3-D EQUILIBRIUM AND MAGNETIC ISLAND DUE TO ERROR MAGNETIC FIELD IN THE DIII-D TOKAMAK

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MOTIVATION / BACKGROUND

- Enhanced confinement of H-mode discharges often leads to large edge density and temperature pedestals with very narrow widths ~ 1-4 cm
- Accurate determination of the edge separatrix location becomes crucial for proper interpretation and understanding of the physical processes governing H-mode discharges
- A 1-4 cm difference between the separatrix vertical position determined from EFIT magnetic analysis and those inferred from Thomson T_e measurements has been observed
- New I-coils are installed inside the DIII-D vacuum vessel

12-coil internal set available for experiments 2003

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GENERAL ATOMICS

QUESTIONS TO ANSWER

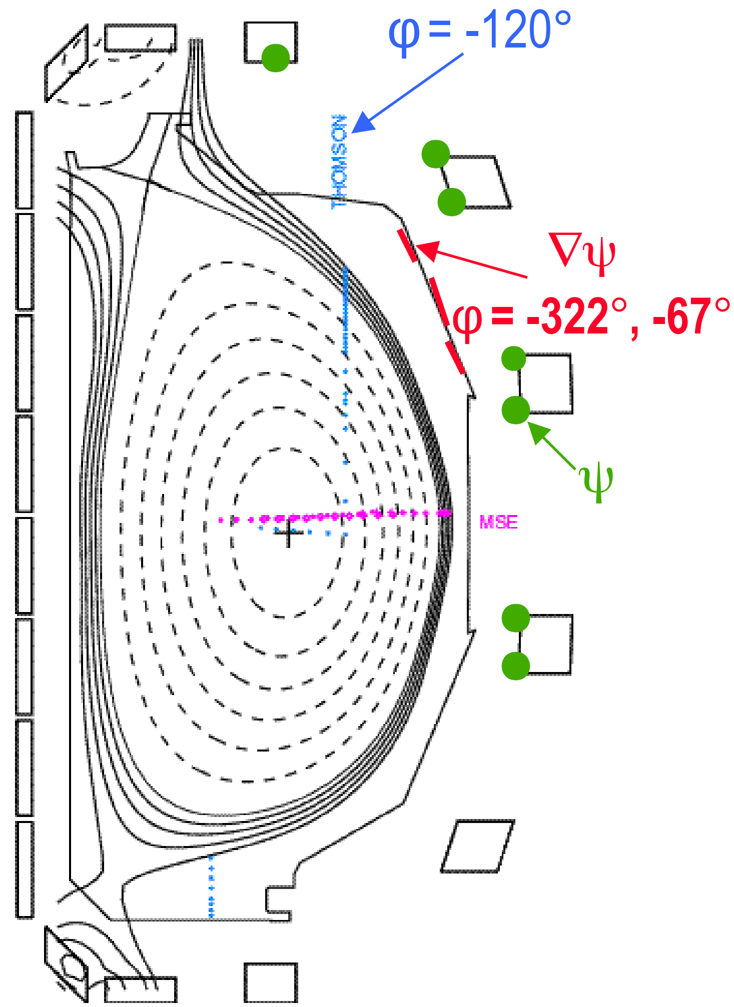
- Are the difference between the edge separatrix vertical positions as determined from EFIT and Thomson T_e due to real physical effects ?
- What physical processes may lead to this difference ?
- What are the effects of externally imposed toroidally asymmetric magnetic field or error magnetic field on the edge separatrix boundary ? The new I-coils ?
- How important are the plasma responses ?

OUTLINE / SUMMARY

- A 1 - 4 cm difference still exists between the separatrix vertical position determined from EFIT magnetic analysis and those inferred from Thomson T_e measurements
  - Removal of metal plate on n1-coil makes little difference
- Perturbative calculations without plasma response indicate a small toroidal asymmetry in the external coil location can introduce significant 3-D magnetic effects such as formation of edge stochastic layers and magnetic islands into the magnetic topology
- Response of error magnetic field correction coils (C-Coils) suggest that plasma response may play a crucial role
  - C-coil currents tend to increase the error magnetic field due to the external shaping coils
- A more self-consistent approach including plasma response is being formulated

SEPARATRIX LOCATION IS TYPICALLY DETERMINED BY EXTRAPOLATING EXTERNAL MAGNETIC MEASUREMENTS INWARD

- EFIT extrapolate magnetic measurements inward assumed discharge in a 2-D equilibrium state
  - 41 flux loops: ψ
  - 73 magnetic probes: $\nabla\psi$
  - Equilibrium relates 2nd derivatives to ψ and $\nabla\psi$
  - Separatrix location defined by largest closed flux surface enclosed by limiter
- Main magnetic probes are at ϕ = -322°, some at -67°
  - Separatrix location largely represents magnetic topology at ϕ = -322°
- Thomson measurements are at ϕ = -120°



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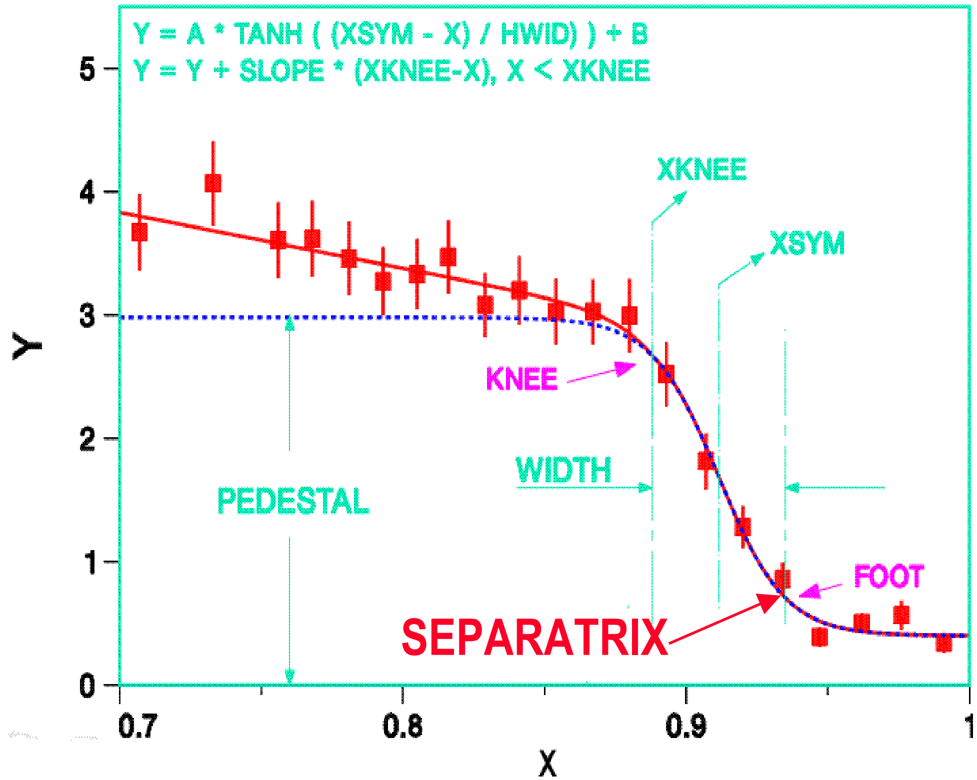
GENERAL ATOMICS

