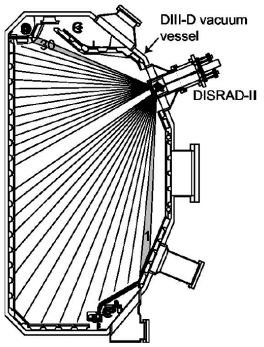
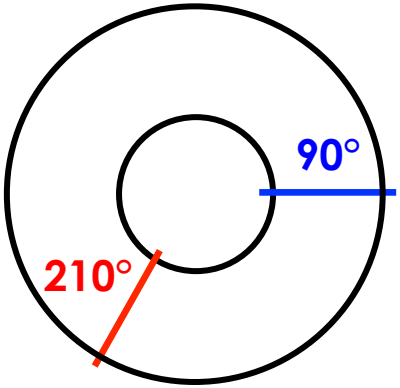
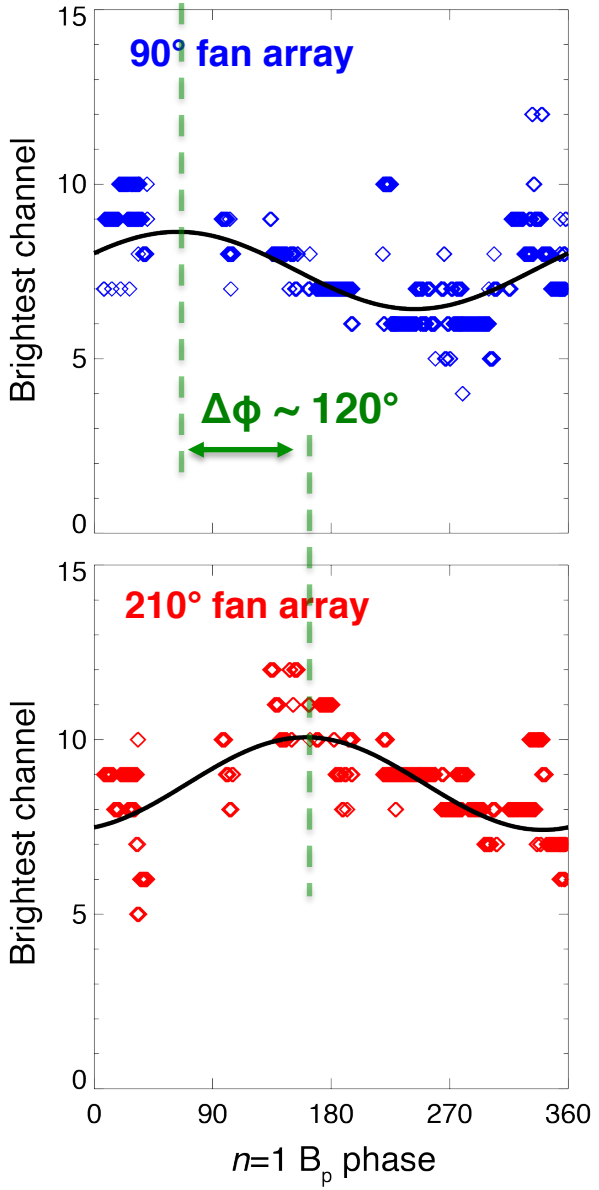
MHD activity and its influence on radiation asymmetry during massive gas injection on DIII-D

by
Daisuke Shiraki







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DIII-D NATIONAL FUSION FACILITY

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Summary

- Following massive gas injection, inwardly propagating cold front destabilizes MHD cascade, as directly detected by magnetics

- The toroidal phase of the *n*=1 MHD appears to affect TQ radiation asymmetry

- Toroidal evolution of mode affected by three factors: injector location, pre-MGI plasma rotation, and large *n*=1 EFs

Outline

- Introduction
- Magnetic measurements of MHD mode structure during MGI
- Relationship between MHD activity and thermal quench (TQ) radiation asymmetry
- Factors influencing evolution of pre-TQ MHD

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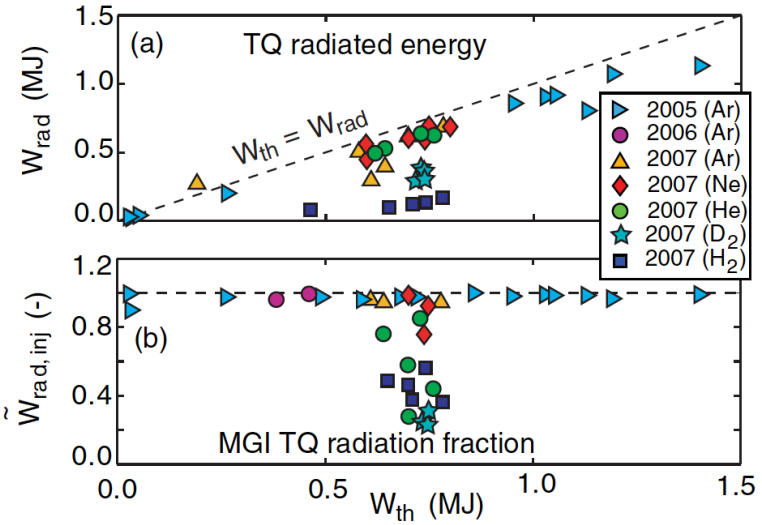
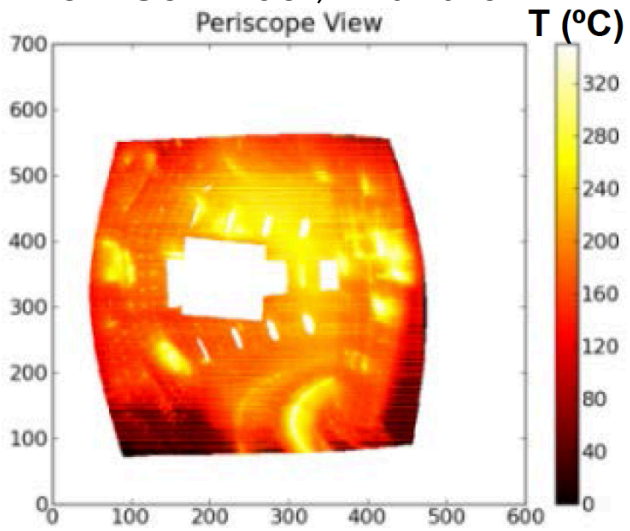
Effective TQ mitigation must account for 3D effects

- **Impurity injection is now a standard tool for disruption mitigation**
  - Gas or pellet injection
- **Effective in increasing radiation fraction, reducing vessel forces (0D effects)**
- **Concerns remain whether radiated heat loads are uniform enough (3D effects)**
  - Radiation asymmetry must be minimized

From Hollmann *et al.* NF **48** (2008) 115007

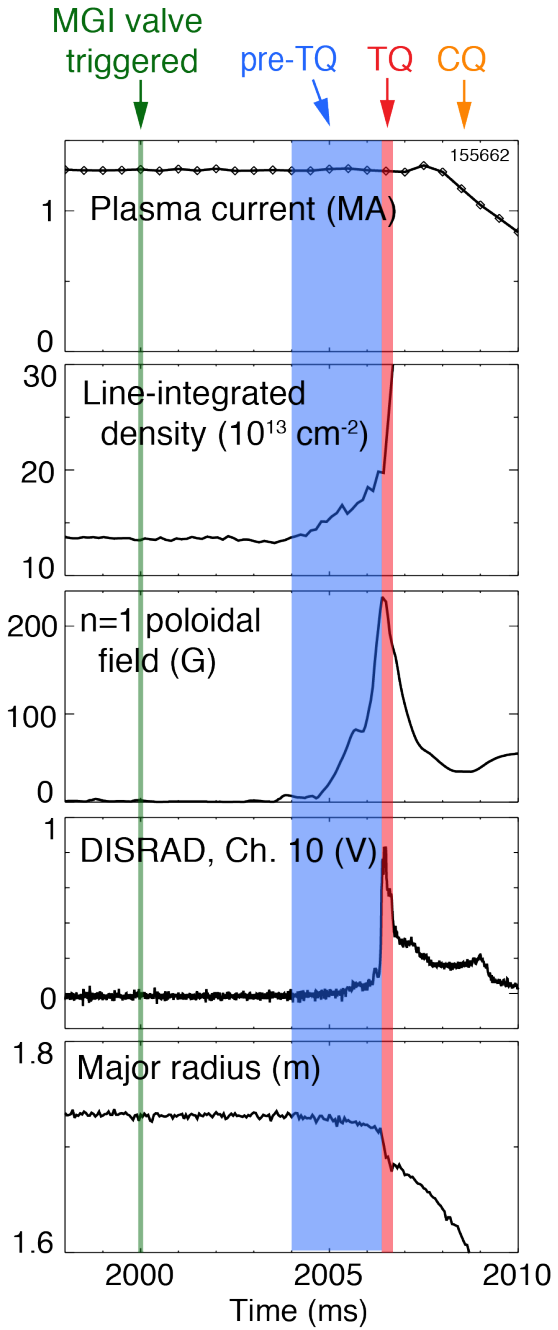


From Commaux, APS 2013



Large MHD activity observed during MGI fast shutdown

- **Typical sequence of MGI shutdown:**
  - MGI triggered at 2000 ms
  - Gas arrives at plasma surface after several ms time-of-flight
  - Cold front propagates in from edge to core, large MHD activity observed (pre-TQ)
  - Rapid TQ occurs, with large P_{rad} flash, major radius collapse
  - Cold resistive plasma decays during current quench (CQ)



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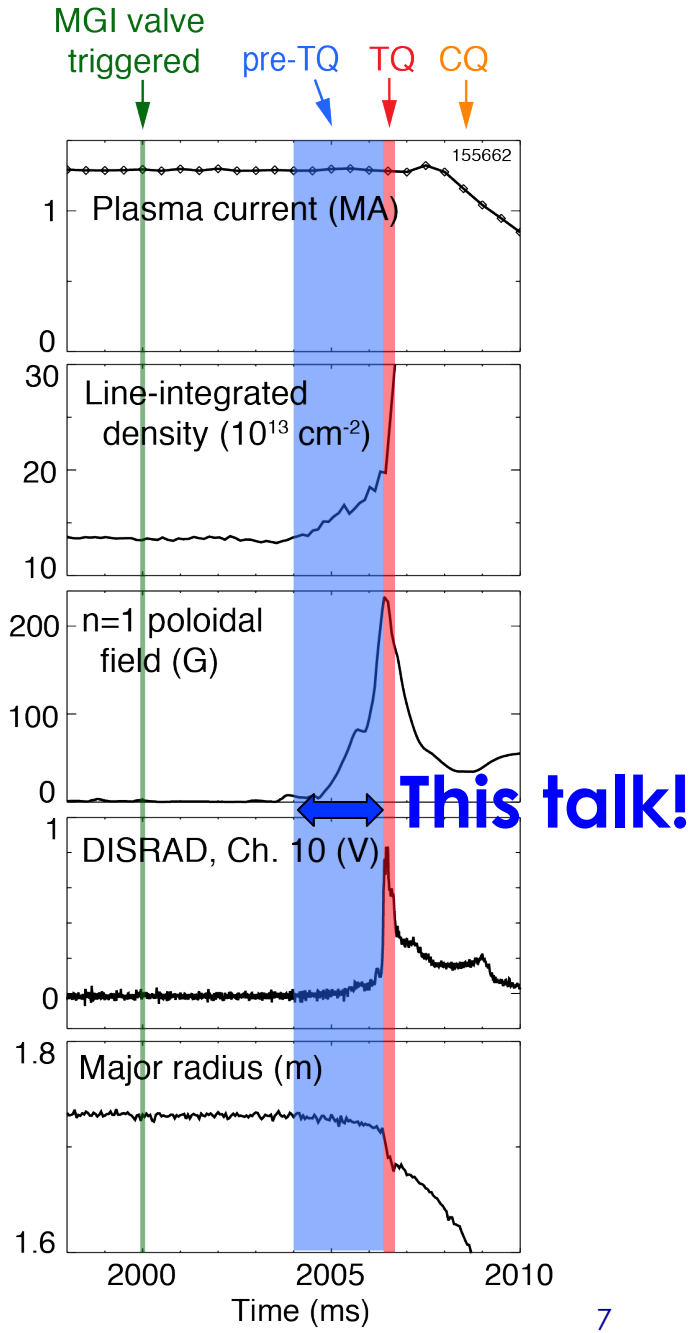
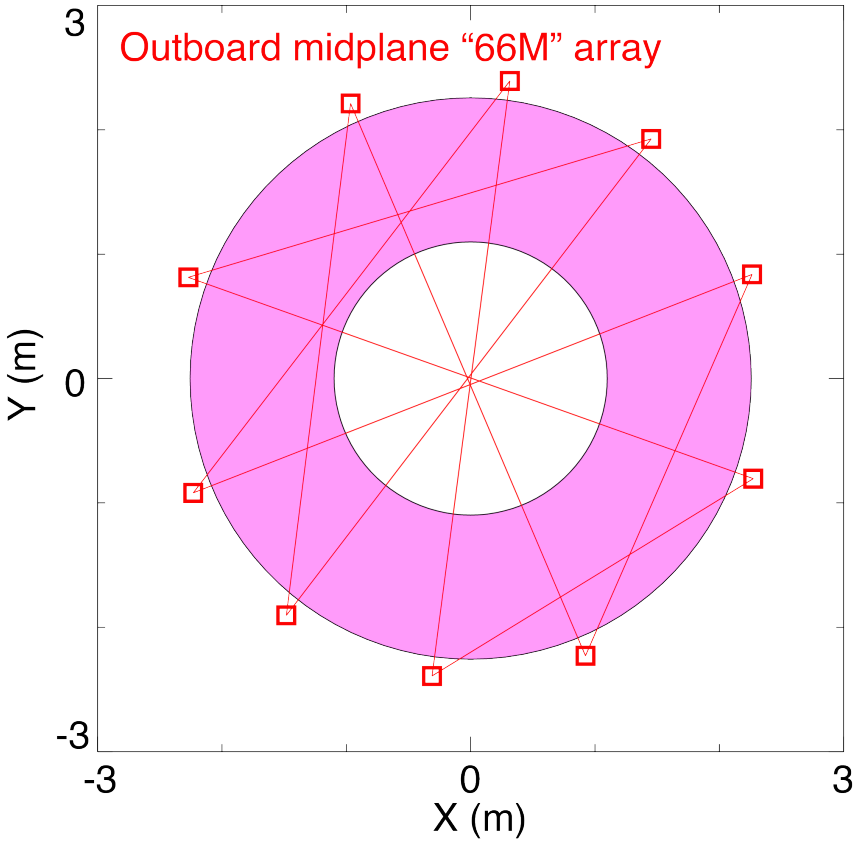


