Error Field Dynamically Generated by Scrape-Off-Layer Current (SOLC)

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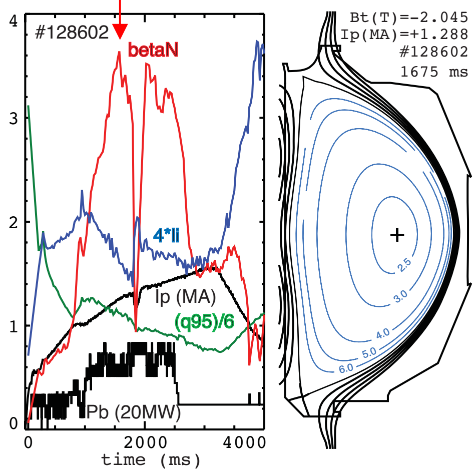
Electrical Current in Scrape-Off-Layer Is an *Obvious* Source of Error Field…

Yet, SOLC appears to be curiously absent from the minds of error-field researchers. Why?

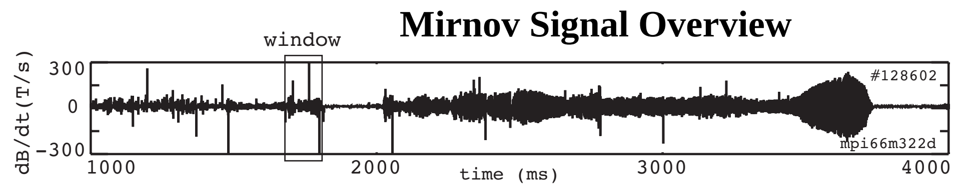
Is it perhaps because SOLC-generated field mostly masquerades as something else and not readily recognizable?

This paper presents two cases of SOLC that appear to be masquerading as either NTMs or RWMs (and also discusses SOLC-based modeling of field observed during ELMs, if time permits).

2- Oscillating B_θ Appears To Be Global Mode…

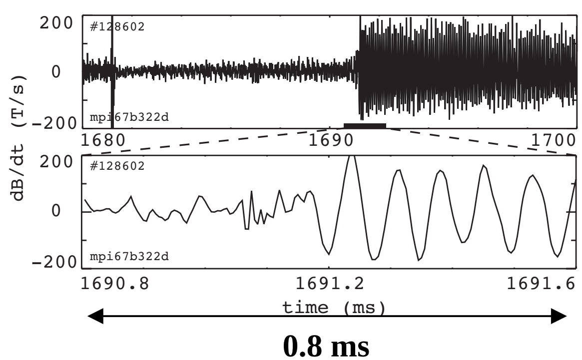


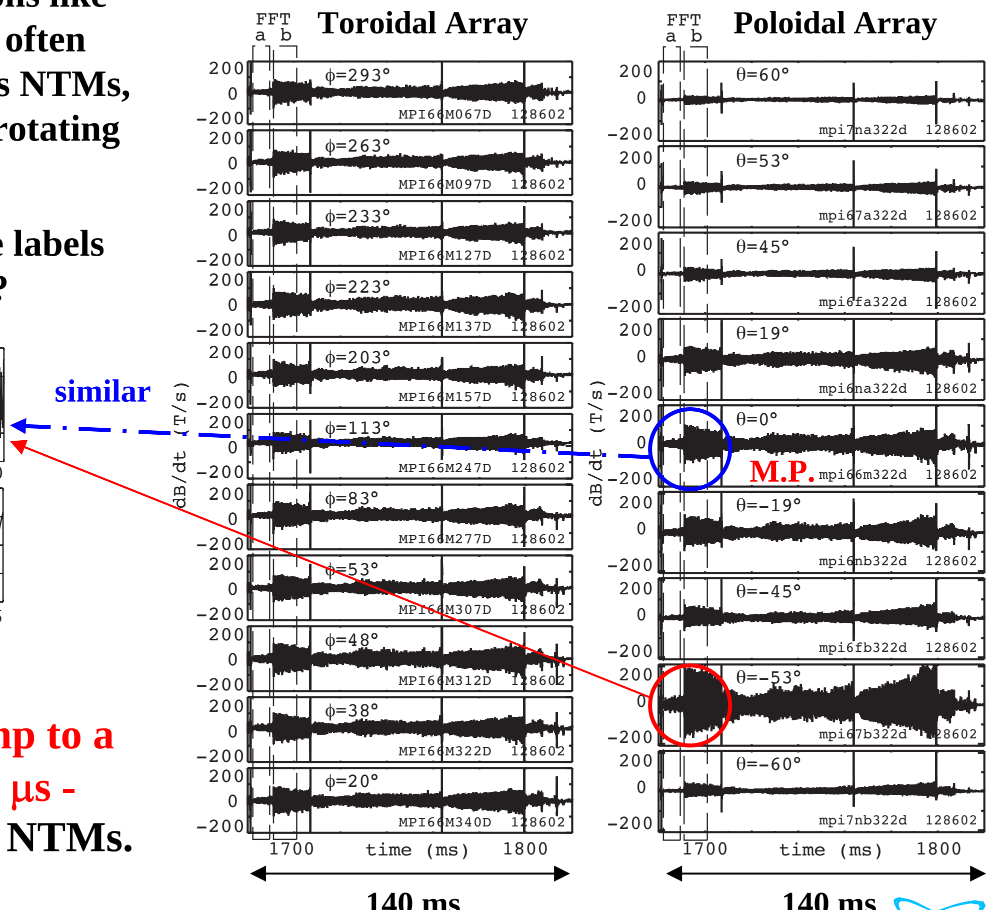
Feedback Control of ELM-driven RWMs (DIIID-MP-2007-04-07) Run on 4/12/07



Oscillations like these are often labeled as NTMs, TMs, or rotating modes.