SEPARATRIX LOCATION CAN ALSO BE INFERRED FROM HYPERBOLIC TANGENT FIT TO THOMSON T_e PROFILE

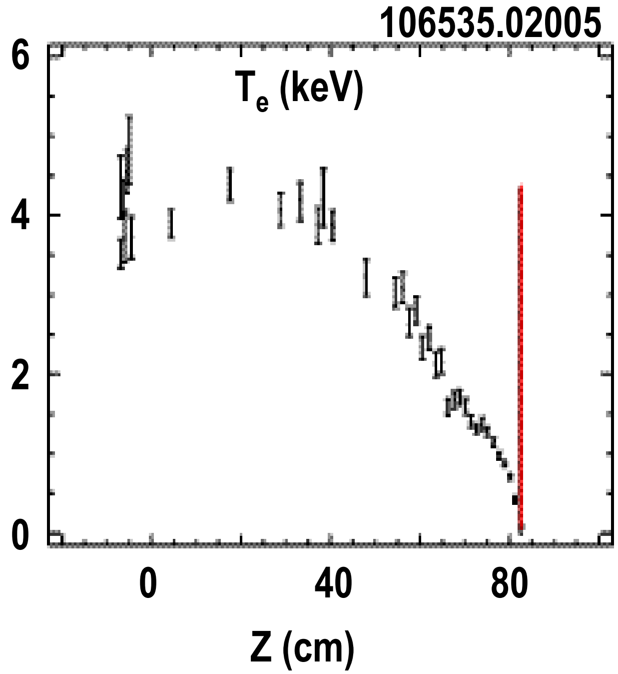
- H-mode discharges only
- 3 parameters amplitude, radius, and width Tanh fit to T_e
- $Z_{TS} = Z_{SYN} + 0.5\ \Delta Z_{WIDTH}$
- Previous analyses indicate some consistency with UEDGE divertor solution with this choice of separatrix location
- Thomson measurements are located at the poloidal plane $\phi = -120°$

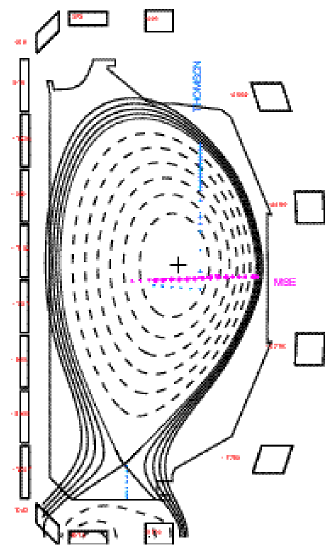
TANH Fit to Thomson T_e

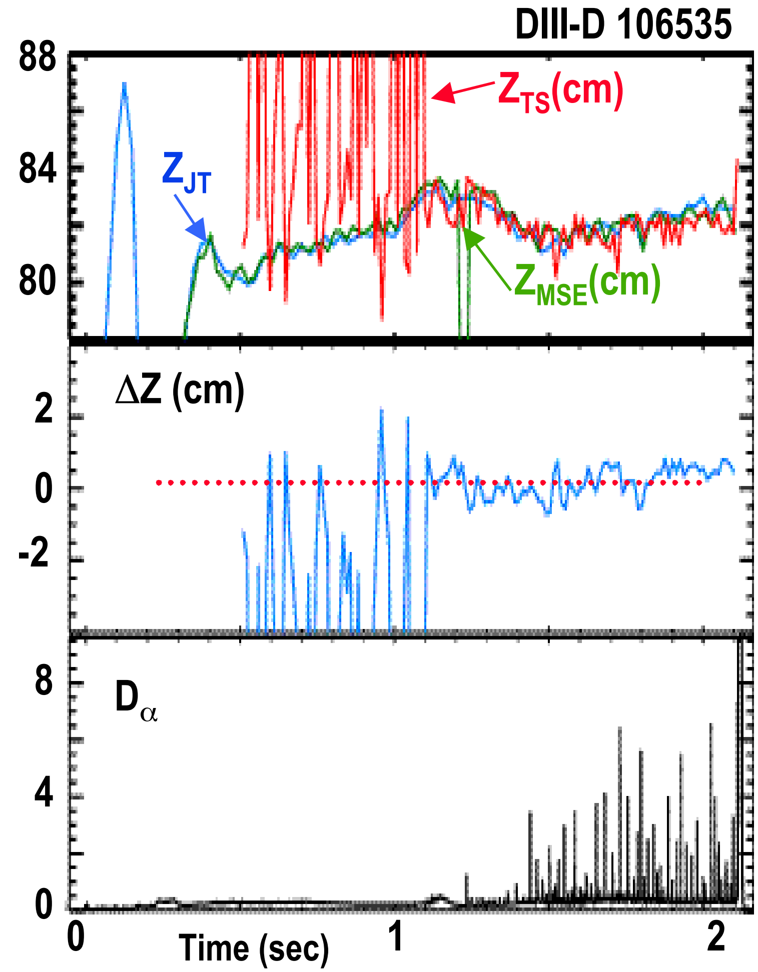


SEPARATRIX LOCATIONS FROM EFIT AND THOMSON AGREE WELL IN LOWER SINGLE-NULL DISCHARGES

- **From 2001 resistive wall mode stabilization experiment, $\beta_N \sim 2\ \beta_{NO\_WALL}$**