Outline

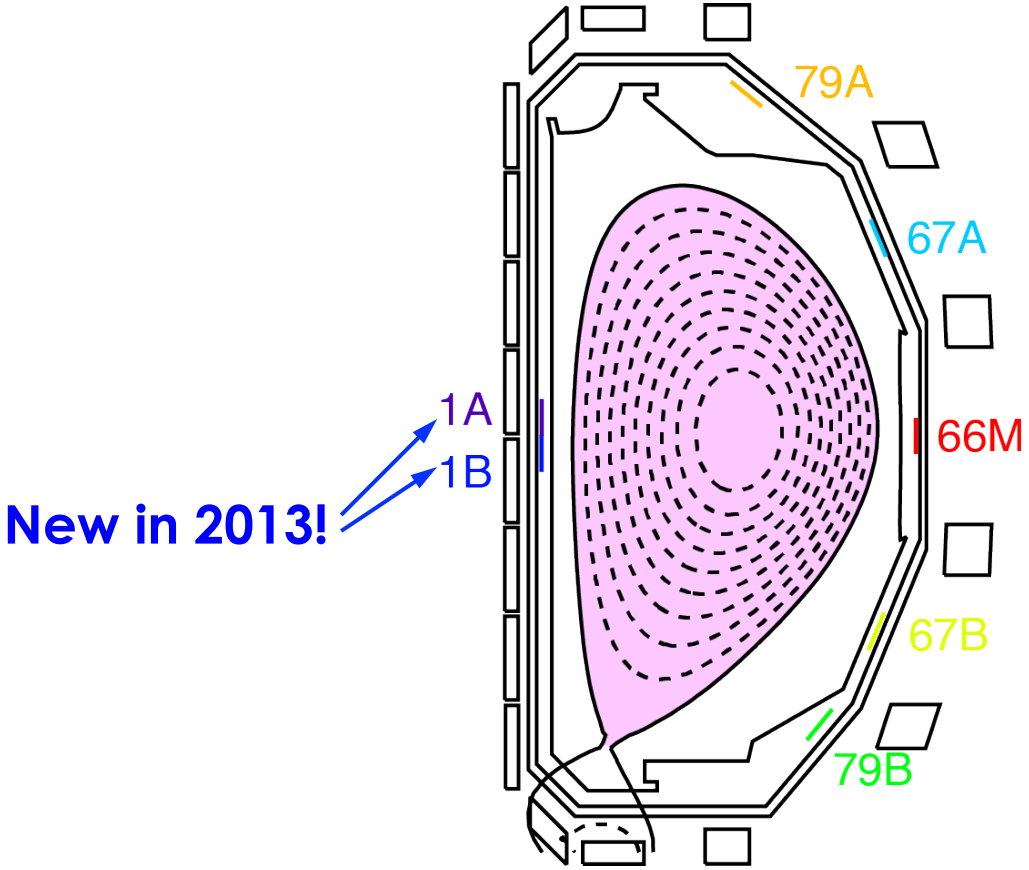
- Introduction
- **Magnetic measurements of MHD mode structure during MGI**
- Relationship between MHD activity and thermal quench (TQ) radiation asymmetry
- Factors influencing evolution of pre-TQ MHD

Large array of magnetic probes measures spatial and temporal evolutions of MHD activity

- **Pair-differenced "3D" magnetics reject *n*=0 components**

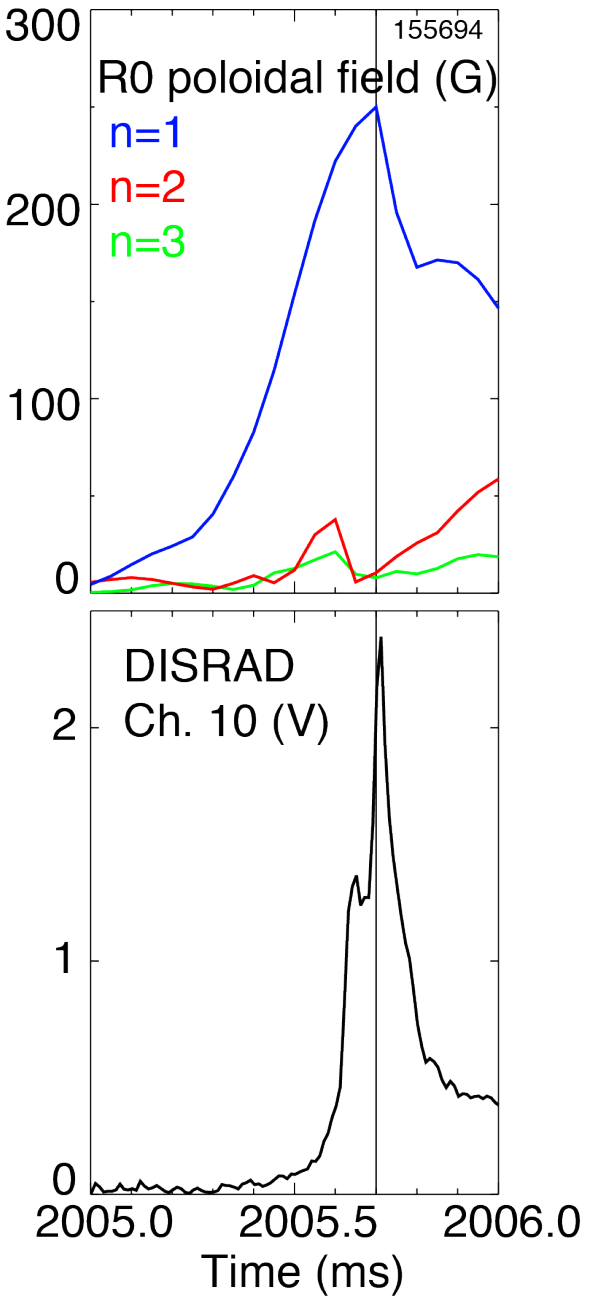


- **Seven toroidal arrays available**



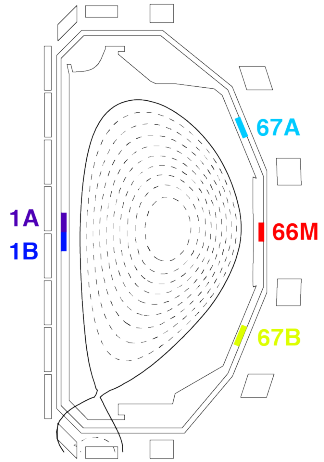
Pre-TQ MHD is dominantly n=1

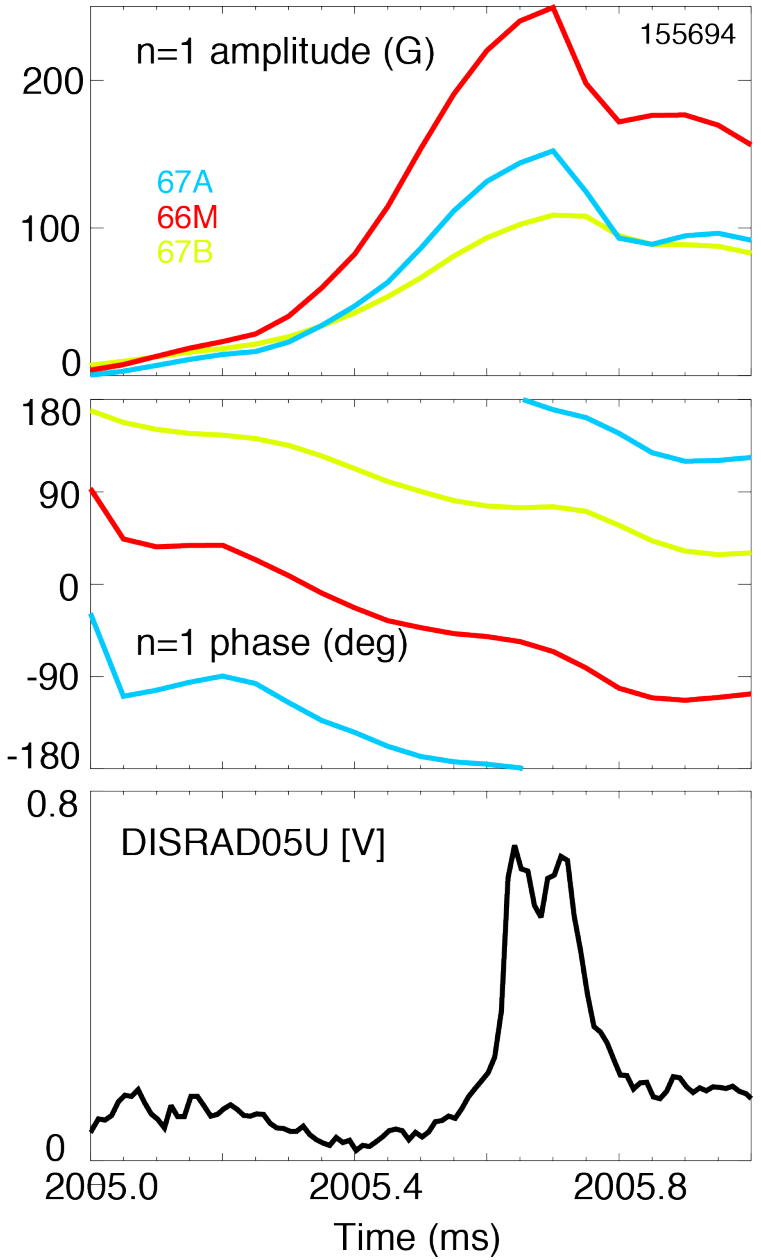
- **Simultaneous fit to *n*=1, 2, 3 for R0 toroidal array (10 difference pair signals)**
- **Pre-TQ MHD is dominantly *n*=1**
- **From now on, will consider *n*=1 signal from each toroidal array**



Low-order MHD mode structure is well-defined during pre-TQ

- **Monotonic growth of *n*=1 signal on LFS (66M, 67A, 67B)**
- **Definite phase relationship between arrays**





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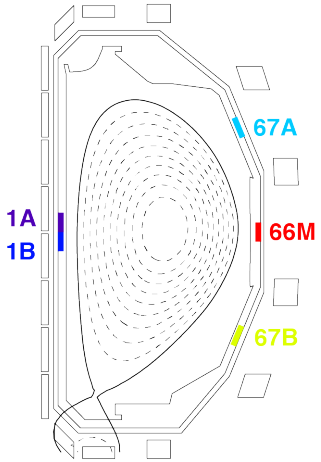
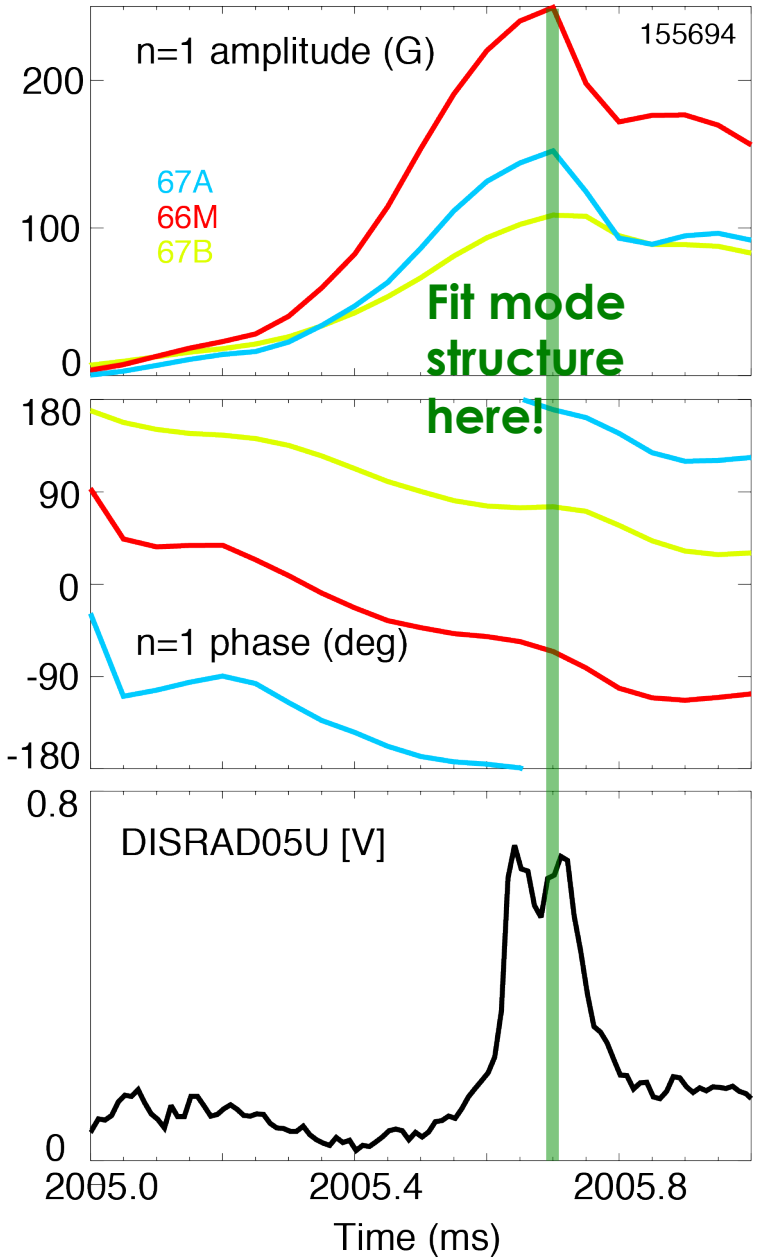
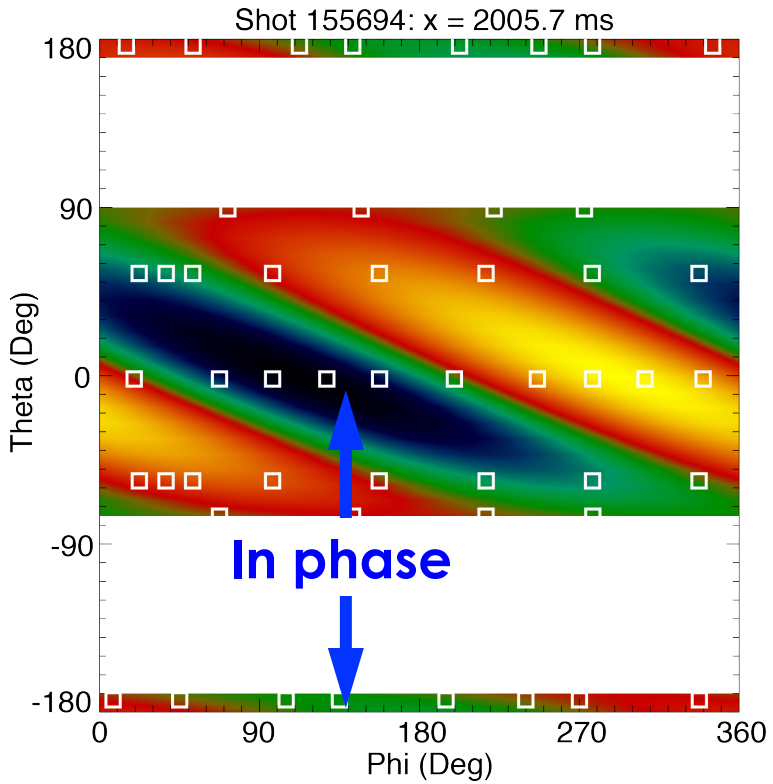
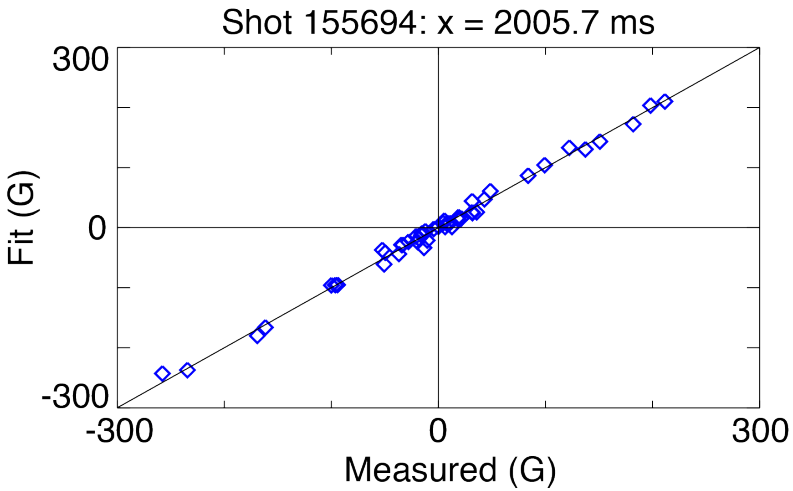