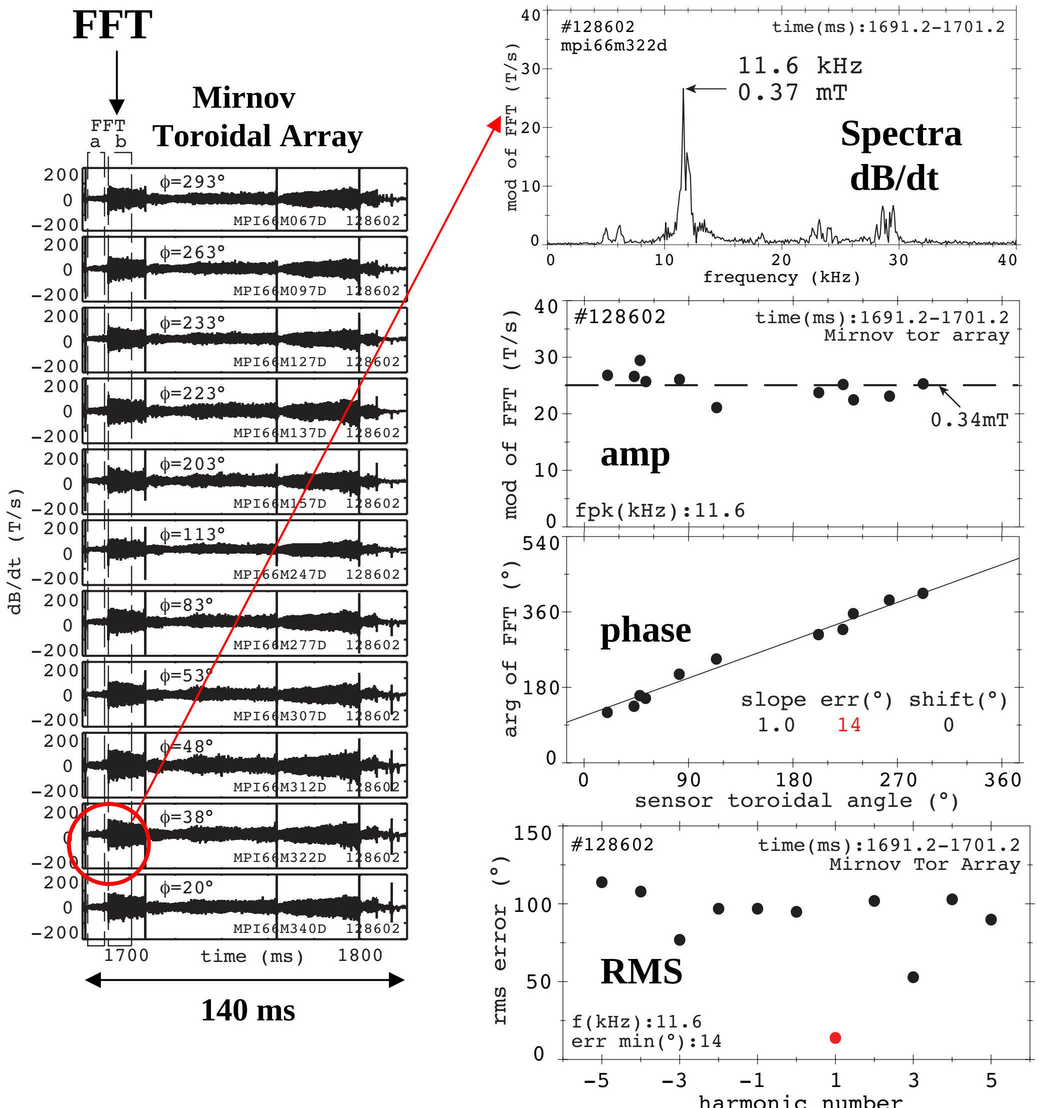
Are these labels accurate?





Amplitude is sometimes seen to jump to a saturated value in ~ 1/4 period ~ 20 μs - unusual feature, if these are indeed NTMs.

Toroidal Array Signals Vary Like Global Mode



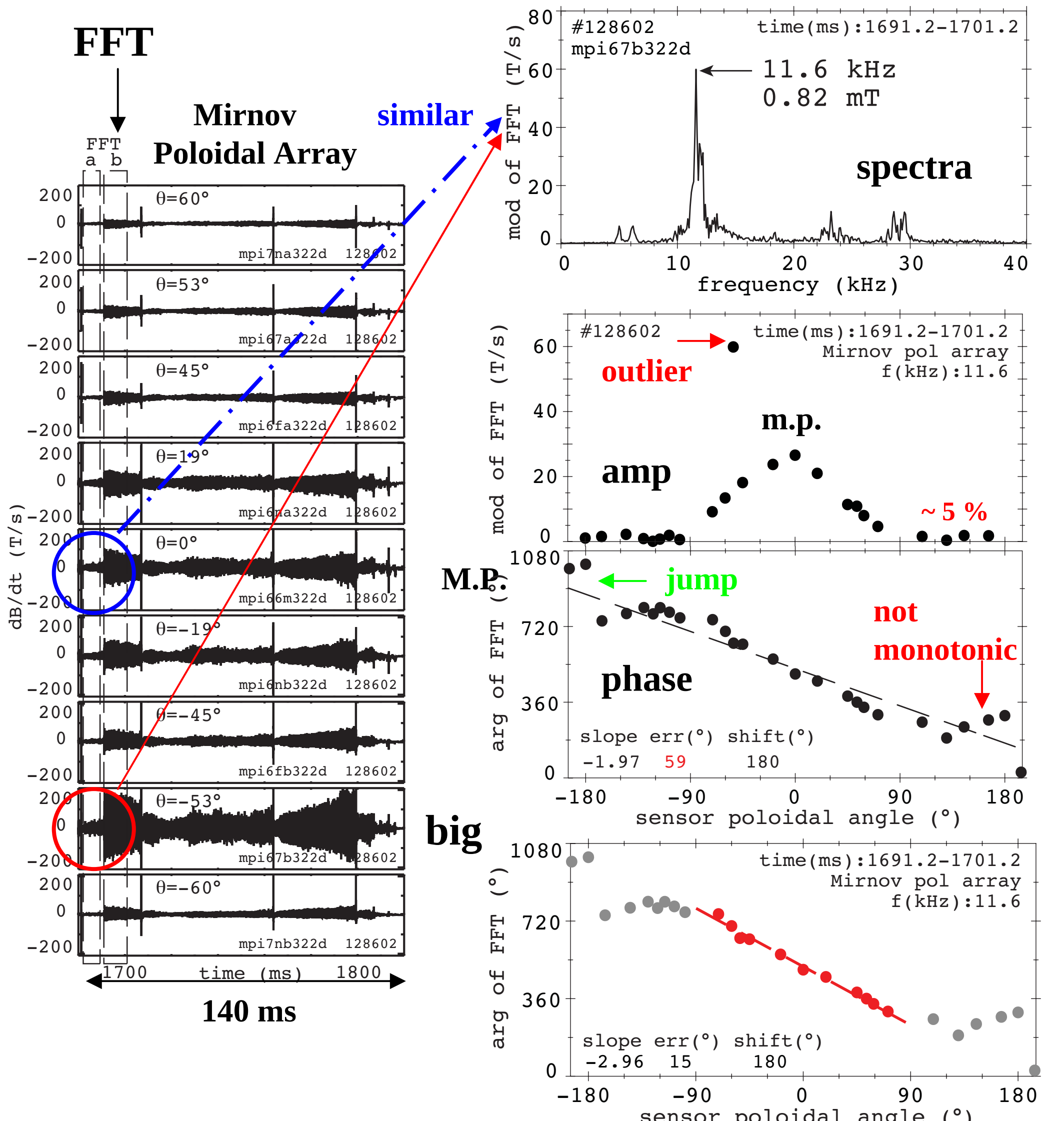
Spectra of mod FFT of dB/dt are similar around torus.