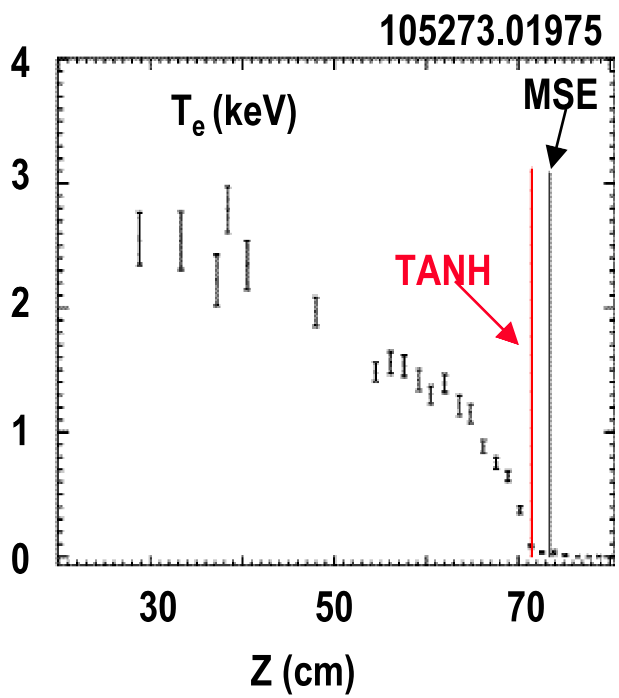


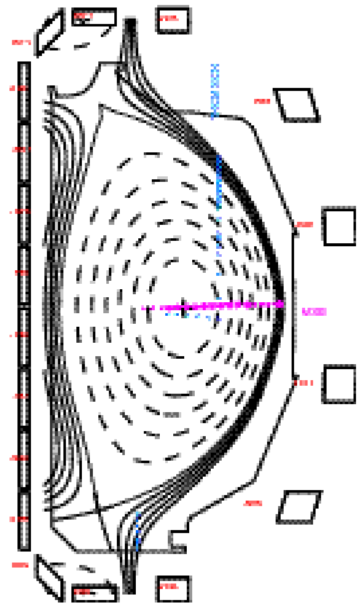


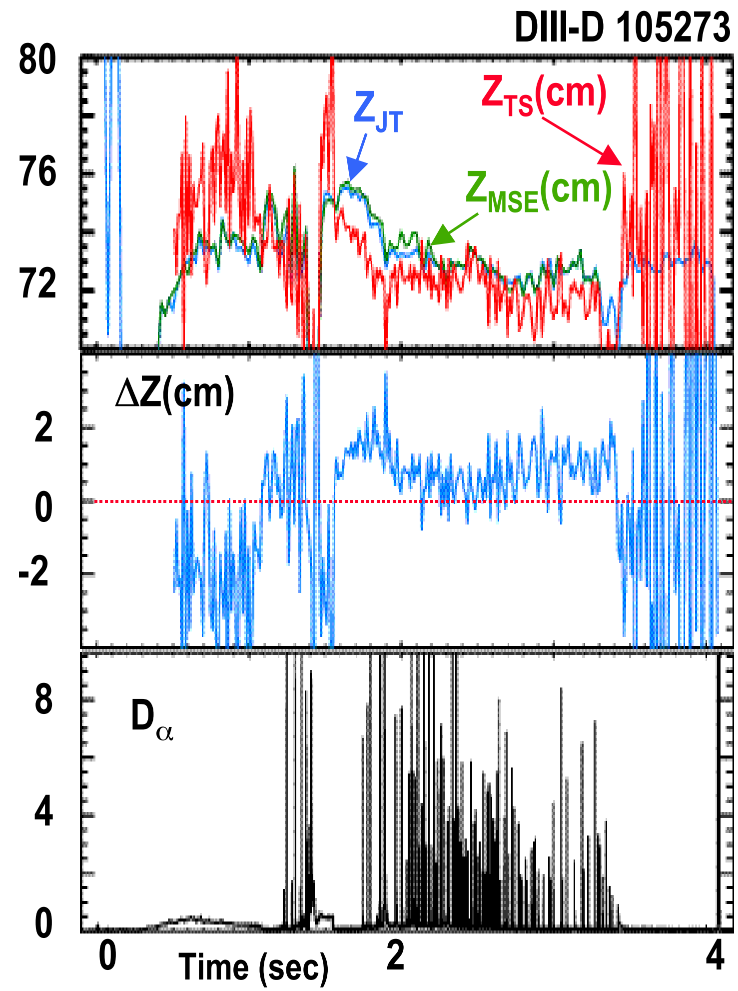


SEPARATRIX LOCATIONS FROM EFIT AND THOMSON CAN DIFFER BY 1-2 cm IN DOUBLE-NULL DISCHARGES

- From 2001 AT stability experiment, $\beta_N \sim 4$, $q_{95} \sim 4.2$







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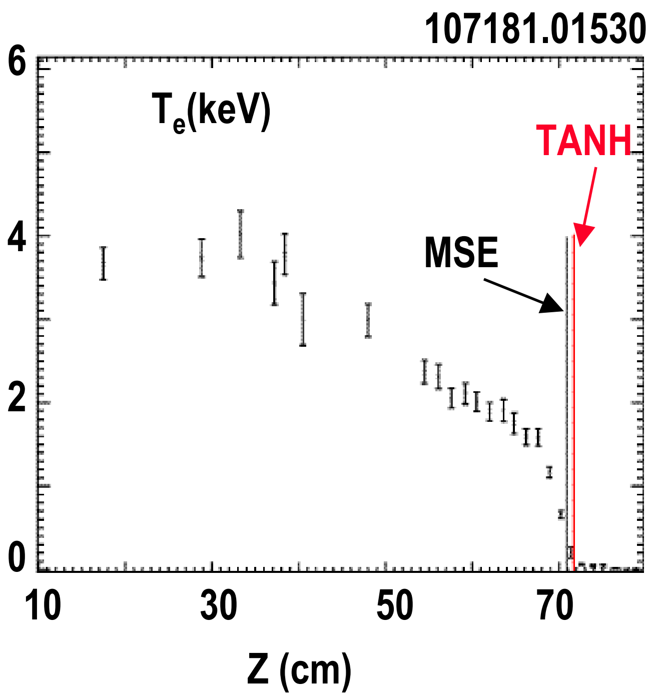
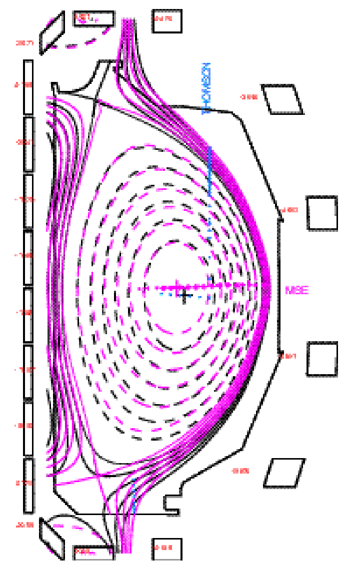
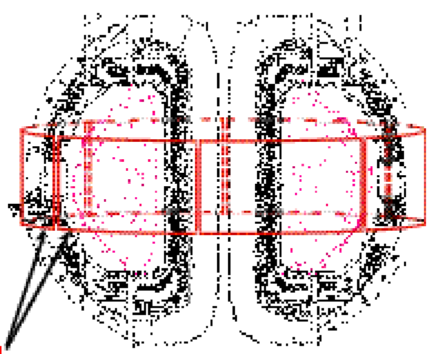
GENERAL ATOMICS

