLC-generated magnetic signal pollution causing the tokamak control to smash the plasma against unconditioned parts of the limiter, leading to a thermal collapse due to infusion neutral gases.