Amp (mod FFT) is approximately constant around torus, consistent with notion of rotating global mode.

Phase (arg FFT) varies toroidally as n = +1 harmonic monotonically with reasonably small RMS error (14 deg).

Other integer harmonic numbers result in significantly poorer fit than n = +1 (red point).

Poloidal Variation *Inconsistent* with Tearing Mode



Spectra similar to toroidal array.

Amp (mod FFT) large on outboard and tiny (~ 5 %) on inboard, a feature inconsistent with TM. Outliers are sometimes seen.

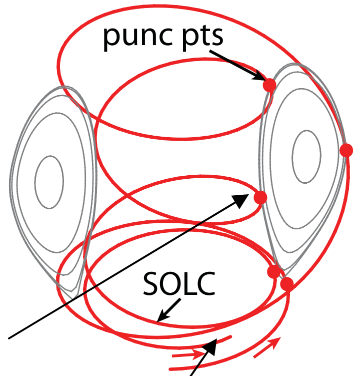
Phase (arg FFT) advances not monotonically and has a jump - a feature inconsistent with TM. Single harmonic fit (m = -2) poor with large RMS error (59 deg).

Fit to only outboard data results in m = -3 with reasonable RMS error (15 deg).

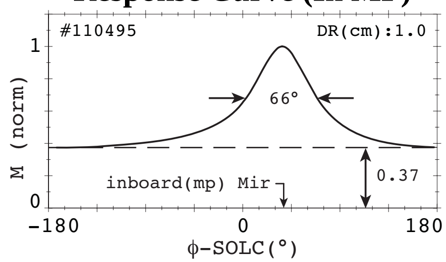
➡ **-3/+1 mode? (but not a whole picture)** no show

Generic Geometrical Features of SOLC Filaments Reflected in Field Patterns They Produce

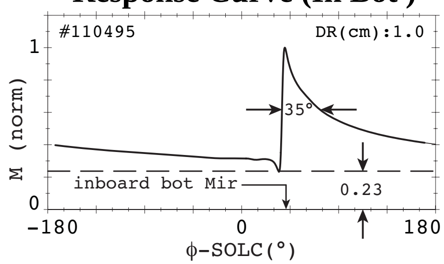
Circumnavigating
SOLC Filament



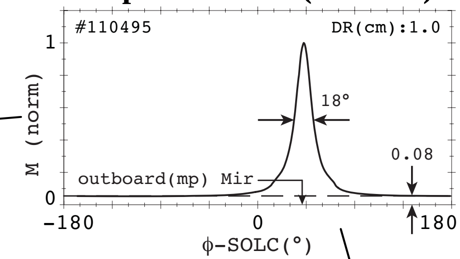
Response Curve (In MP)

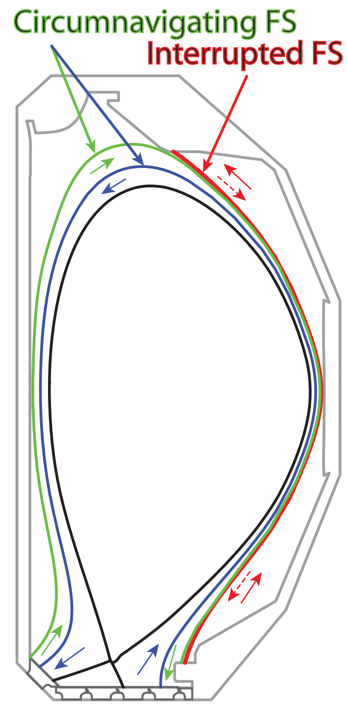


Response Curve (In Bot)

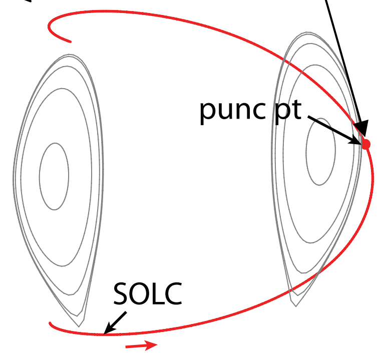


Response Curve (Out MP)





Interrupted
SOLC Filament



Each filament generates field toroidally spread out on inboard side and in divertors

Each filament generates field toroidally localized on outboard side

PPPL PRINCETON PLASMA PHYSICS LABORATORY

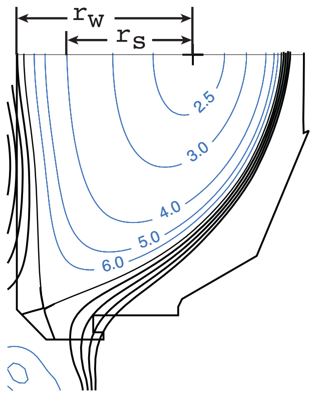
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

‘Interrupted’ SOLC Filaments Is a Possible Source of Observed B_θ Perturbations

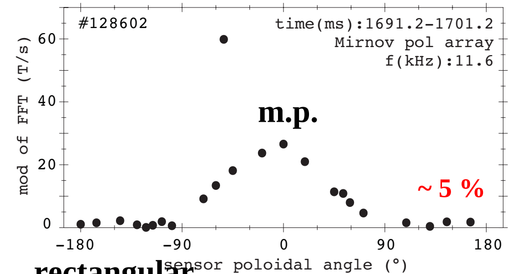
multi-pole field decay

$(\frac{r_s}{r_w})^{m+1}$ (%)

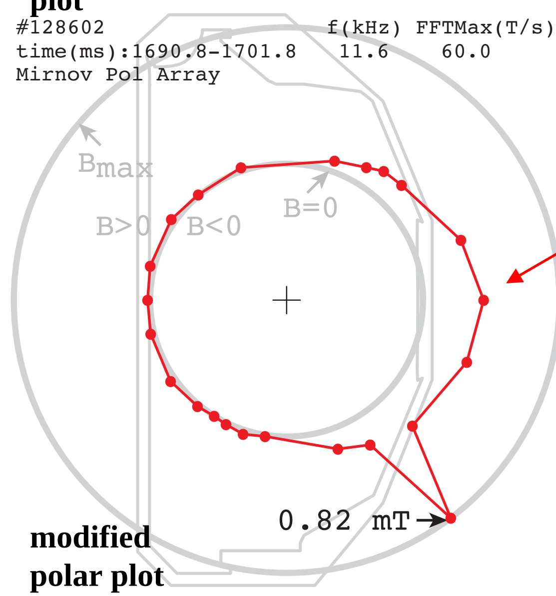
m	in	out	in/out
3	4.2	5.6	0.76
4	19	12	1.55
5	35	14	2.48