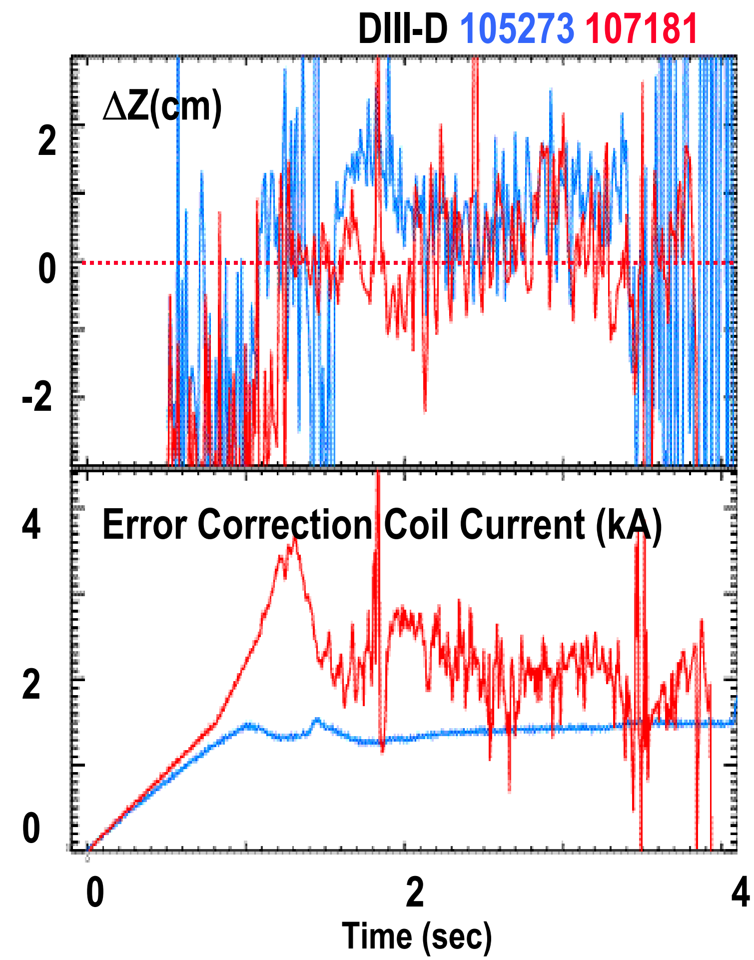
ERROR FIELD CORRECTION COIL CURRENT APPEARS TO PLAY A ROLE IN THE EFIT-THOMSON SEPARATRIX LOCATION DIFFERENCE

- **From 2001 AT stability experiment, β_N ~ 3.8, q_{95} ~ 5.1, higher C_{79} current**



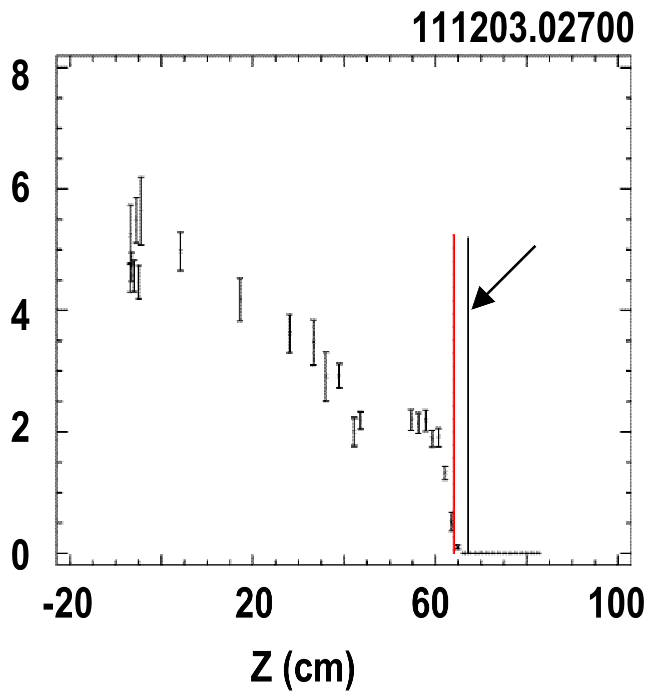


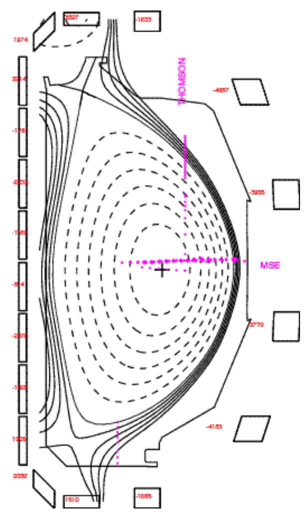


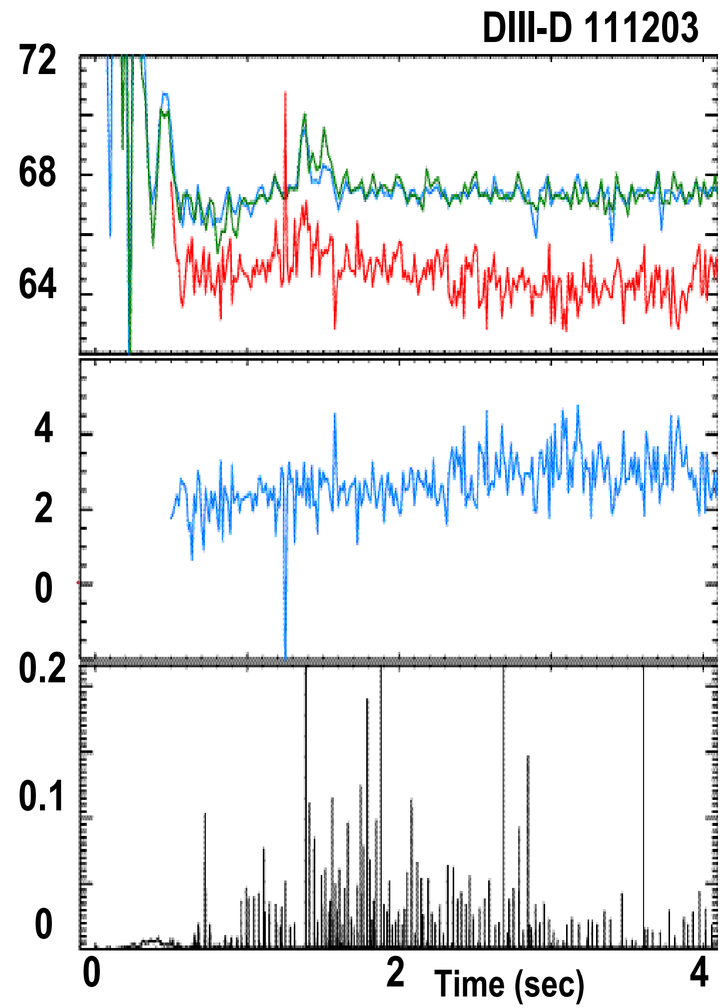


SEPARATRIX LOCATIONS FROM EFIT AND THOMSON CAN DIFFER BY 1-4 cm IN UPPER SINGLE-NULL DISCHARGES

- From 2002 AT ECCD experiment
- Metal plate on n1-coil has been removed but makes little difference

