DISTORTION OF MAGNETIC SURFACE DUE TO TOROIDALLY ASYMMETRIC EXTERNAL MAGNETIC FIELD

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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
- Recently, a 1-4 cm difference is found between the separatrix vertical position determined from EFIT magnetic analysis and those inferred from Thomson T_e measurements
  - — First seen in some quiescent H-mode (QH-mode) upper single-null discharges but since found also exist for other discharges

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 external toroidally asymmetric error magnetic field on the edge separatrix boundary ?**

OUTLINE / SUMMARY

- Separatrix location can be conveniently obtained from EFIT magnetic analysis and inferred from Thomson T_e measurements in H-mode discharges
- Results from the two methods agree for lower single-null discharges
- There can be a 1-4 cm difference in the Thomson separatrix vertical position in upper single-nul and double-null discharges
- Results of an heat flux analysis for a upper single-null discharge are consistent with a 1-2 cm difference seen between EFIT and Thomson
- A leading explanation for this difference is the toroidal asymmetry due to external magnetic field
- Perturbative 3-D calculations indicate a 1-2 cm radial shift in the external coil location can lead to formation of an edge ergodic layer with observable distortion of the plasma shape
- A more self-consistent variational approach including plasma response is being formulated

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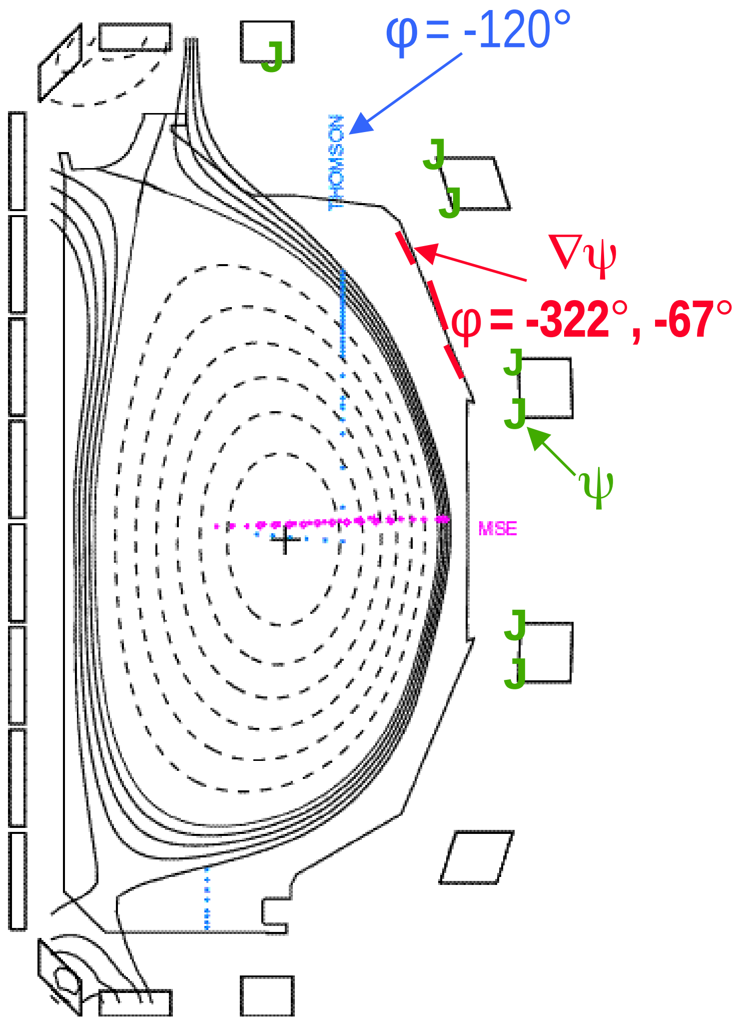
SEPARATRIX LOCATION IS TYPICALLY DETERMINED BY EXTRAPOLATING EXTERNAL MAGNETIC MEASUREMENTS INWARD