Modulus of FFT of dB/dt Vs θ

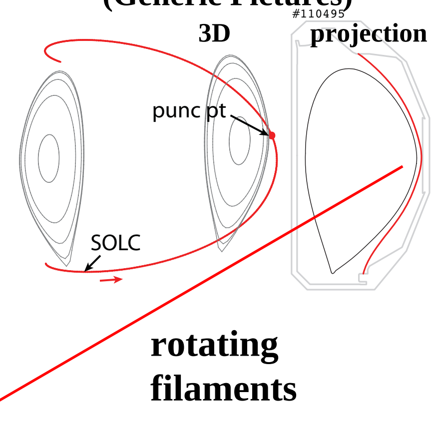


rectangular plot



modified polar plot

Interrupted **SOLC Filament (Generic Pictures)**



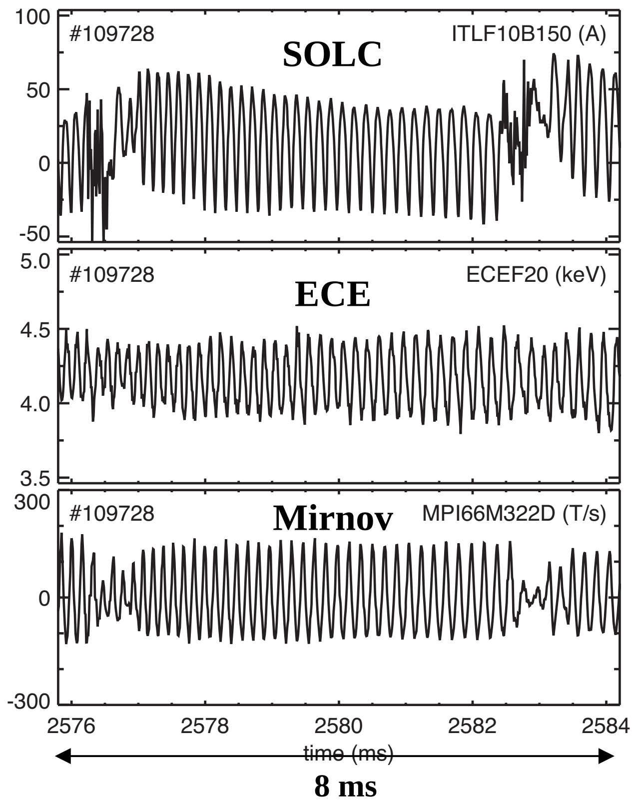
rotating filaments

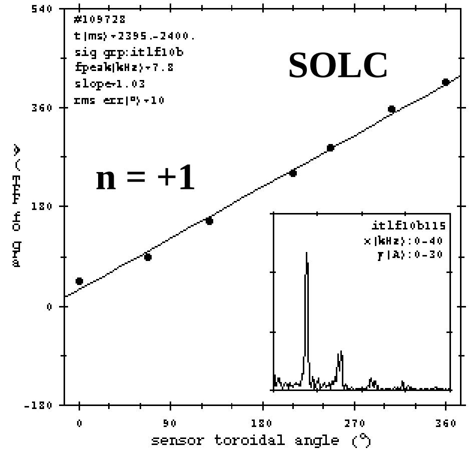
Zero-th order geometrical consideration leads to B_θ larger on *inboard* than outboard for most m’s - opposite from observation

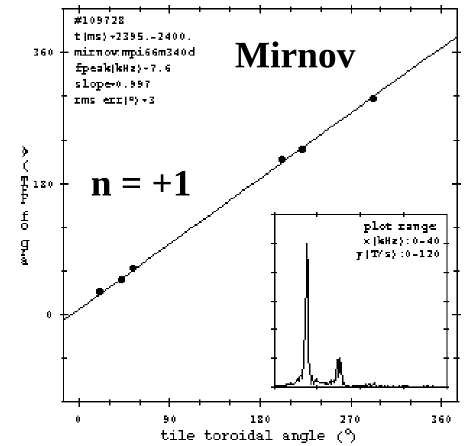
Modeling of observed B_θ by a distribution of interrupted SOLC filaments is underway.

Same Toroidal Structure for Mirnov & SOLC

different shot





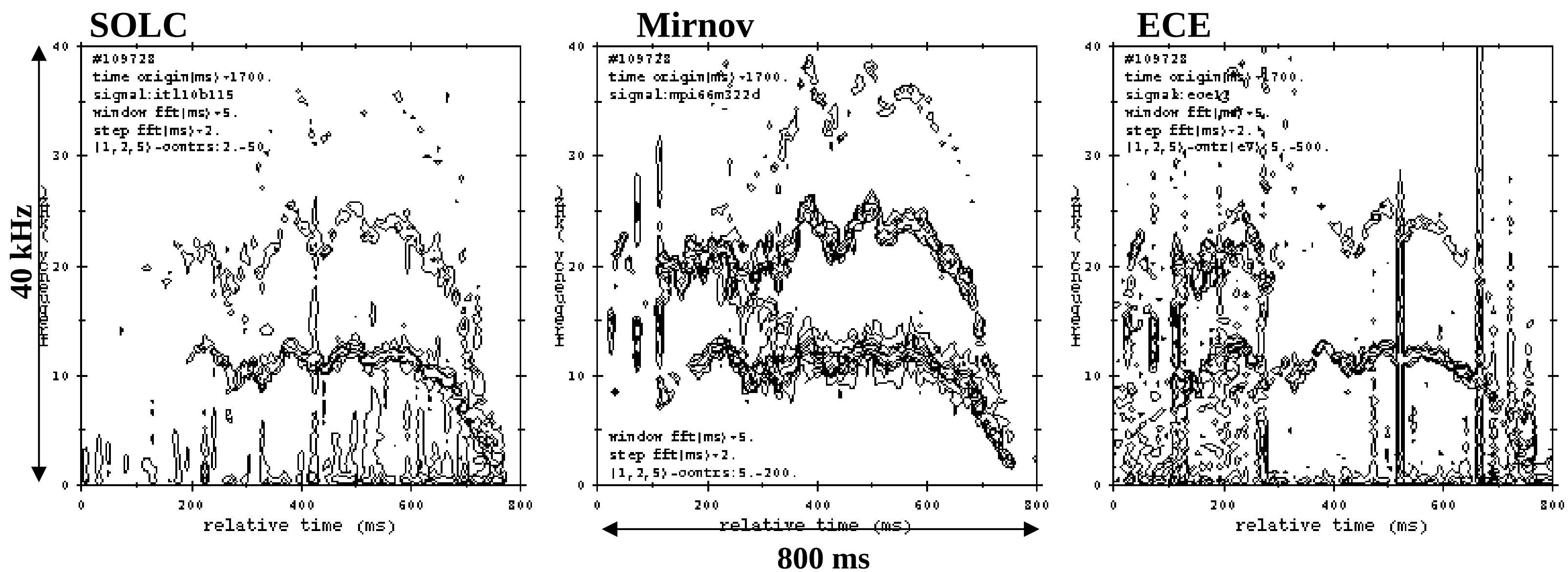


Both spectra and toroidal structures similar for SOLC and Mirnov signals.