Dominant mode at peak of TQ is *m*/*n* = 2/1

- **Mode structure fit to 50 B_p difference pairs**
  - Probe locations indicated by squares
- **Outboard/inboard midplane signals in phase**
- **Dominant *m* is even**





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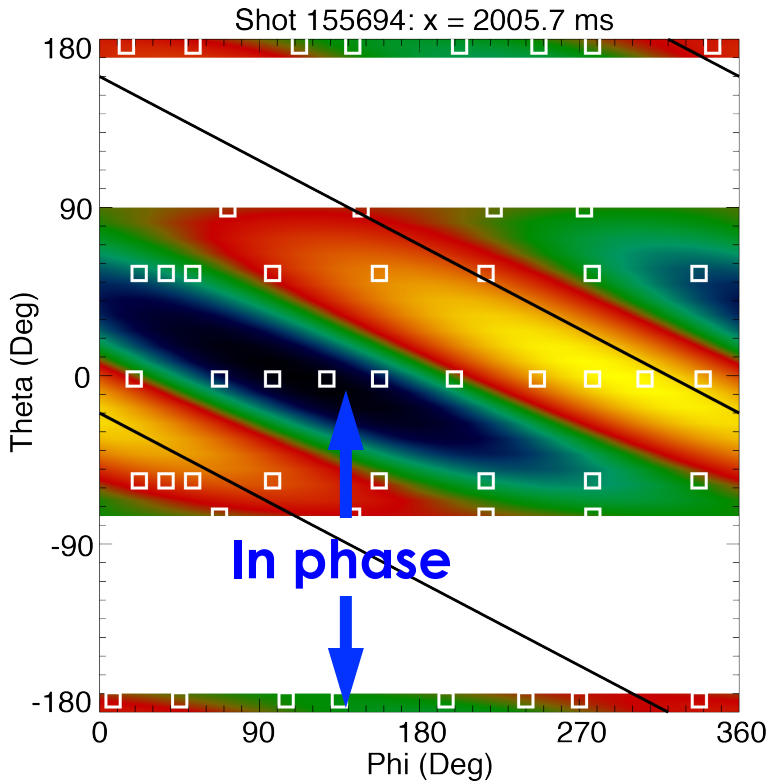
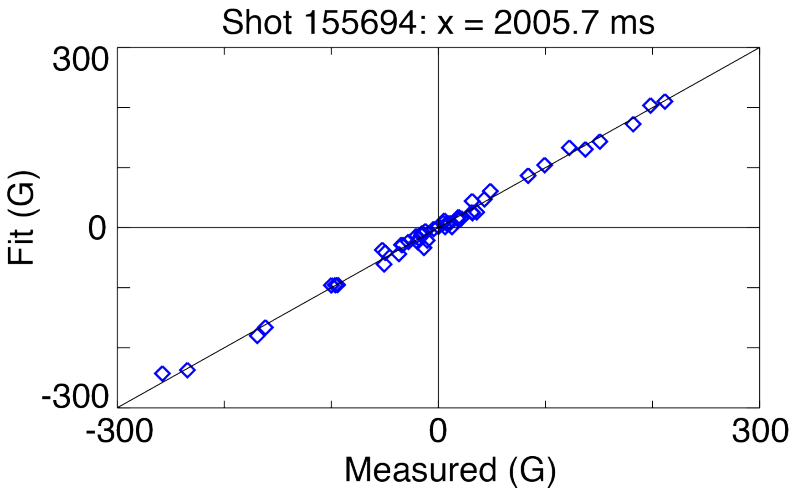
- **At peak of TQ, 2/1 is dominant**





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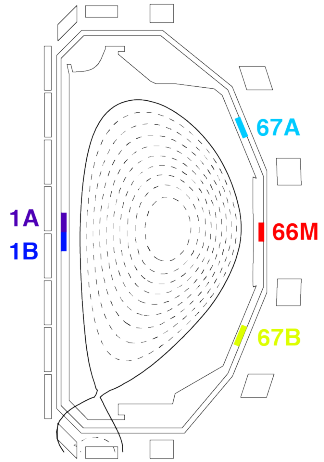

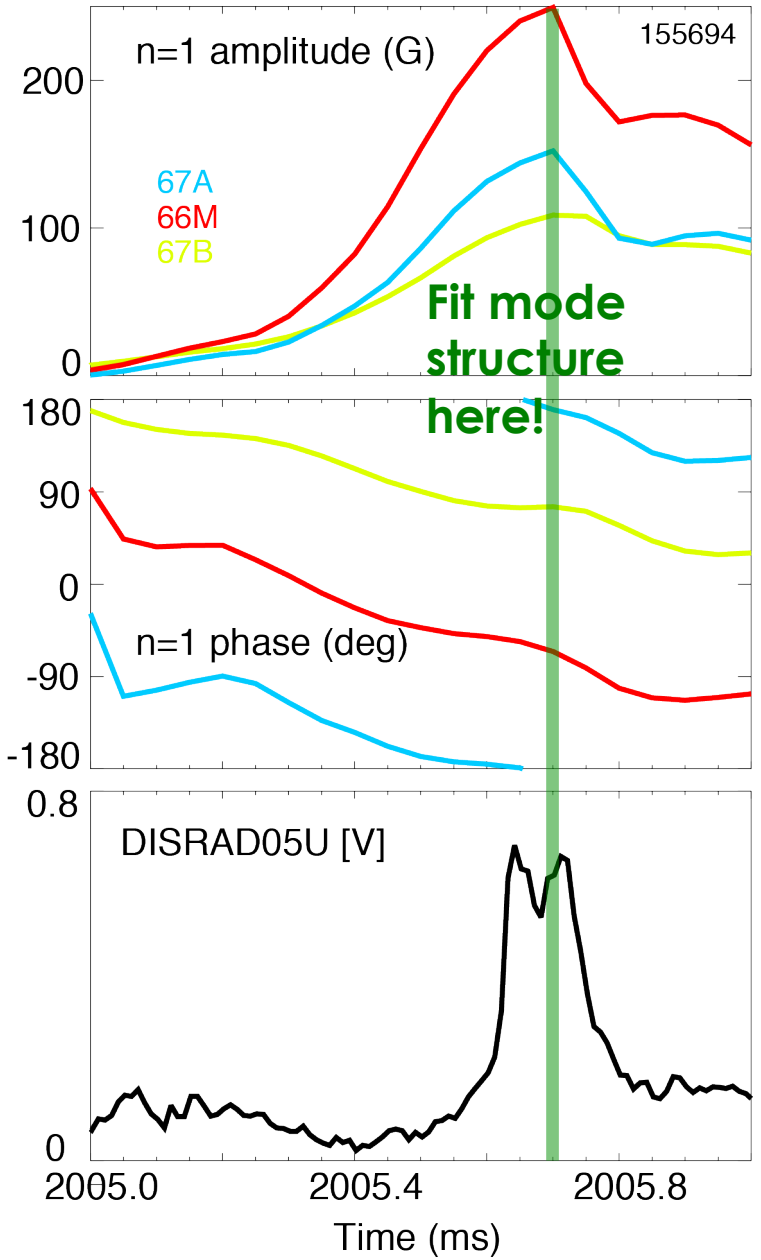

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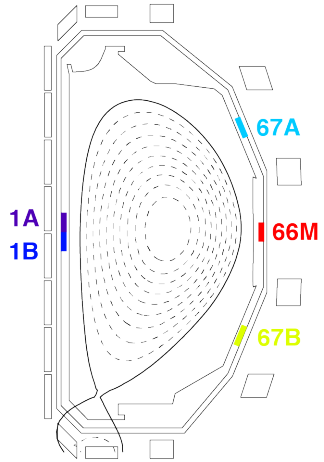
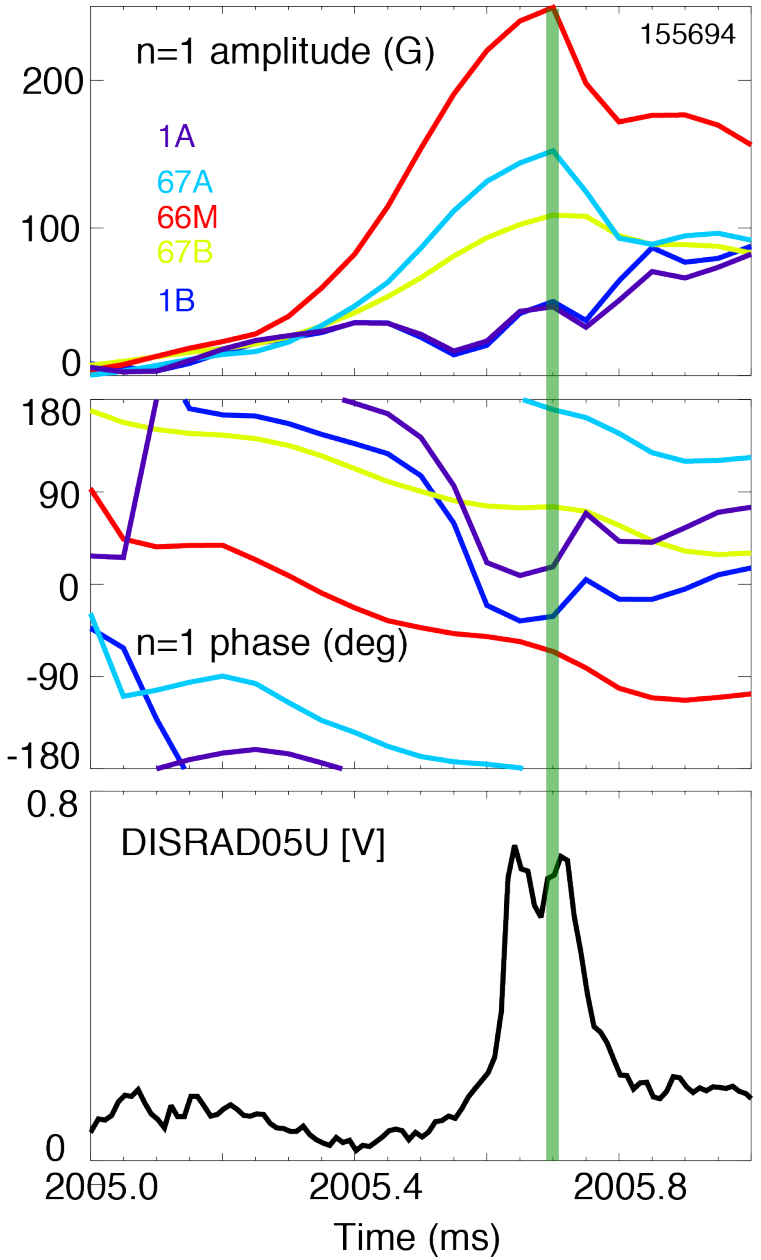
- Monotonic growth of n=1 signal on LFS (66M, 67A, 67B)
- Definite phase relationship between arrays
- On HFS (1A,1B) mode "flips phase"
- This is a robust feature observed in each shot!