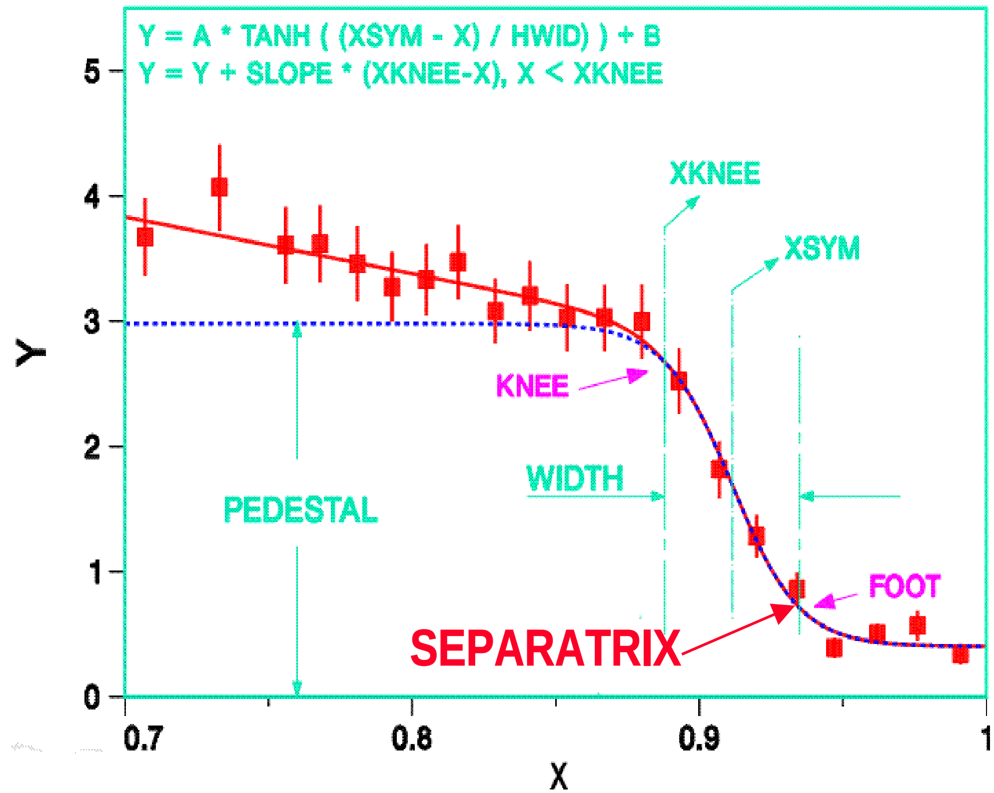
- **EFIT extrapolate magnetic measurements inward assumed discharge in a 2-D equilibrium state**
  - **41 flux loops: ψ**
  - **73 magnetic probes: $\nabla\psi$**
  - **Equilibrium relates 2nd derivatives to ψ and $\nabla\psi$**
  - **Separatrix location defined by largest closed flux surface enclosed 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°**



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

- 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



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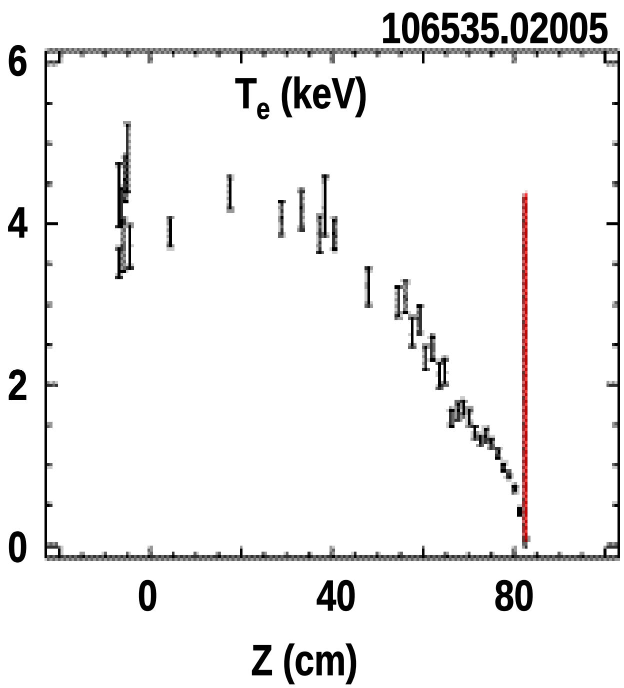
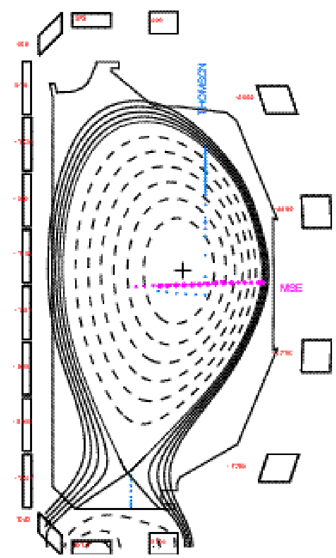
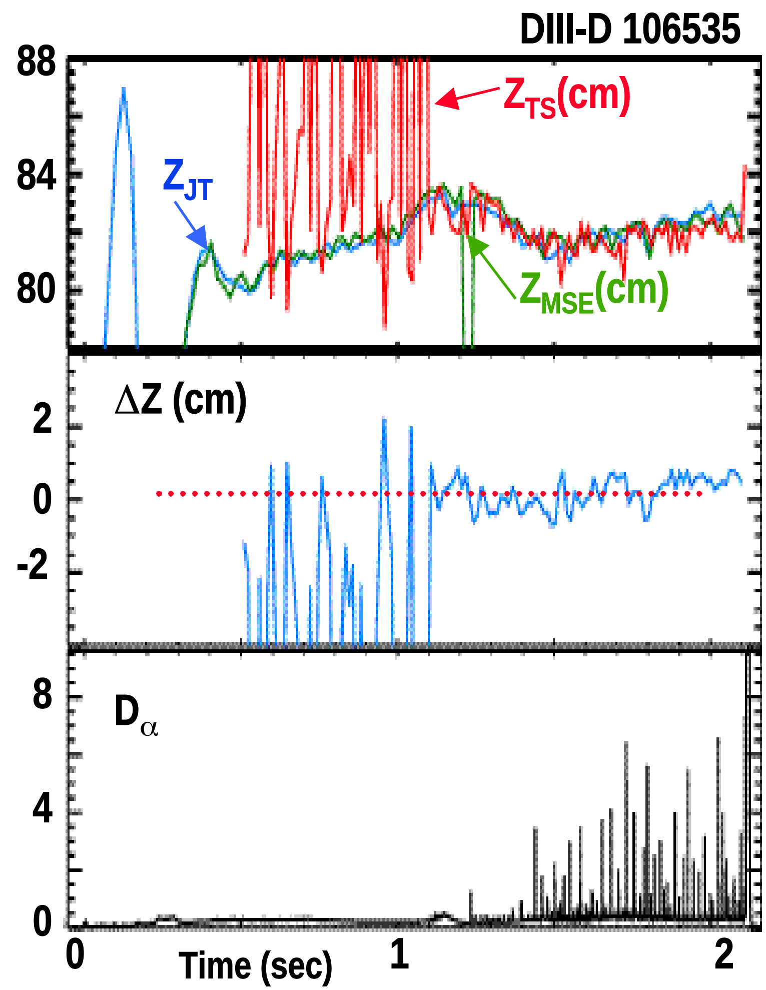
SEPARATRIX LOCATIONS FROM EFIT AND THOMSON AGREE WELL IN LOWER SINGLE-NULL DISCHARGES