SOLC, ECE, and Mirnov signals at same frequency and phase-locked. Only small islands (~ 3 cm) detected by ECE. Observed field much greater (factor ~ 50) than one commensurate to observed island width.

Spectral Evolution Similar for SOLC, ECE, and Mirnov Signals

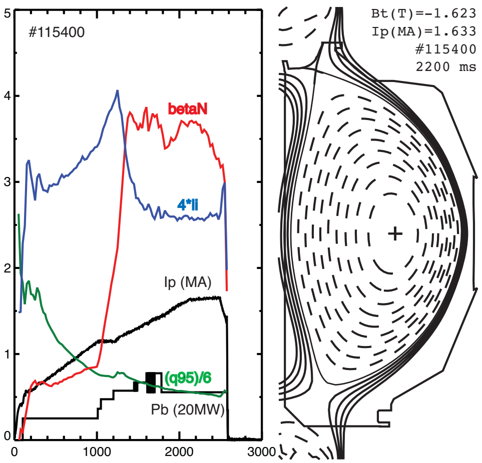
Amplitude Contours in Frequency Vs Time Plane



Working hypothesis: **non-axisymmetric current in plasma (associated with islands or kink mode) *entrains* SOLC, which in turn produces bulk of observed field.**

Strong Ballooning Predicted for Field in RWMs

USN Discharge in DIII-D



M. Chu and M. Chance

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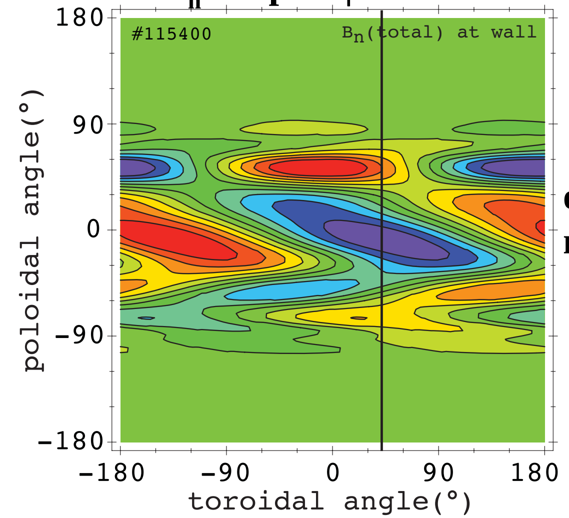
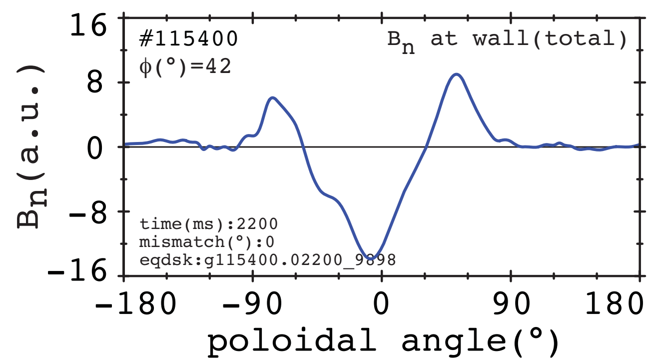
n = 1 & all m's feedback at marginal gain

RWM Theory
B_n Amp in ϕ-θ Plane



outboard mid-plane

Profile through ϕ=42 deg

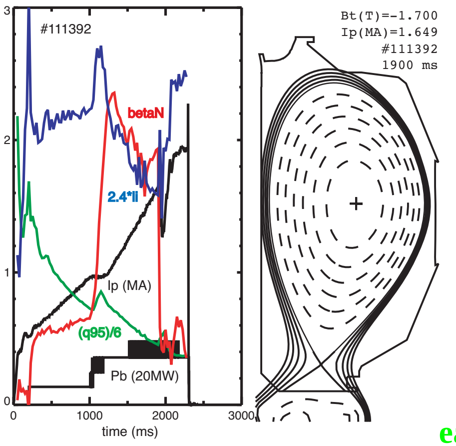


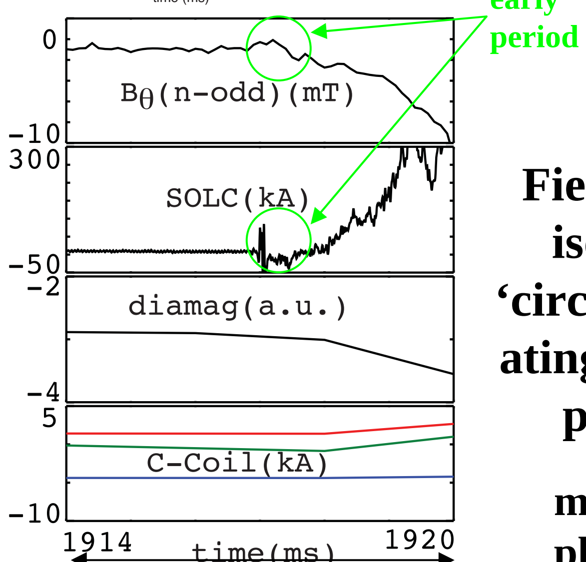
Little perturbation is predicted on inboard and in divertors.