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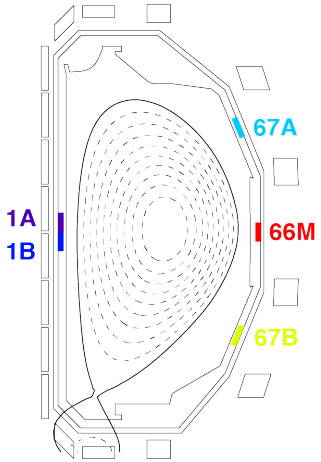
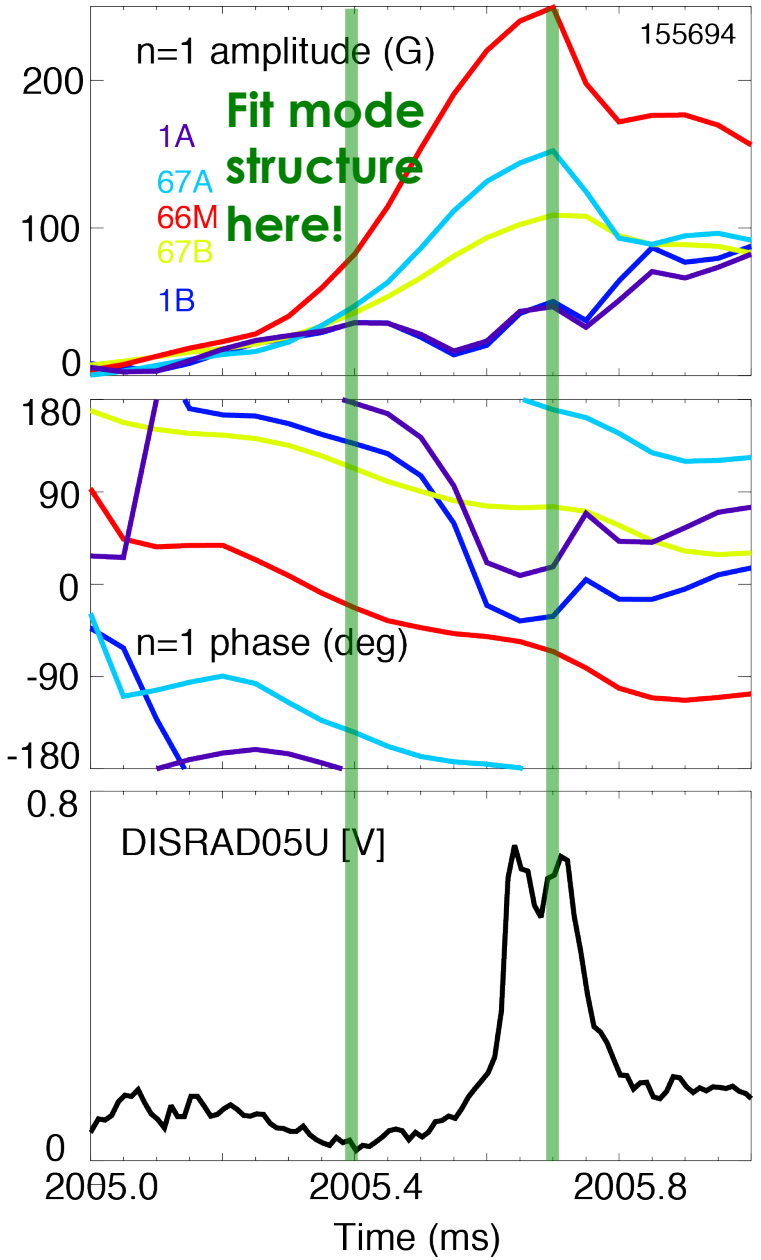
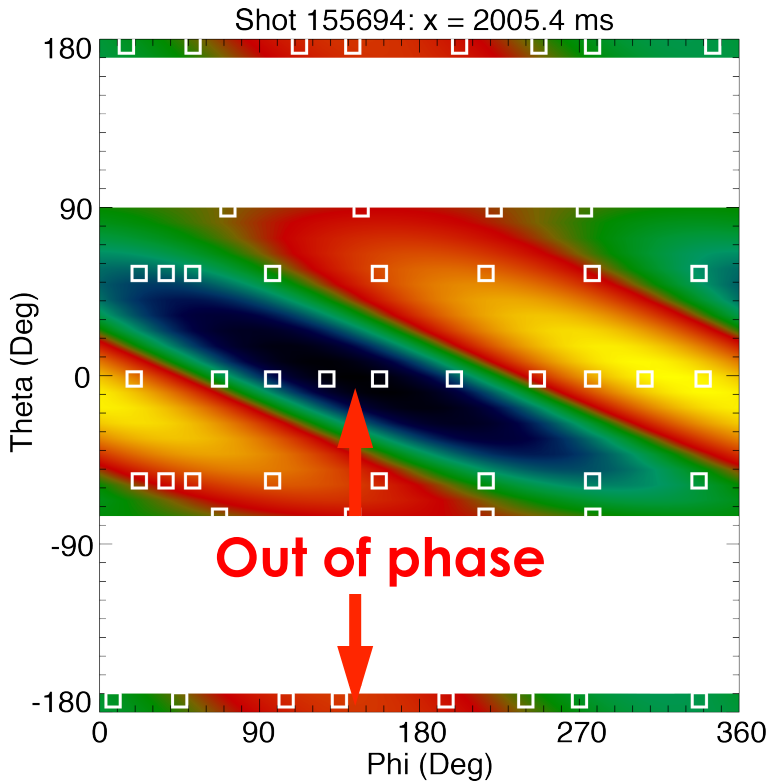
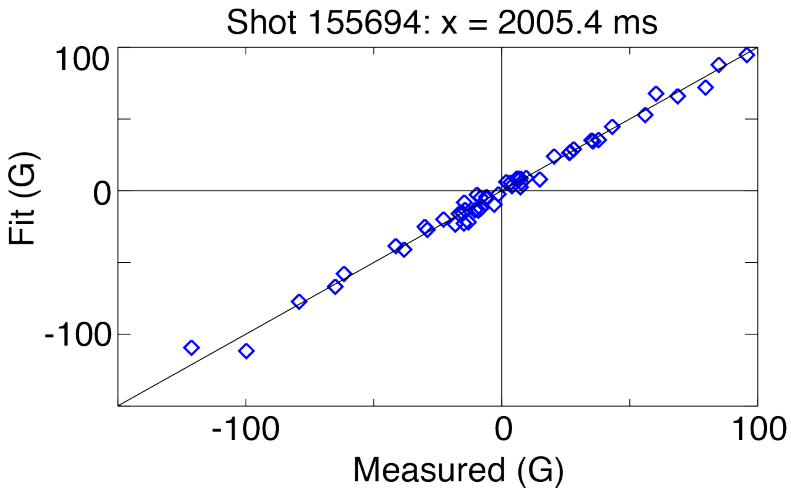




Prior to 2/1 onset, 3/1 mode is dominant

- **Mode structure fit to 50 B_p difference pairs**
  - Probe locations indicated by squares
- **Outboard/inboard midplane signals out of phase**
- **Dominant *m* is odd**





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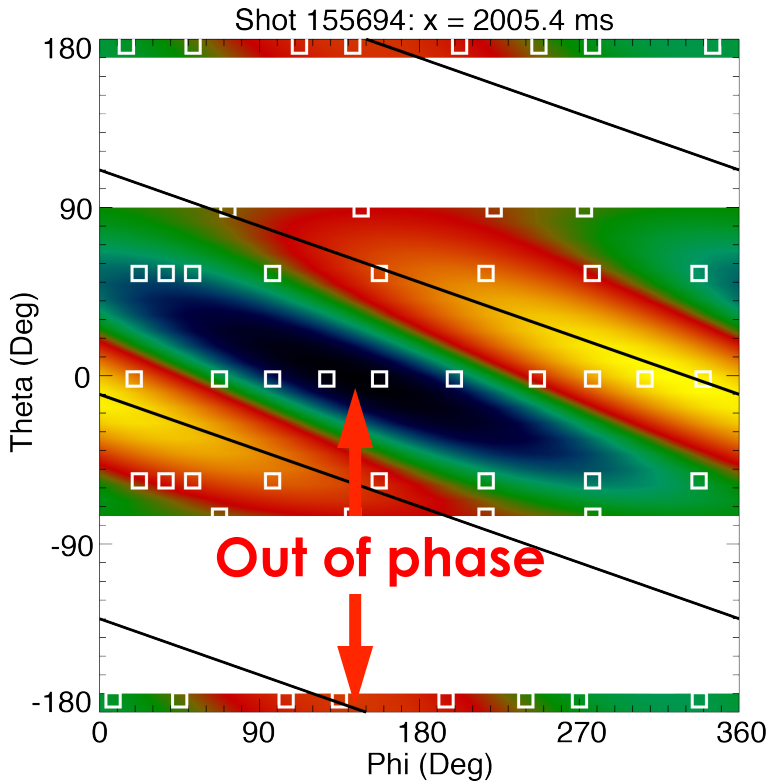
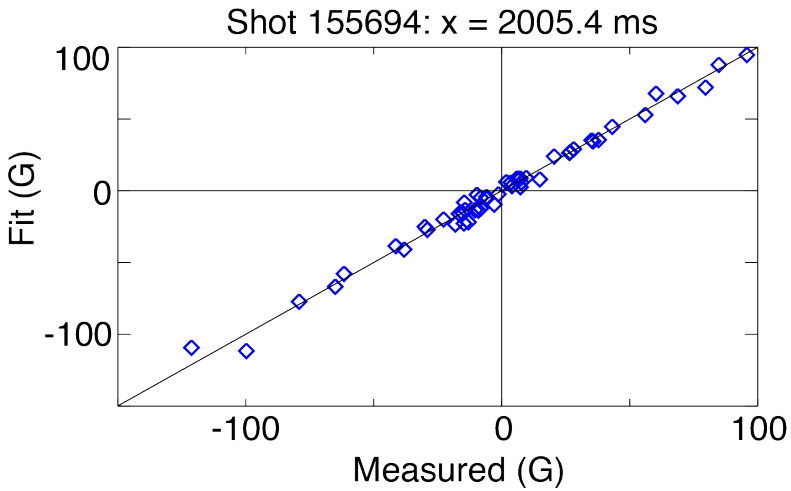
- **Mode structure fit to 50 B_p difference pairs**
  - Probe locations indicated by squares
- **Outboard/inboard midplane signals out of phase**
- **Dominant *m* is odd**
- **Early in the pre-TQ, 3/1 is dominant**





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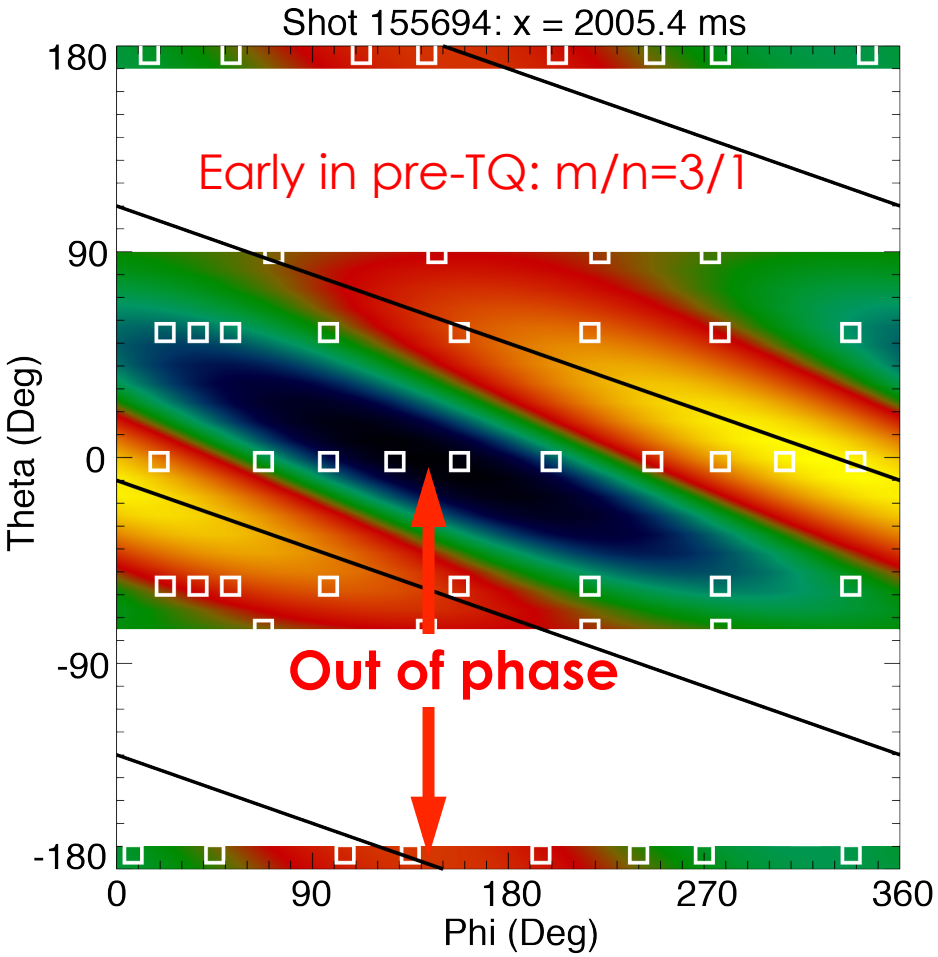

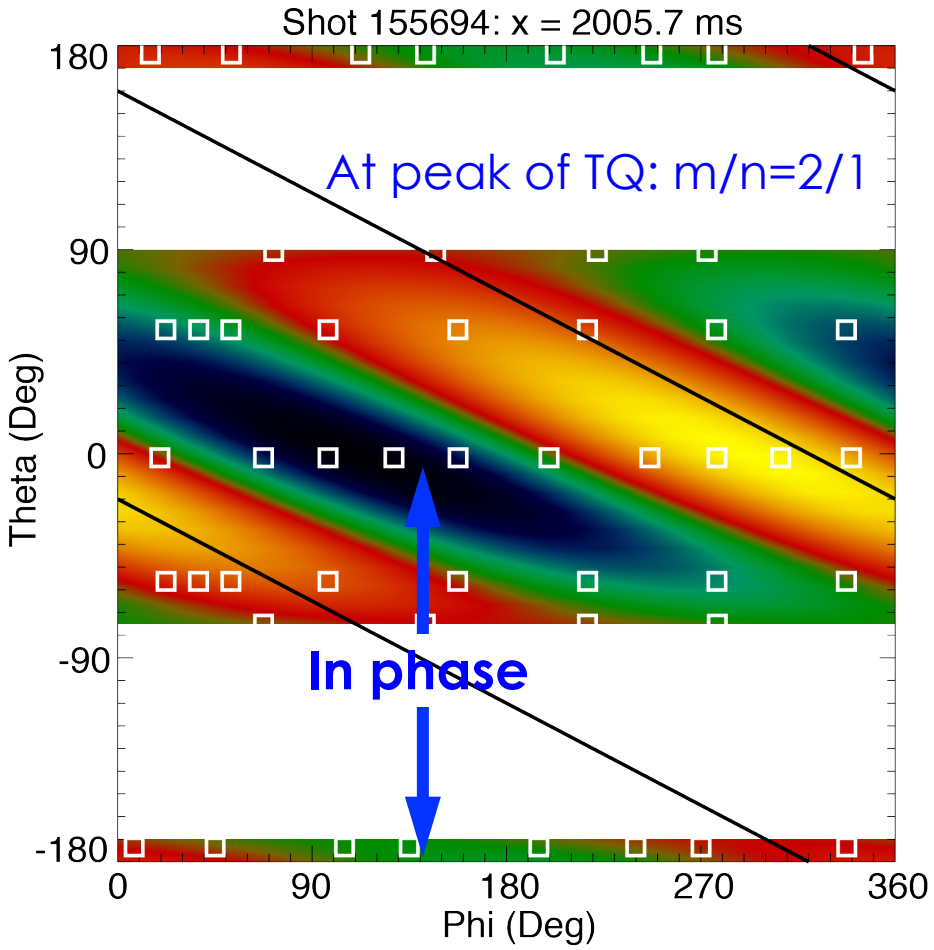

- **The two modes can only be distinguished using the new high-field side arrays!**