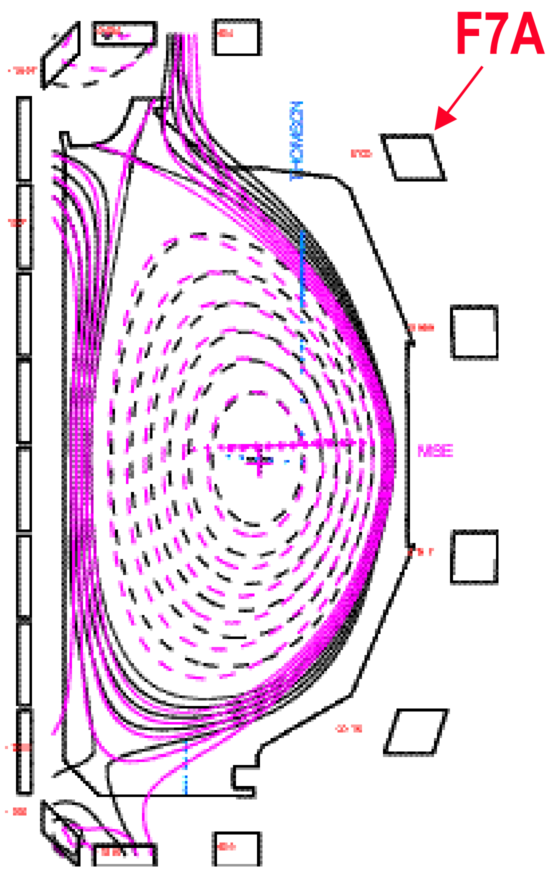


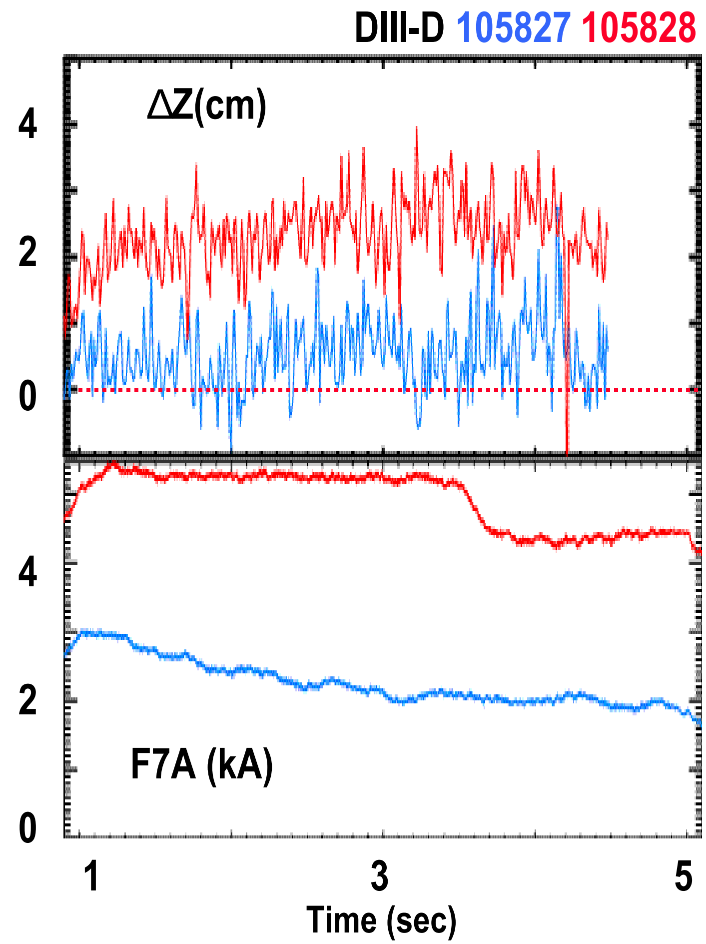




CURRENT IN F7A APPEARS TO PLAY A ROLE IN THE EFIT-THOMSON SEPARATRIX LOCATION DIFFERENCE

- From 2001 QH mode experiment using 1.3 MA and 1.6 MA panels





DATABASE SURVEY

- Shot range ~ 97600 - 105500, 1999 - early 2001 using an IDL code
- H-mode only with 1 sec < time < 4 sec (based on electron edge pedestal height and width) and JT-like control room EFITs (EFIT01), sorted by
  - Lower single null (LSN), δR_{SEP} < -1 cm
  - Double null (DND), -1 cm < δR_{SEP} < 1 cm
  - Upper single null (USN), δR_{SEP} > 1 cm
- EFIT-Thomson separatrix difference generally within acceptable bound for LSN, but can differ by 1-4 cm in DND and USN cases
  - No correlation with electron edge pedestal pressure, β_P and β_N, lower triangularity
  - Weak correlation with upper triangularity and l_i
  - Some correlation with F7A and C-Coil currents, and q_{95}

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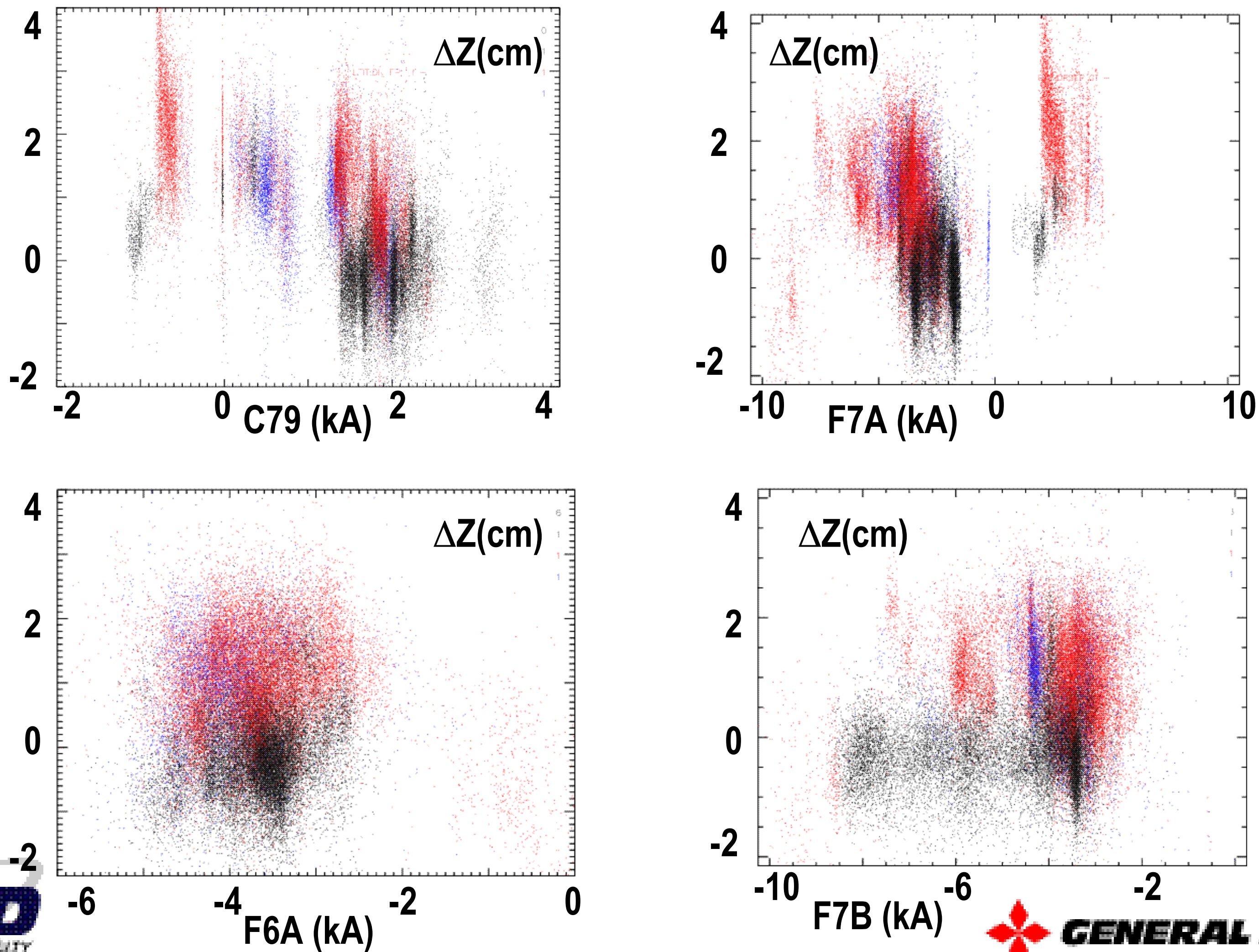
GENERAL ATOMICS