1 - 'Unexpected' B_θ Measured in 'RWM Event'

Different Shot

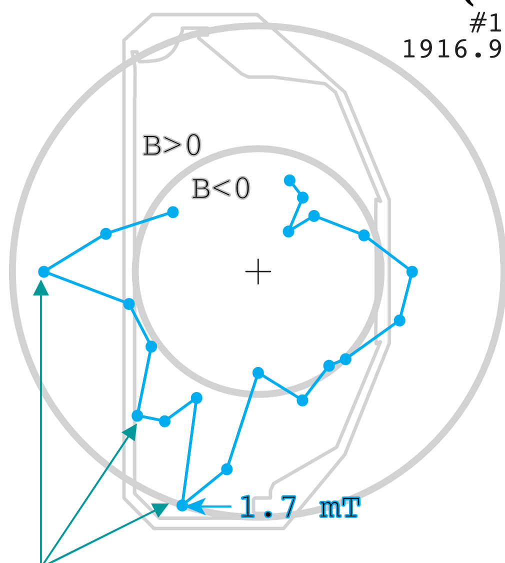
LSN Discharge in DIII-D





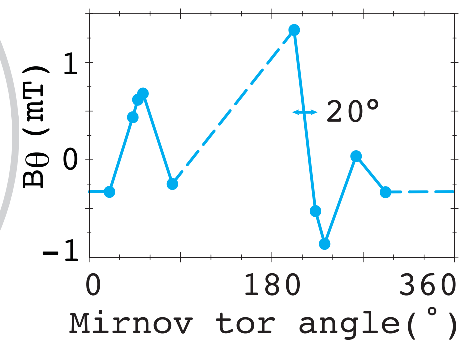
6 ms

Poloidal Variation
Modified **Polar Plot vs θ**



B_θ at ~ 0.4 ms after Onset (Integrated Mirnov Signals)

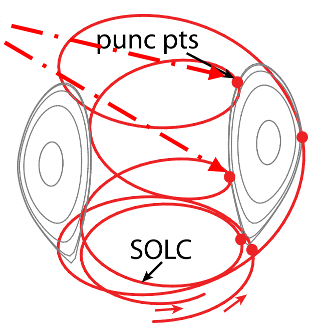
Toroidal Variation
outboard mid-plane



Sharp bipolar change in ϕ < 20 deg, *not* n=1-like

Field from isolated 'circumnavigating' SOLC paths?

modeling planned

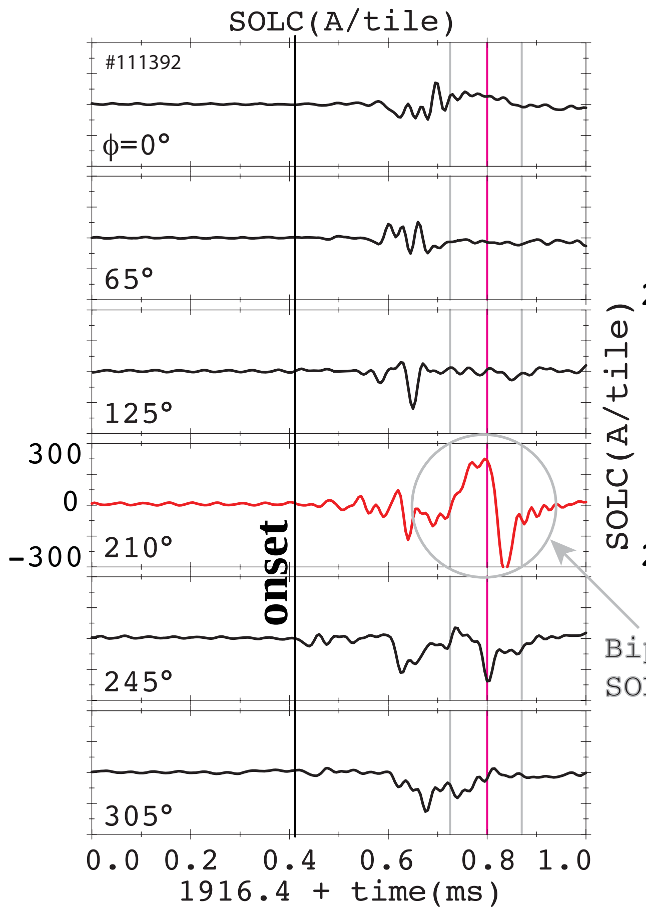


SOLC path illustration (typical shot)

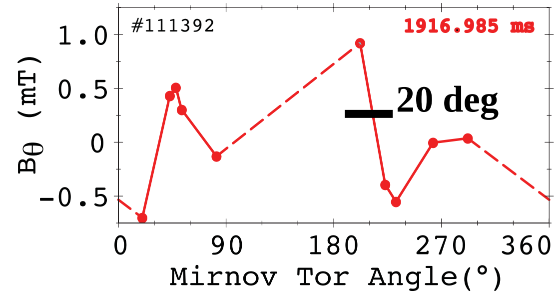
Narrow features in B_θ patterns suggestive of a small number of isolated SOLC filaments producing field.

SOLC Possible Source of Field in 'RWM Event'

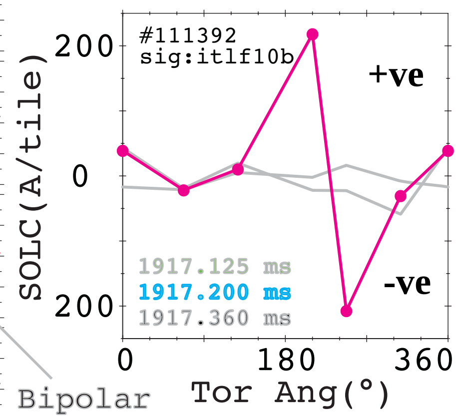
SOLC vs Time at Various ϕ



sharp bipolar changes in B_θ

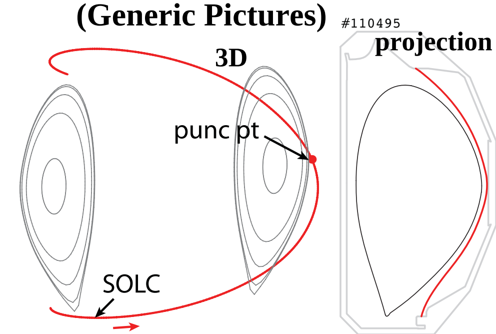


SOLC ϕ-variation



***Interrupted* SOLC Filament**

(Generic Pictures)

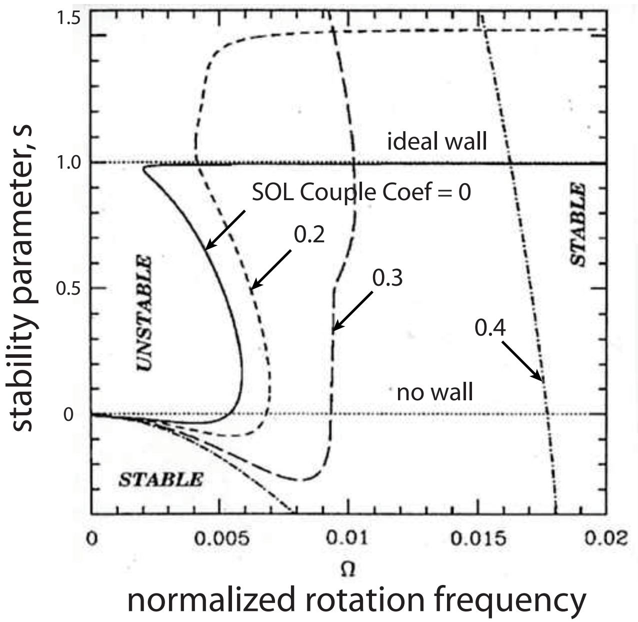


A pair of SOLC filaments carrying current of opposite polarities could produce observed bipolar field swing (modeling underway).