Observed mode evolution consistent with inwardly propagating cold front

- **Consistent with modes destabilized by inward propagation of cold front and contraction of current channel**
  - Previously inferred from disruption timsecales in *q*-scans

- **This allows an estimate of cooling front propagation speed**

- **Very crudely, v ~ (0.1 m) / (300 μs) = 300 m/s**

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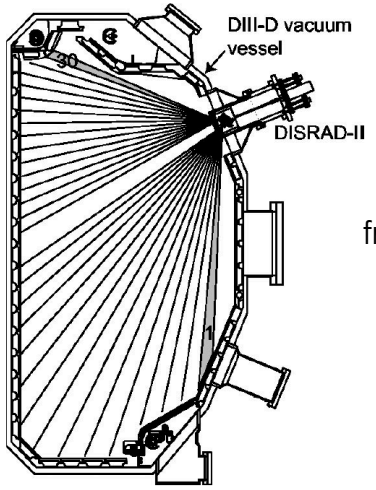
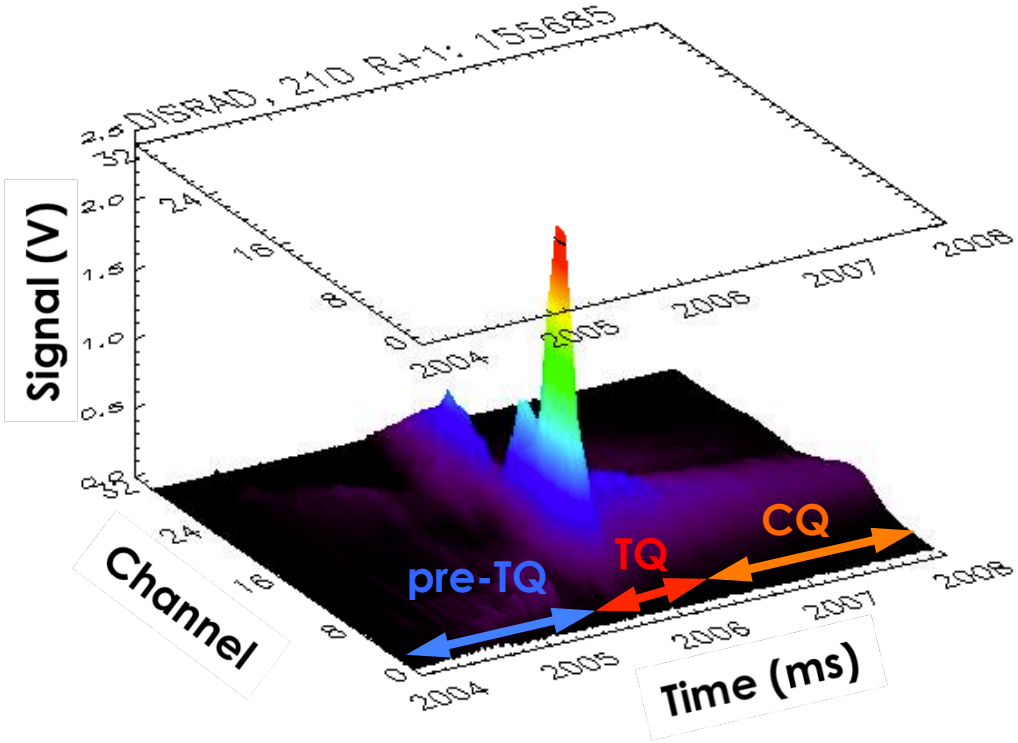
Radiated power measured during disruptions

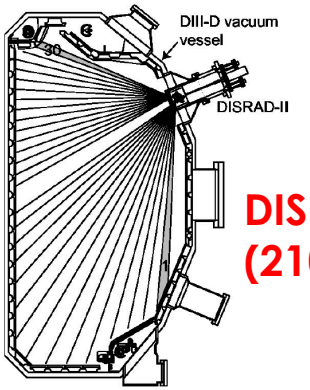
- **Two photodiode arrays provide fast measurements of radiated power**
- **Broad sensitivity gives bolometer-like measurement**
- **Each array has poloidally resolved views**



from Gray, RSI 2004



Radiation asymmetries measured in DIII-D by toroidally separated photodiode arrays



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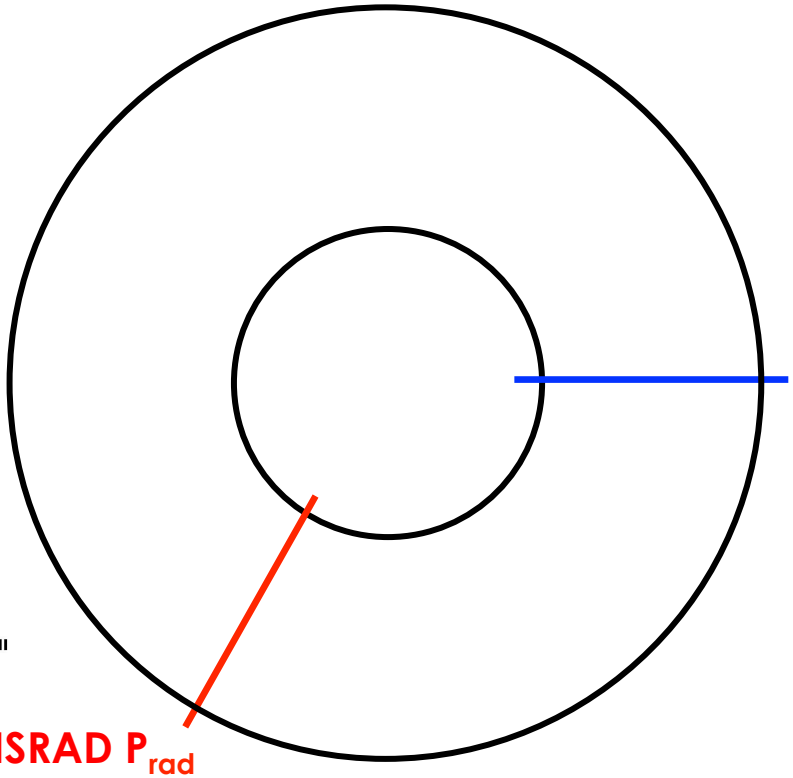

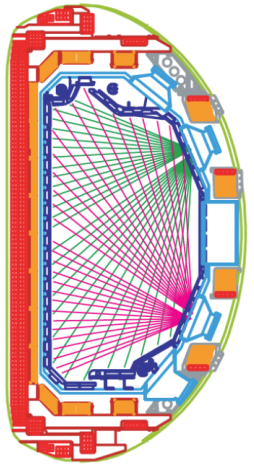

from Hollmann, RSI 2011

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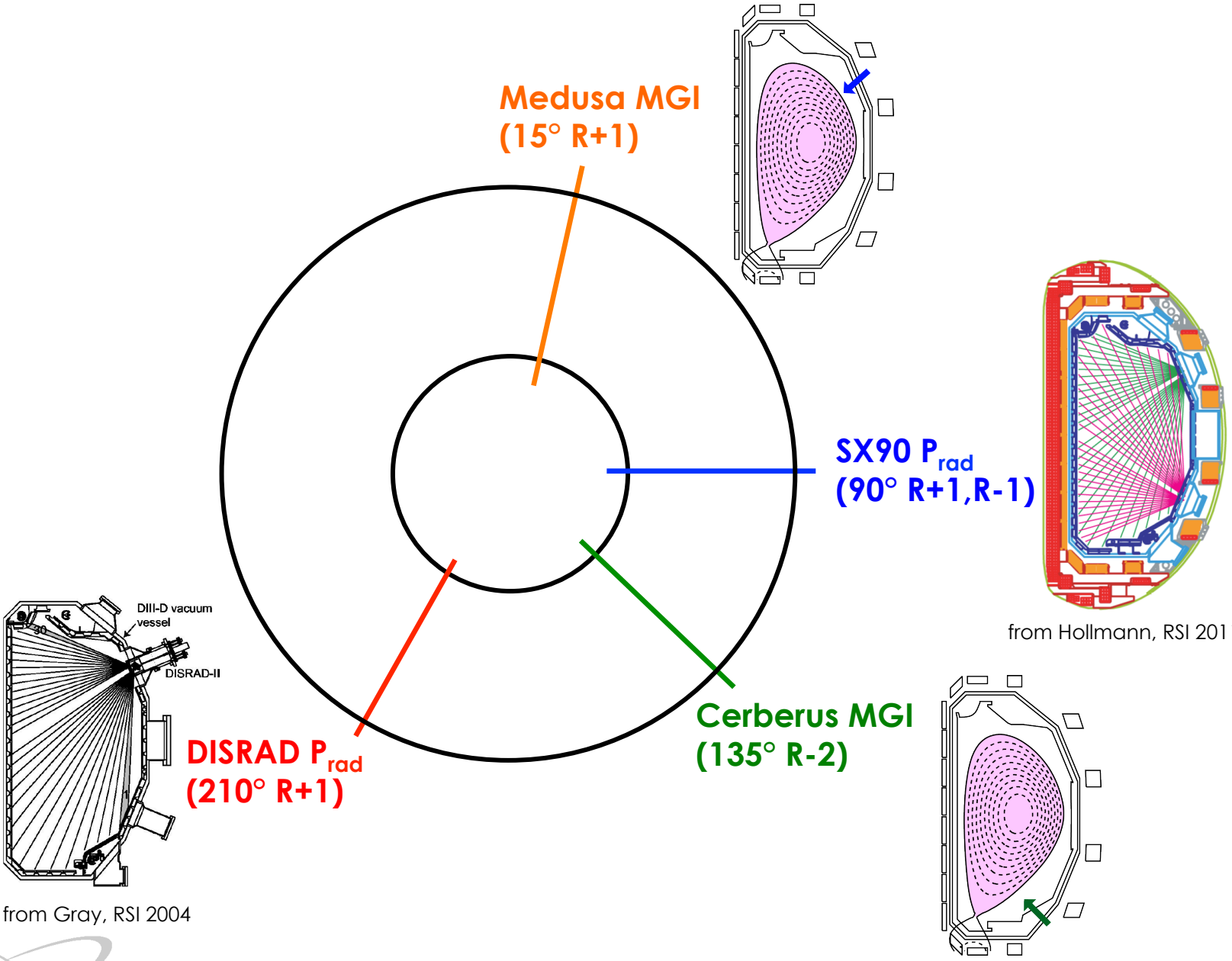
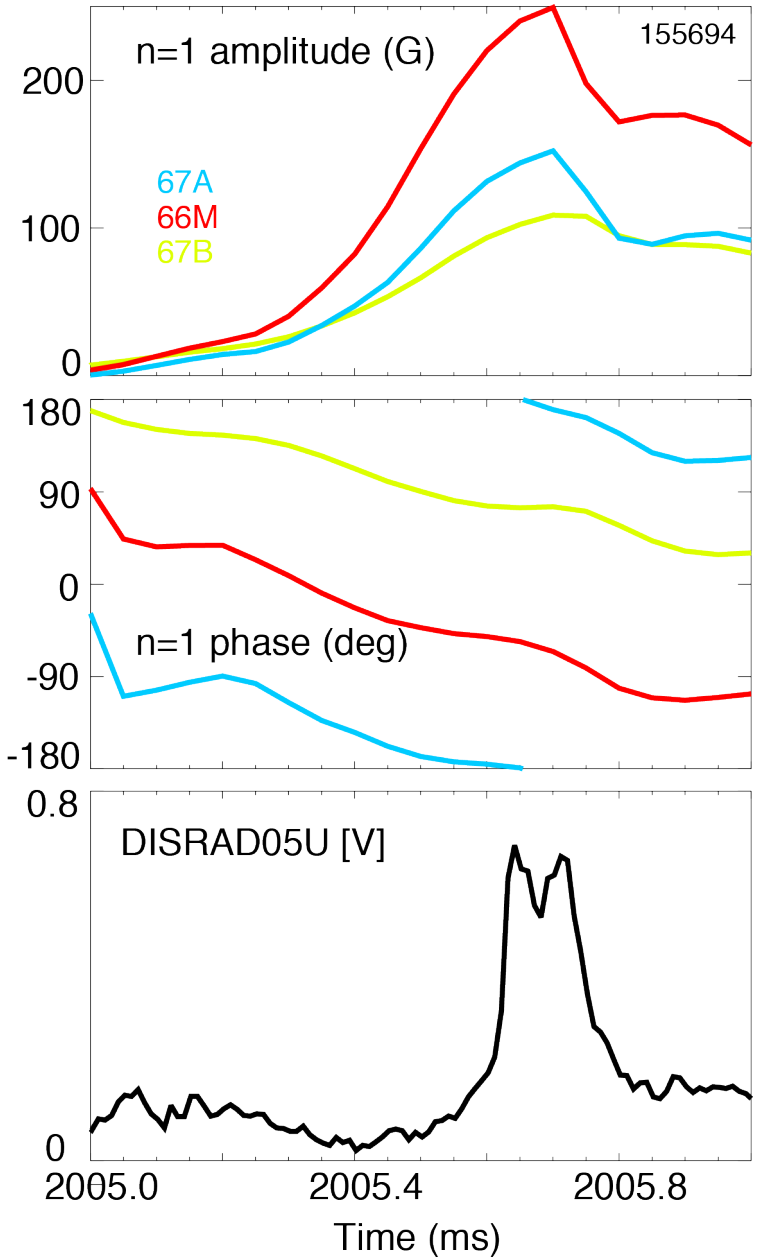
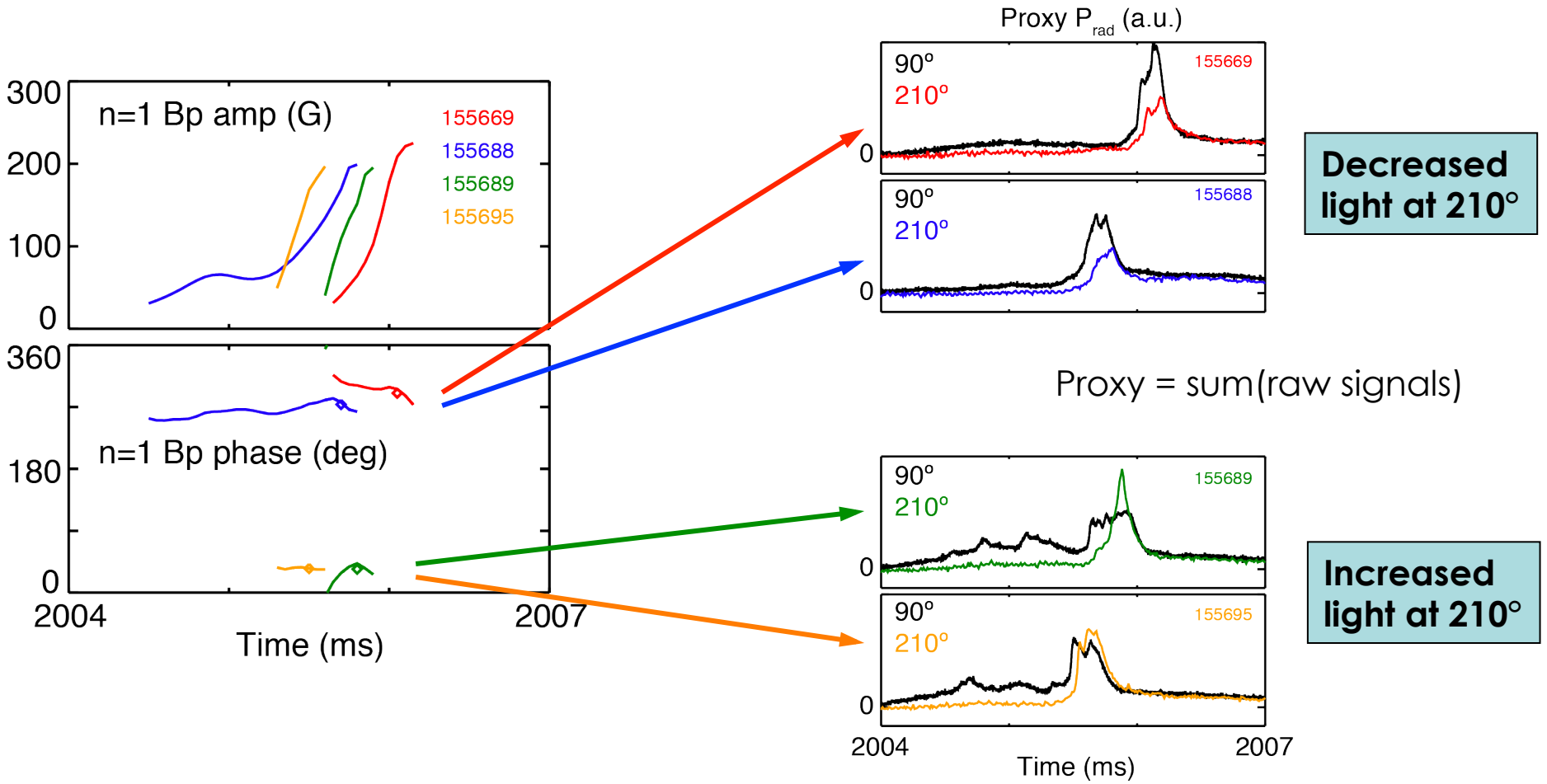