DATABASE SURVEY INDICATES SOME CORRELATION WITH CURRENTS IN F7A AND C-COIL

- **Main sorting variables: DND, USN, and LSN. H-mode only, 1999 - early 2001**



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GENERAL ATOMICS

THE EFFECTS OF ERROR FIELD ON MAGNETIC SURFACES ARE ESTIMATED USING A PERTURBATIVE APPROACH

- F-coil irregularities has recently been re-measured
  - F7A has largest ~ 1.2 cm radial shift as in previous measurements [1]
- Perturbative 3-D calculations
  - 3-D effects taken to be small, plasma assumed to remain in a 2-D axisymmetric equilibrium state
  - 3-D corrections to the magnetic surfaces are then computed by super-imposing the asymmetric external magnetic field onto the background toroidally symmetric magnetic field due to the plasma using a Green's function approach
  - PLOTLINE code

Radial Deviations of F-coil from B-coil (Luxon, Schaffer)

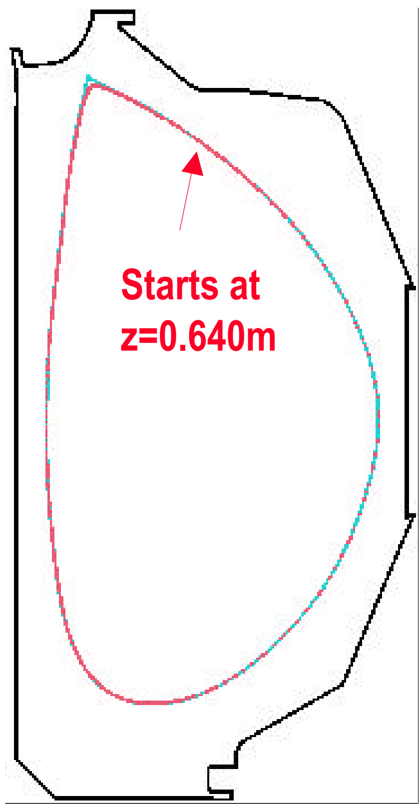
F-coil	Toroidal Angle	Δr(cm)
F1A	24.237	0.210
F2A	-16.500	0.250
F3A	3.336	0.322
F4A	9.155	0.247
F5A	-37.307	0.271
F6A	-153.112	0.554
F7A	-101.527	1.206
F8A	-81.411	0.361
F9A	-95.623	0.310
F1B	-58.591	0.125
F2B	-43.359	0.295
F3B	-73.825	0.277
F4B	-72.300	0.185
F5B	-92.760	0.261
F6B	-108.792	0.692
F7B	-137.713	0.739
F8B	-163.708	0.604
F9B	-113.650	0.534

La Haye and Scoville, Rev. Sci. Instrum. 62 (1991) 2146

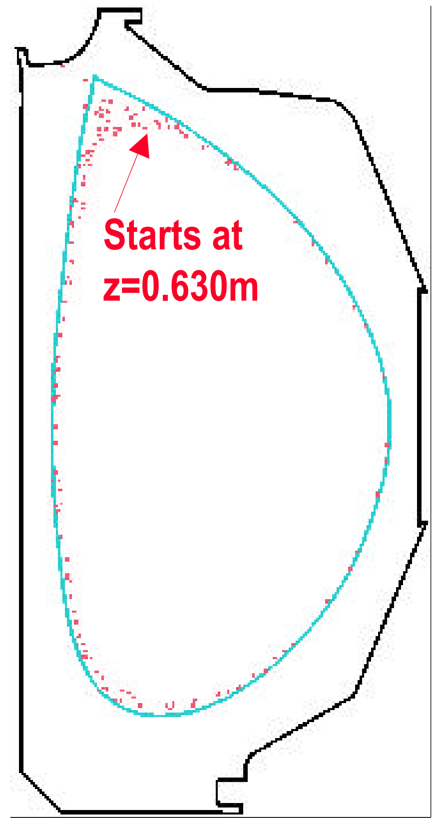
A 1-2 cm RADIAL SHIFT IN F-COILS CAN LEAD TO FORMATION OF A LARGE EDGE STOCHASTIC REGION

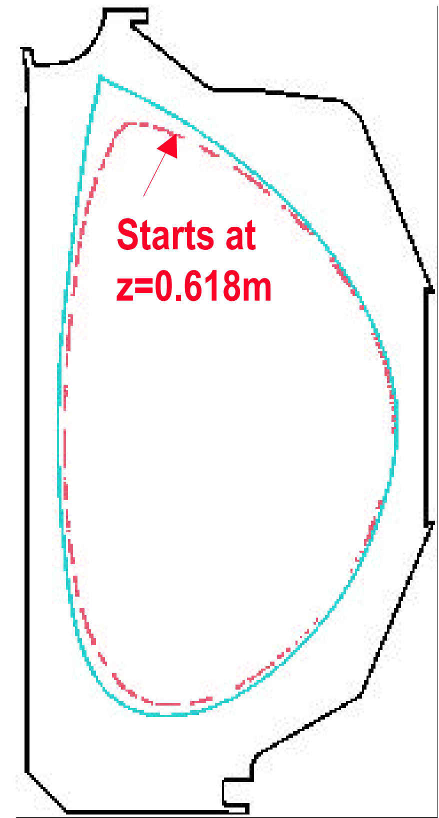
- **3-D perturbative calculations based on QH-mode USN discharge 105828 at 3000 ms**