SOLC May Have Profound Effect on RWMs

(*) R. Fitzpatrick PoP14(2007)062505

RWM Stability Diagram(*)



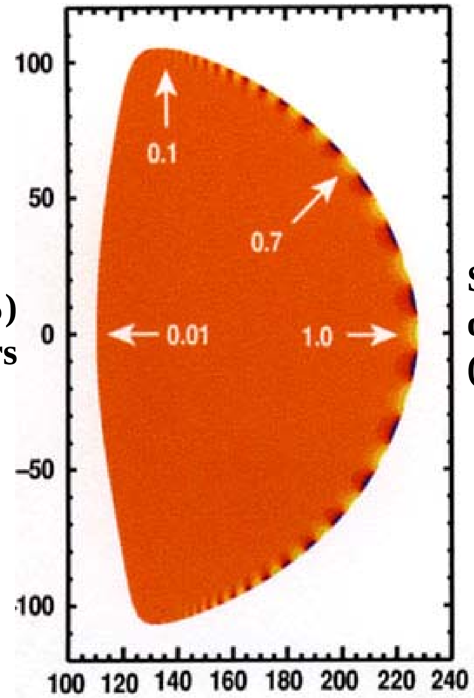
Fitzpatrick theory includes SOLC driven only by inductive coupling to MHD mode (not by thermoelectric potential and other mechanisms)

SOLC acts like image current in resistive wall, but with different effective time constants for different helical perturbations(*)

Leading Theory Predicts Strongly Ballooning Multi-pole Field during ELMs

Relative Field Amp in R-Z Plane

Little field on inboard (~ 1 %) and in divertors (~ 10 %)



Strong field on outboard (ballooning)

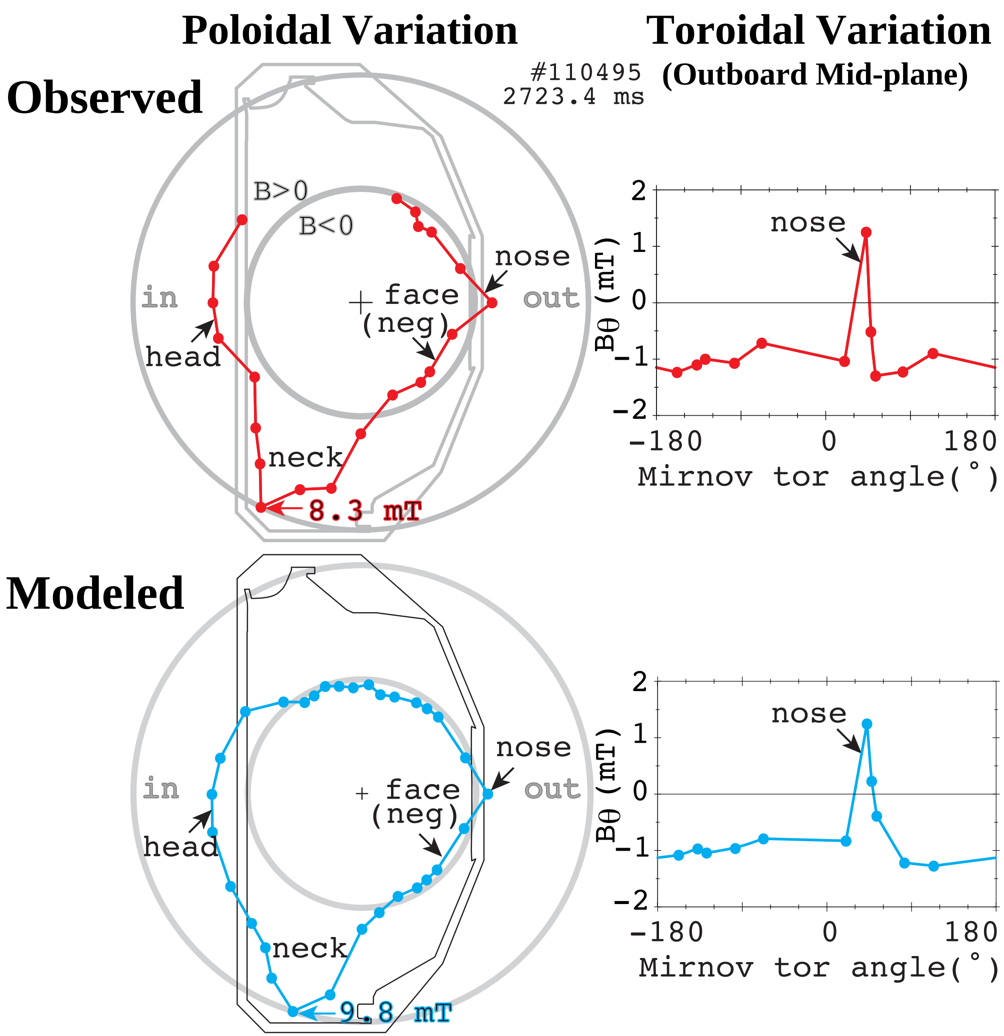
ELM simulation result by P. Snyder (in M. Fenstermacher et al., PPCF(2003)1597)

Peeling-ballooning mode in linear phase has high multi-pole field, which decays rapidly with distance away from the plasma surface.

Field detected by Mirnov coils during ELM precursor may thus be largely of origins other than the mode *(even in the presence of mode)*.

P.-B. mode is predicted to form a narrow 'filament-like' structure in non-linear phase, which thus still has largely a high multi-pole spectrum.