During TQ, mode phase well defined

- **Mode can rotate during pre-TQ growth**
  - Typically on the order of half a toroidal transit
- **But during rapid P_{rad} flash, mode phase is approximately constant**
  - Characterized by midplane phase
- **Question: does this TQ MHD phase affect radiation flash?**



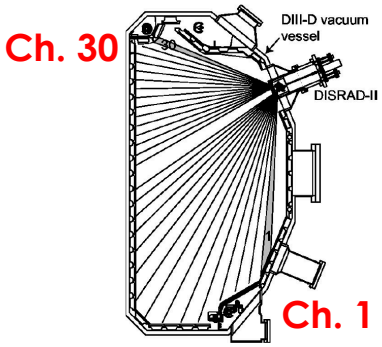
Toroidal phase of mode may affect TQ radiation asymmetry

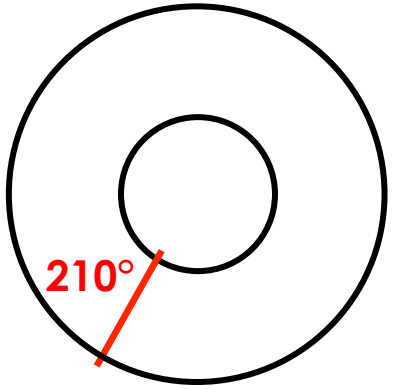


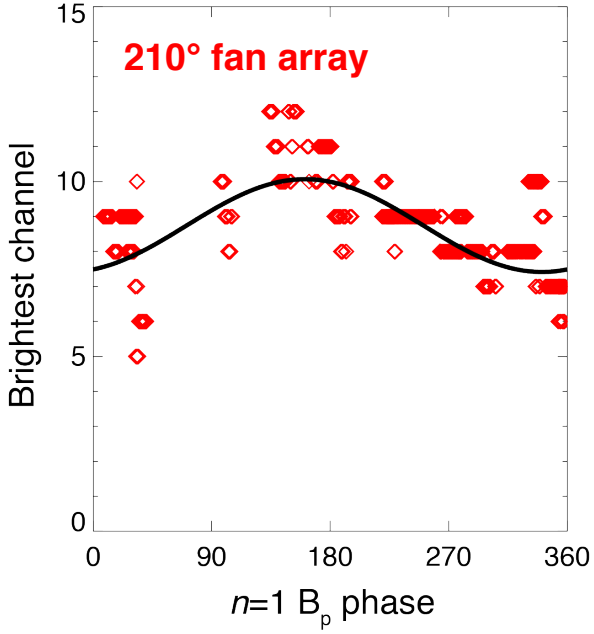
- **P_{rad} at 210° increases (relative to P_{rad} at 90°) when mode is near ~30°**

3D distribution of radiation sources depends on mode phase

- 13 shots with applied EFs to influence mode phase
- Poloidal distribution of P_{rad} at 210° depends on *n*=1 mode phase

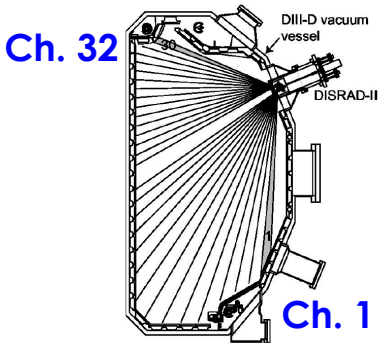


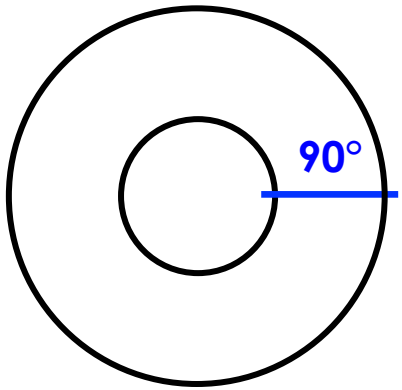


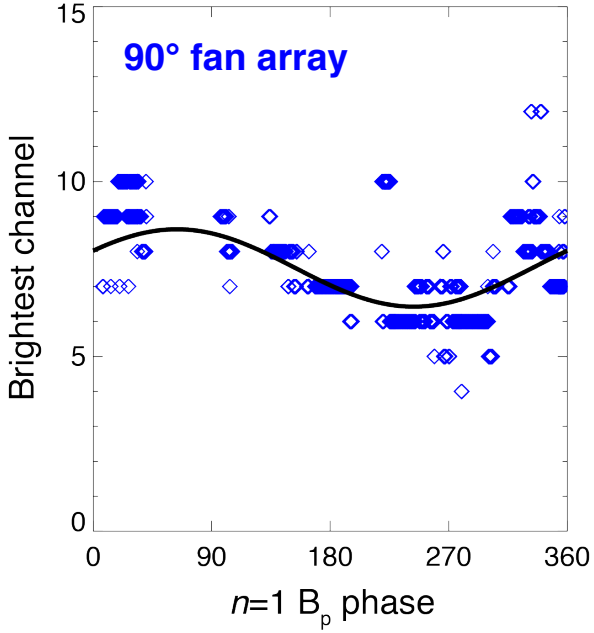


3D distribution of radiation sources depends on mode phase

- 13 shots with applied EFs to influence mode phase
- Poloidal distribution of P_{rad} at 90° depends on *n*=1 mode phase

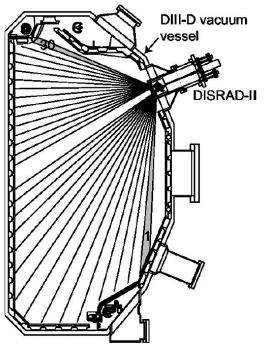


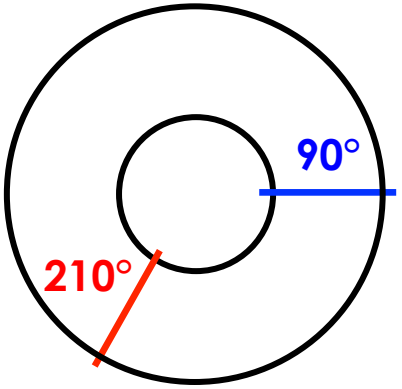


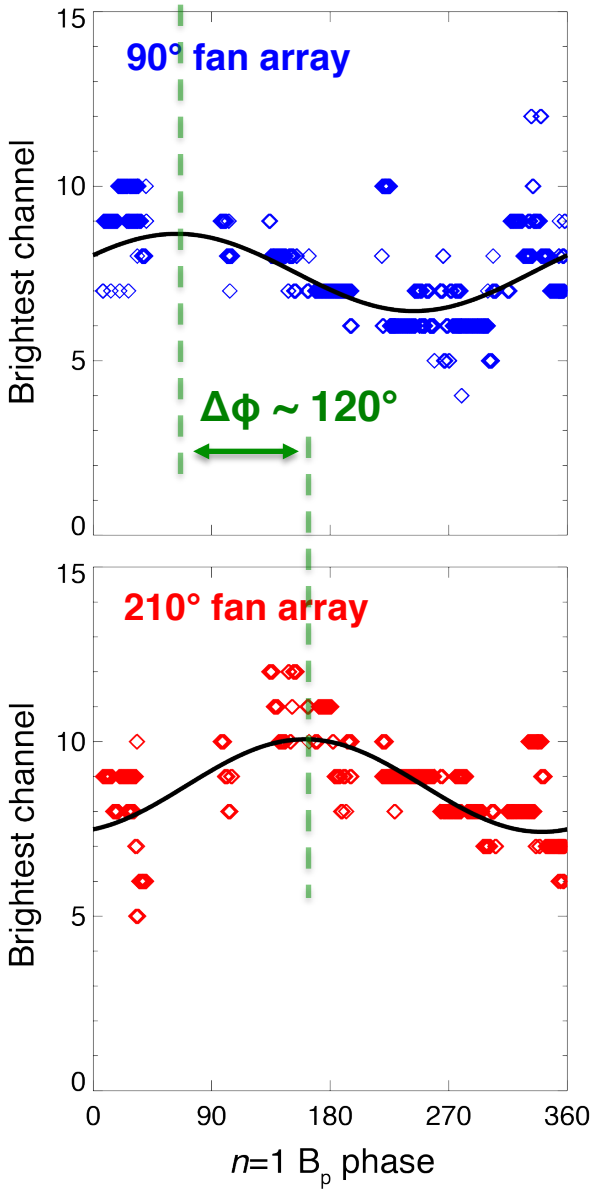


Measurements from both arrays indicate helical mode structure important

- 13 shots with applied EFs to influence mode phase
- Phase relationship between P_{rad} at two fan arrays is equal to their toroidal separation
- Suggests that poloidal/ toroidal structure of 3D radiation pattern related to MHD



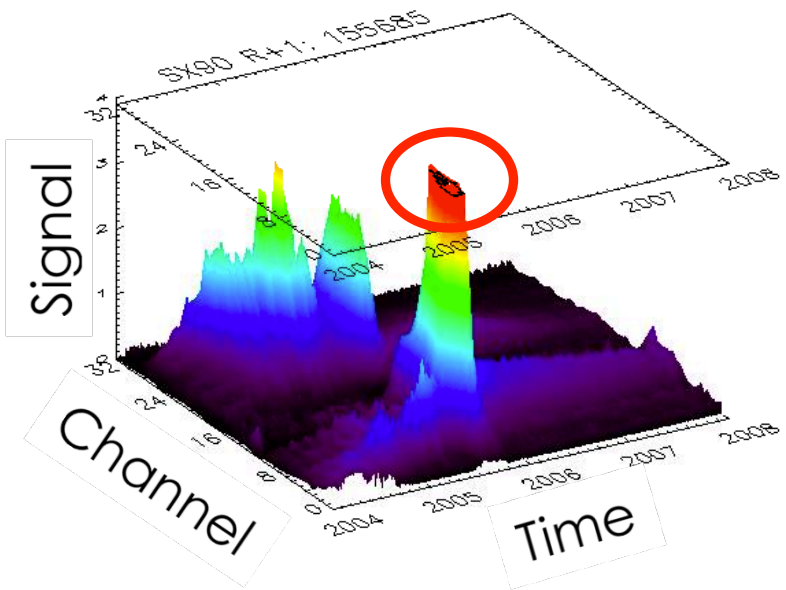




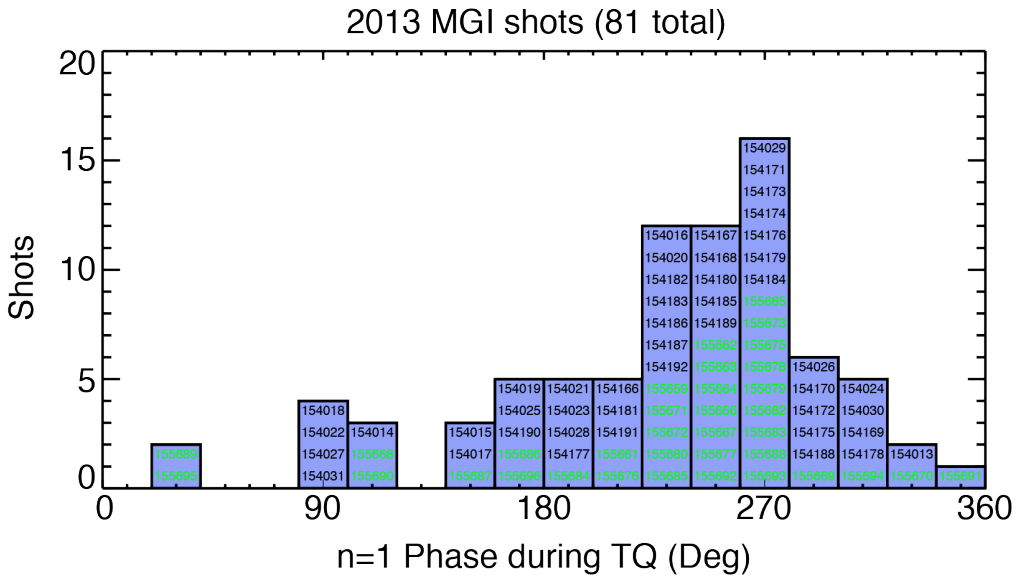
Radiation asymmetry measurements believed to be underestimates