Axisymmetric



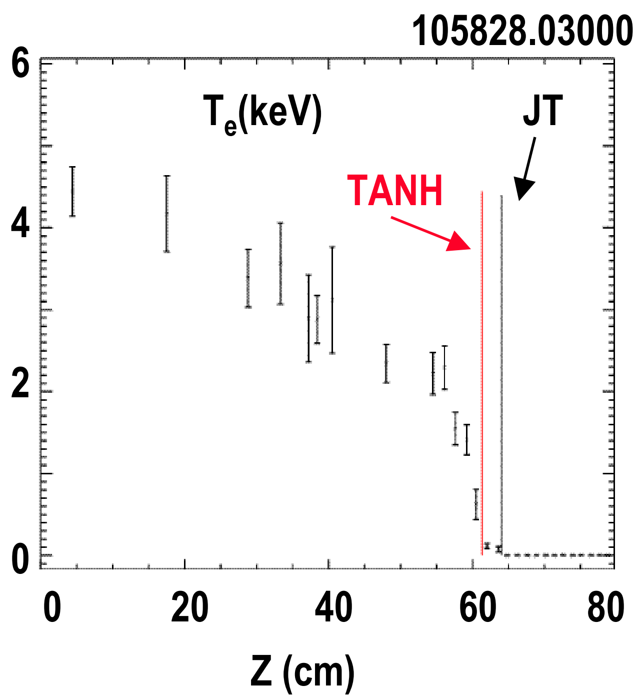
Shifted F-coils + C-coils

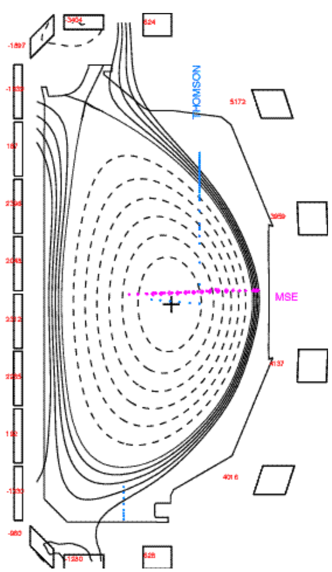


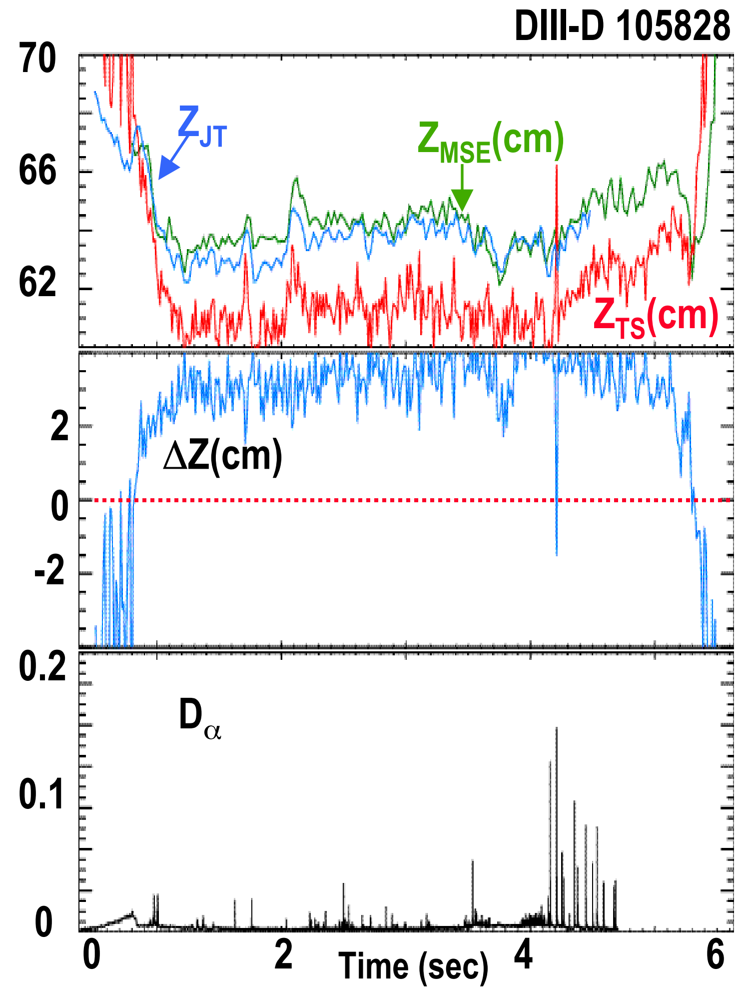


SEPARATRIX LOCATIONS FROM EFIT AND THOMSON DIFFER BY 2-4 cm IN THIS UPPER SINGLE-NULL DISCHARGE

- From 2001 QH mode experiment using 1.6 MA shape control panel

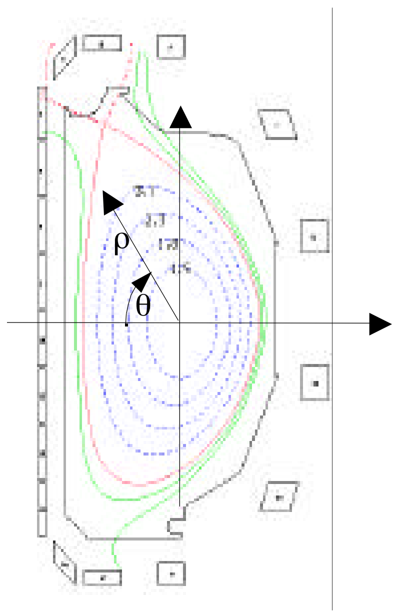


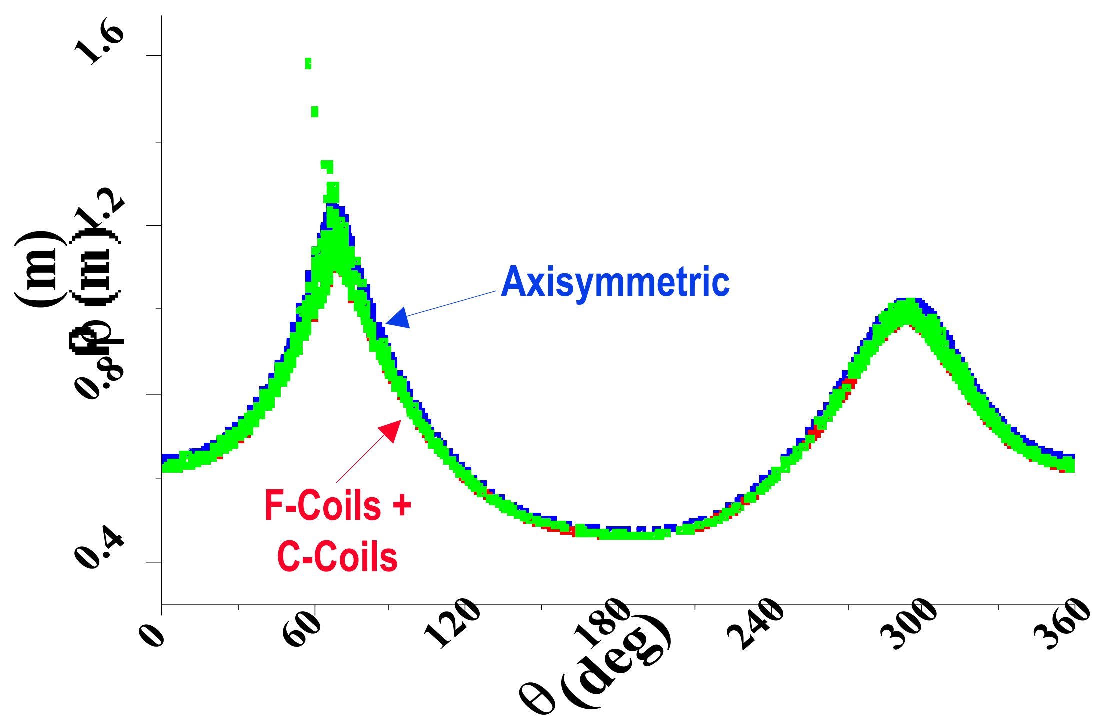




A SMALL TOROIDAL ASYMMETRY OF F-COIL LOCATION CAN PRODUCE A LARGE EDGE STOCHASTIC REGION

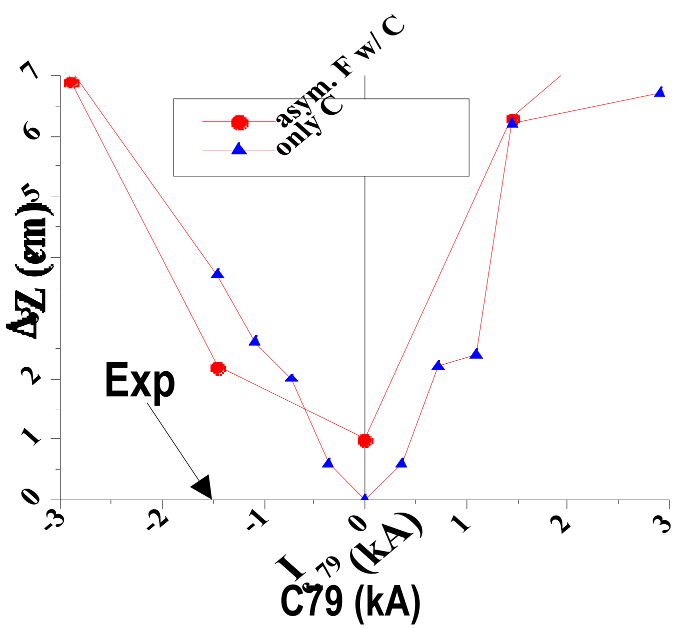
- **DIII-D USN discharge 105828.03000**

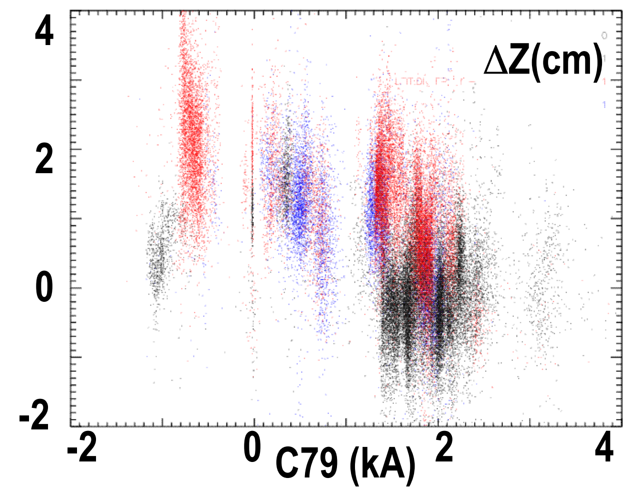




C-COIL RESPONSES ARE NOT CONSISTENT WITH OBSERVATIONS WITHOUT PLASMA RESPONSE

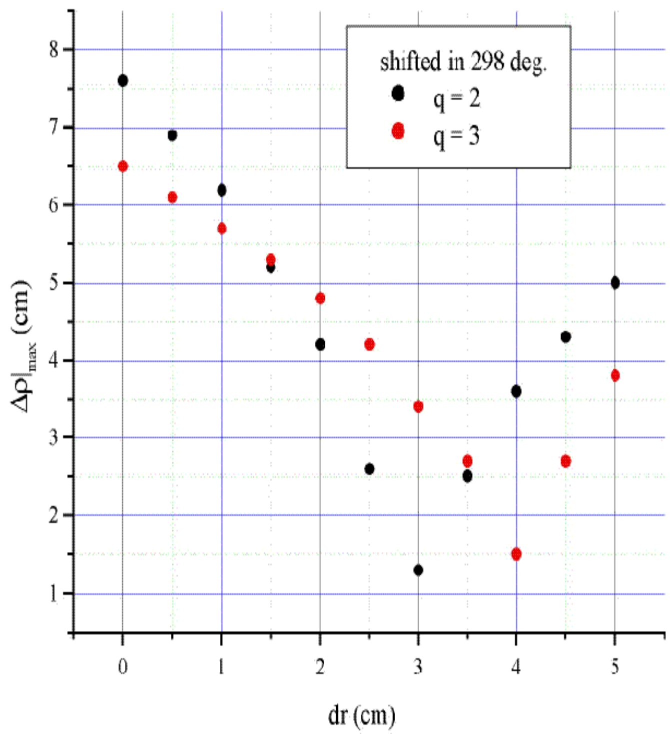
- Main sorting variables: DND, USN, and LSN. H-mode only, 1999 - early 2001
- Simulations based on USN discharge 105828.03000 with asymmetric F-coils + C-coils and with C-coils only



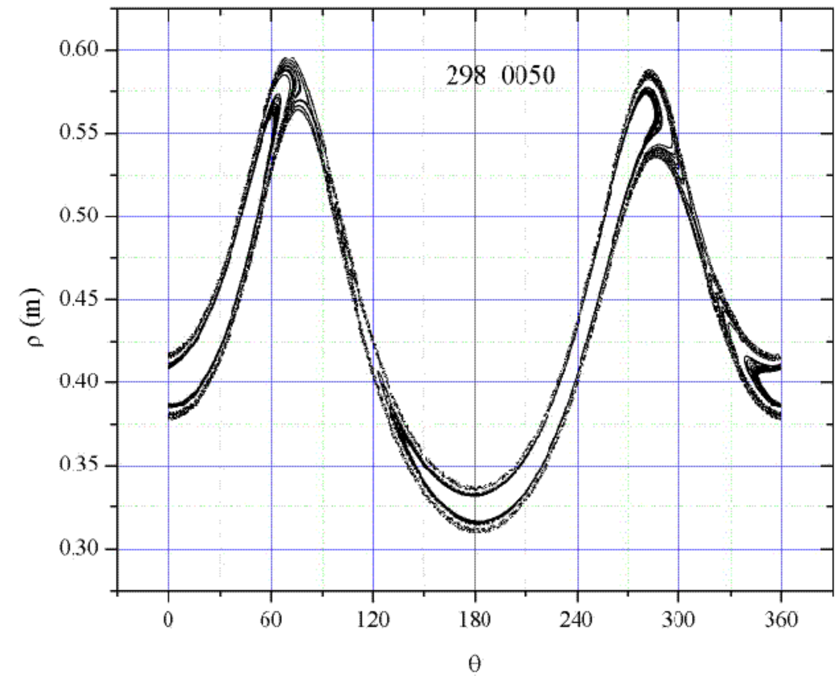


C-COIL CAN PRODUCE LARGE MAGNETIC ISLANDS AT OUTER RATIONAL q SURFACES WITHOUT PLASMA RESPONSE

- **F-coil shifted uniformly along the radial direction at ϕ = 298 degree to reduce the C-coil effects at q = 2 and 3 surfaces**
- **Simulations based on DIII-D USN discharge 105828.03000**



Δr = 5 cm at ϕ= 198 degree



SUMMARY

- A 1 - 4 cm difference still exists between the separatrix vertical position determined from EFIT magnetic analysis and those inferred from Thomson T_e measurements
  - Removal of metal plate on n1-coil makes little difference
- Perturbative calculations without plasma response indicate a small toroidal asymmetry in the external coil location can introduce significant 3-D magnetic effects such as formation of edge stochastic layers and magnetic islands into the magnetic topology
- Response of error magnetic field correction coils (C-Coils) suggest that plasma response may play a crucial role
  - C-coil currents tend to increase the error magnetic field due to the external shaping coils
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