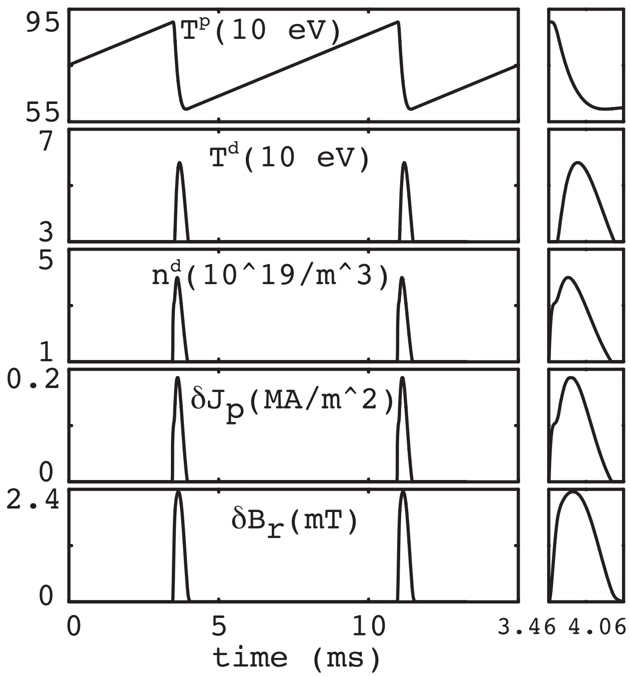
Field at Peak of ELM Modeled Based on SOLC



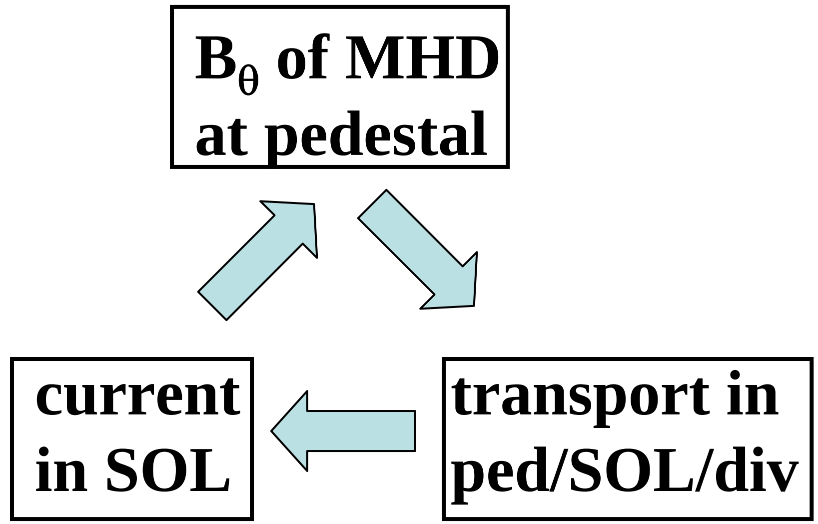
- In calculations, SOLC distribution was made consistent with measured patterns, both toroidal and radial, on circumnavigating flux surfaces, and was postulated on interrupted flux surfaces to match the observed field.
- Idiosyncratic features of B_θ patterns observed at ELM peak can be modeled well as SOLC-generated field.

Positive Feedback between B_θ at Pedestal and SOLC May Explain Explosive Rise of ELMs

ELM Simulation



Positive Feedback Loop



L.-j. Zheng submitted

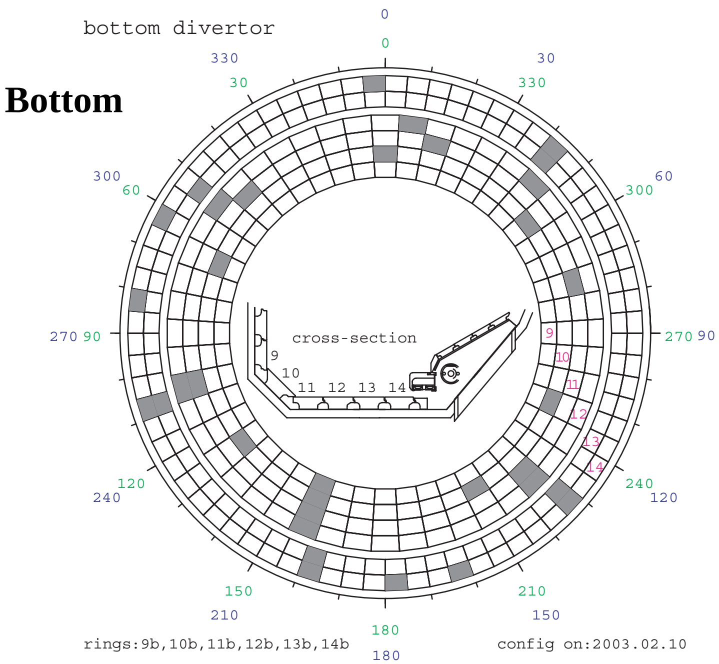
Pedestal evolves with inter-ELM time scale through marginal and linear MHD stability regimes, and this slow change may be inconsistent with observed explosive rise of ELMs.

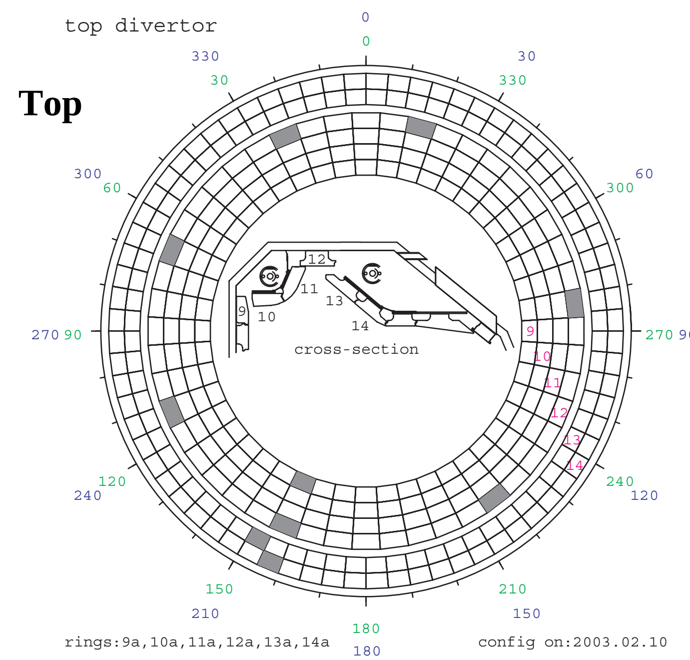
Summary

- **SOLC generates *dynamic* error field; Can SOLC:**
  - **Masquerade as huge islands?**
  - **Provide seed islands to 'seedless' NTMs (resonant at finite rotation)?**
  - **Masquerade as RWMs?**
  - **Slow down rotation and generate locked mode?**
  - **Destabilize RWMs? ("Yes," says Fitzpatrick)**
  - **Spoil RWM feedback?**

- **Field at ELM peak has been modeled, consistent both with B_θ observed at Mirnov locations and SOLC measured at divertor tiles. Can SOLC:**
  - **Help destabilize peeling-ballooning mode?**
  - **Provide explosive rise via positive feedback? ("Yes," says Zheng)**
  - **Generate stochastic field at plasma edge?**

Sensors Measure SOLC through Divertor Tiles





Each shaded divertor tile is instrumented with a resistive-element current sensor, which *sums* current over a significant radial extent.

A narrow SOLC channel may escape detection because < ~ 10 % of tiles in selected tile-rings have sensors.