- There are two reasons for this:

- 1. Saturation of signals



- 2. Skewed distribution of actual mode phases



Outline

- Introduction
- Magnetic measurements of MHD mode structure during MGI
- Relationship between MHD activity and thermal quench (TQ) radiation asymmetry
- **Factors influencing evolution of pre-TQ MHD**

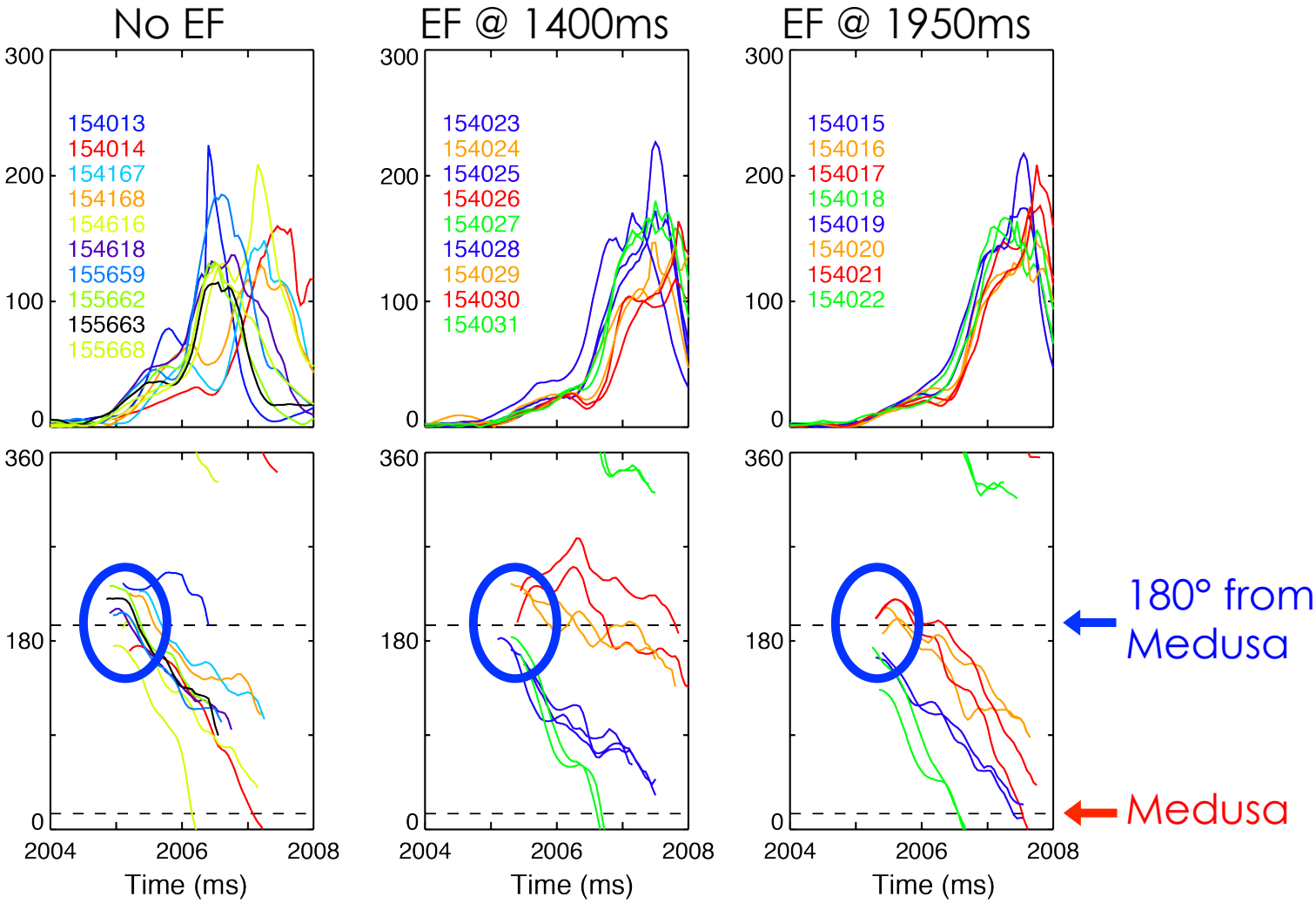
MHD toroidal dynamics are observed to be influenced by three factors

- Injector location
- Pre-MGI plasma rotation
- *n*=1 error fields

Initial mode phase determined by injection location (Medusa, R+1, 15°)

n=1 B_p amp (G)
measured at R+1

n=1 B_p phase (deg)
measured at R+1

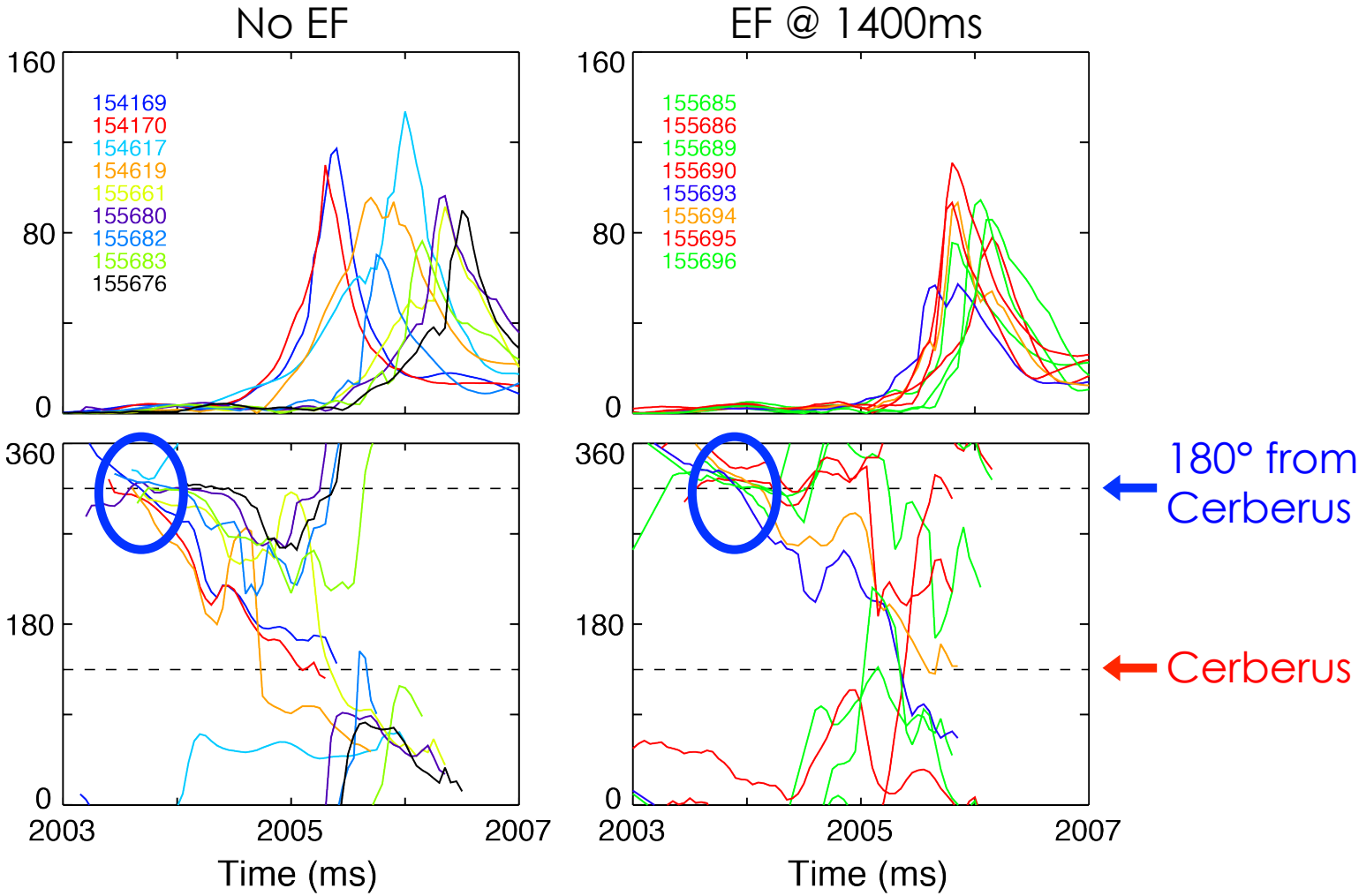


- **Mode begins 180° from injection: as predicted by NIMROD!**

Initial mode phase determined by injection location (Cerberus, R-2, 135°)

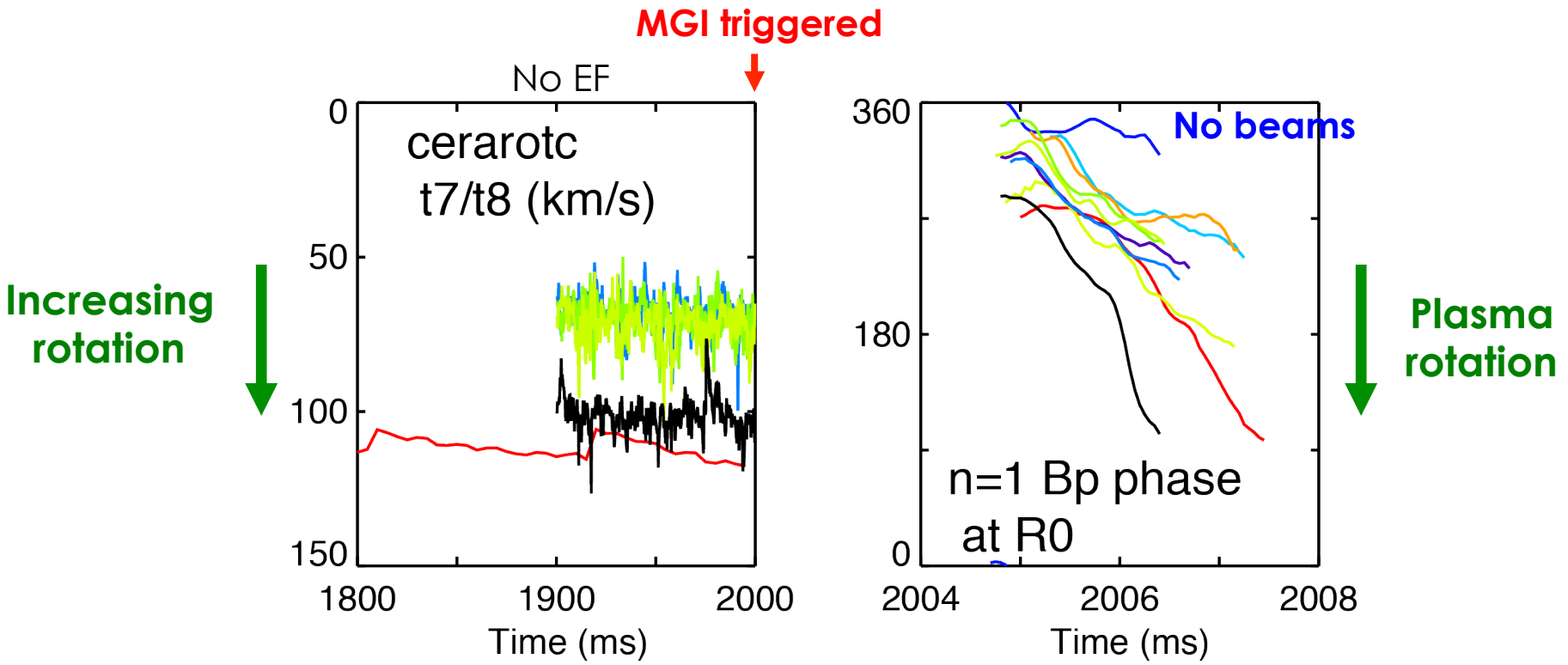
n=1 B_p amp (G)
measured at R-2

n=1 B_p phase (deg)
measured at R-2



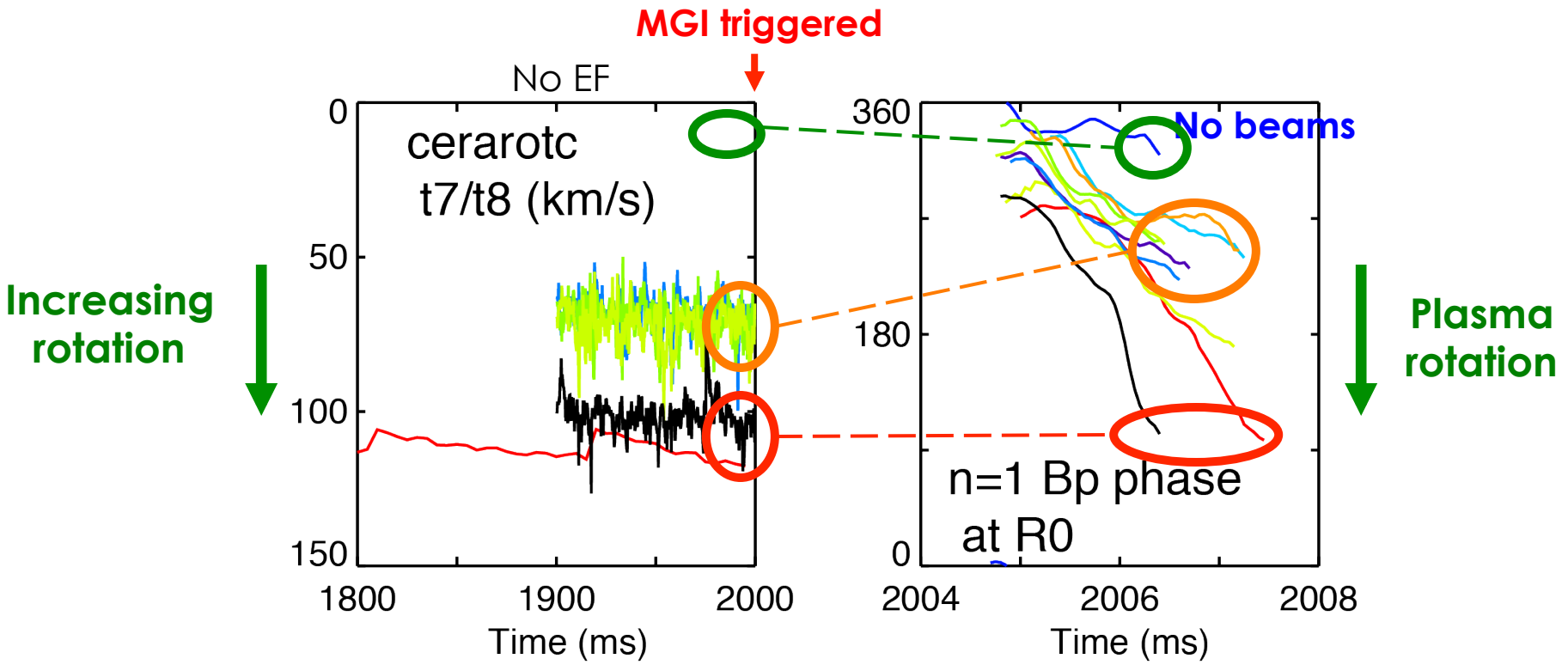
- **Mode begins 180° from injection: as predicted by NIMROD!**

Mode rotates from initial phase due to pre-MGI plasma rotation (Medusa)



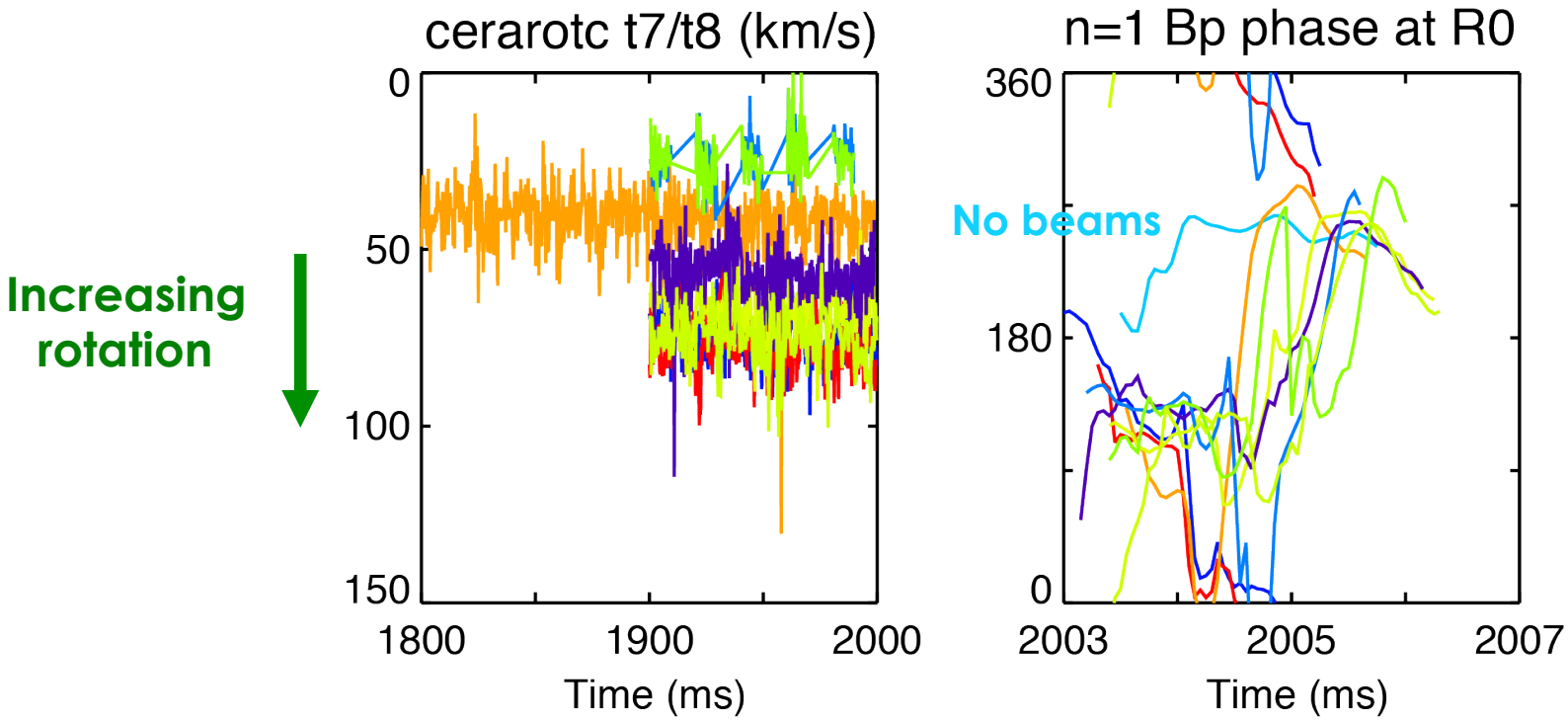
- **Plasma rotation before MGI influences pre-TQ mode rotation**
  - Pre-TQ rotation << pre-MGI rotation
- **Most end near ~250°, due to initial phase plus typical rotation**

Mode rotates from initial phase due to pre-MGI plasma rotation (Medusa)



- **Plasma rotation before MGI influences pre-TQ mode rotation**
  - Pre-TQ rotation << pre-MGI rotation
- **Most end near ~250°, due to initial phase plus typical rotation**

Rotation effect with Cerberus less clear

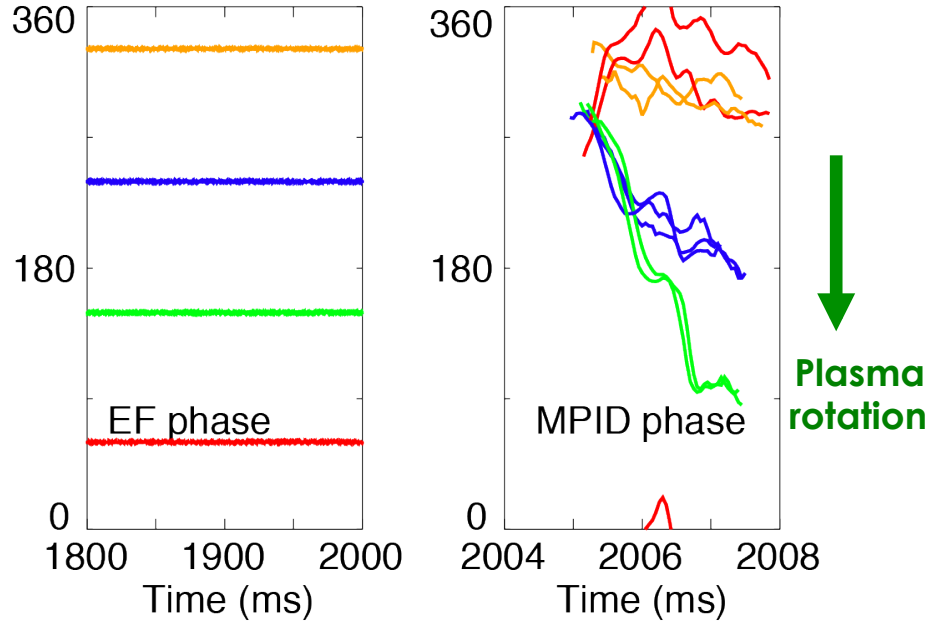


- **Modes tend to go to ~250° (residual EF?)**
- **Rotation affects how the mode gets there**
  - Mode sometimes rotates against flow

EF competes with rotation in determining mode phase (Medusa)

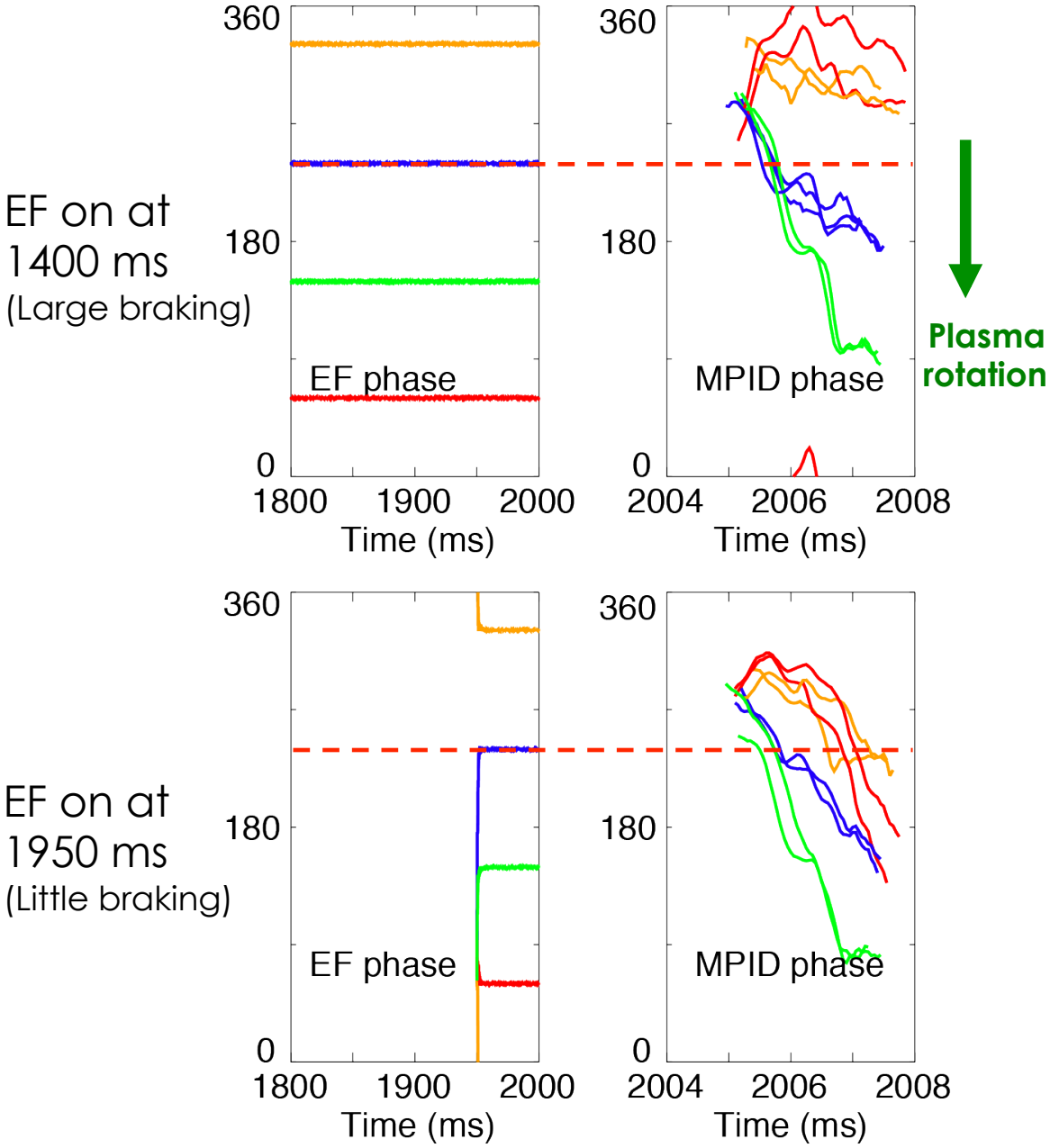
- Large *n*=1 EF applied using I-coils
- Mode rotates from initial phase towards EF
- Torque from EF competes against rotation effect

EF on at 1400 ms



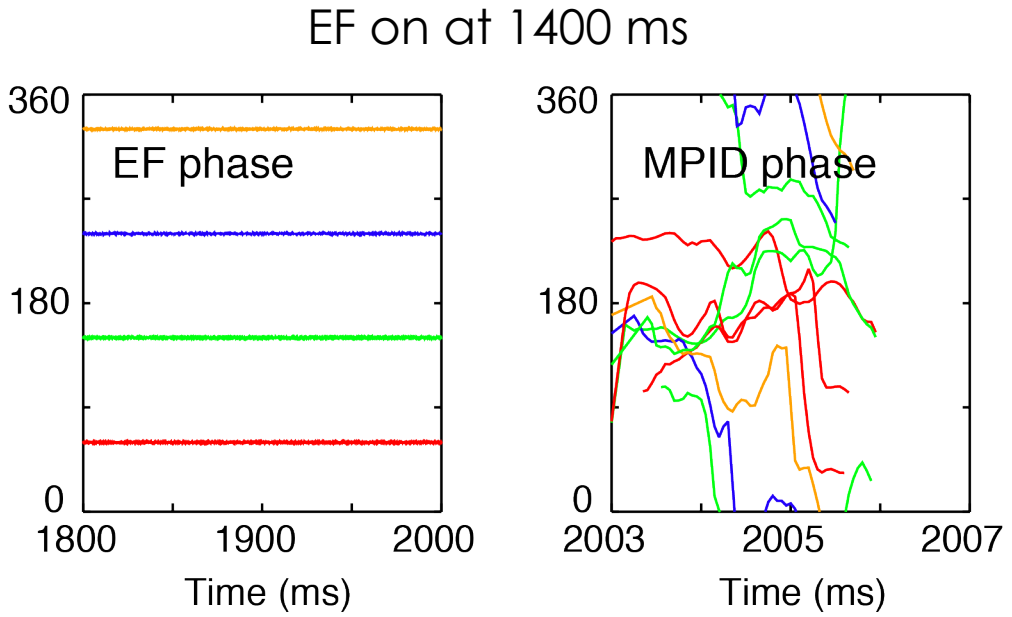
EF competes with rotation in determining mode phase (Medusa)

- **Large *n*=1 EF applied using I-coils**
- **Mode rotates from initial phase towards EF**
- **Torque from EF competes against rotation effect**
  - Red case is like inverted pendulum



EF effect observed for Cerberus, but less clear

- **Final mode phase affected by applied EF**
- **Evolution of mode to get there is again more complex**



- **In general, mode behavior with Cerberus injection needs further analysis**

Summary

- Following massive gas injection, inwardly propagating cold front destabilizes MHD cascade, as directly detected by magnetics

- The toroidal phase of the *n*=1 MHD appears to affect TQ radiation asymmetry

- Toroidal evolution of mode affected by three factors: injector location, pre-MGI plasma rotation, and large *n*=1 EFs

Future work: three upcoming DIII-D experiments on TQ mitigation this year

- **MGI radiation asymmetry**
  - Better isolate different effects on *n*=1 mode phase
  - Accurately measure radiation asymmetry with current MGI system
- **SPI v. MGI**
  - Are these 3D effects similar in SPI fast shutdown?
- **Disruption mitigation in the presence of MHD instability**
  - 0D effects: particle assimilation, radiation fraction, disruption timescales, etc.
  - 3D effects: MHD, radiation asymmetry