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







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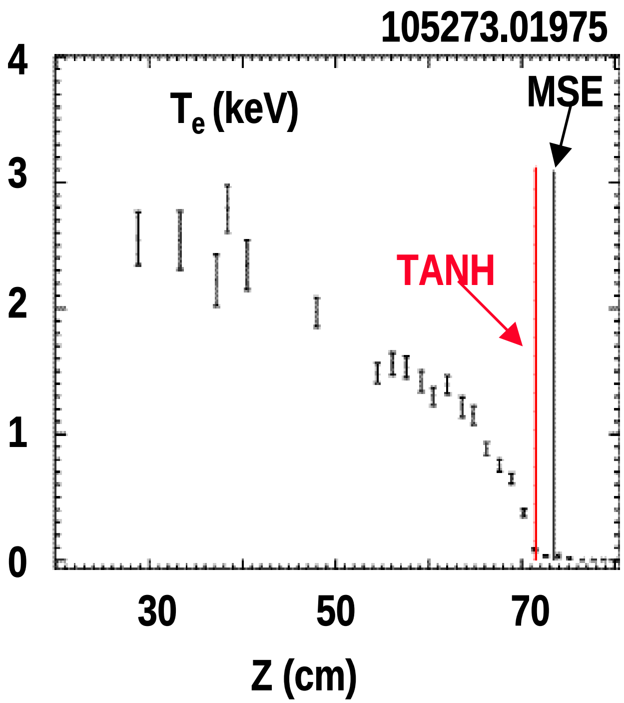
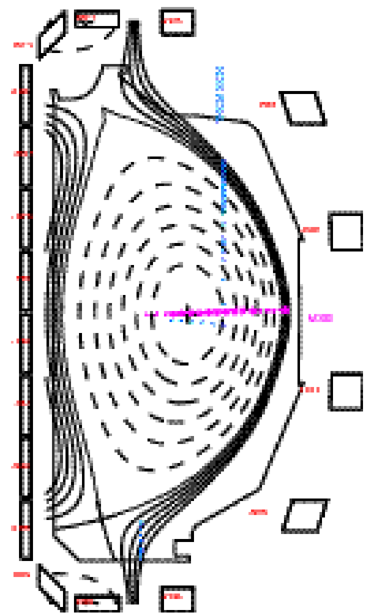
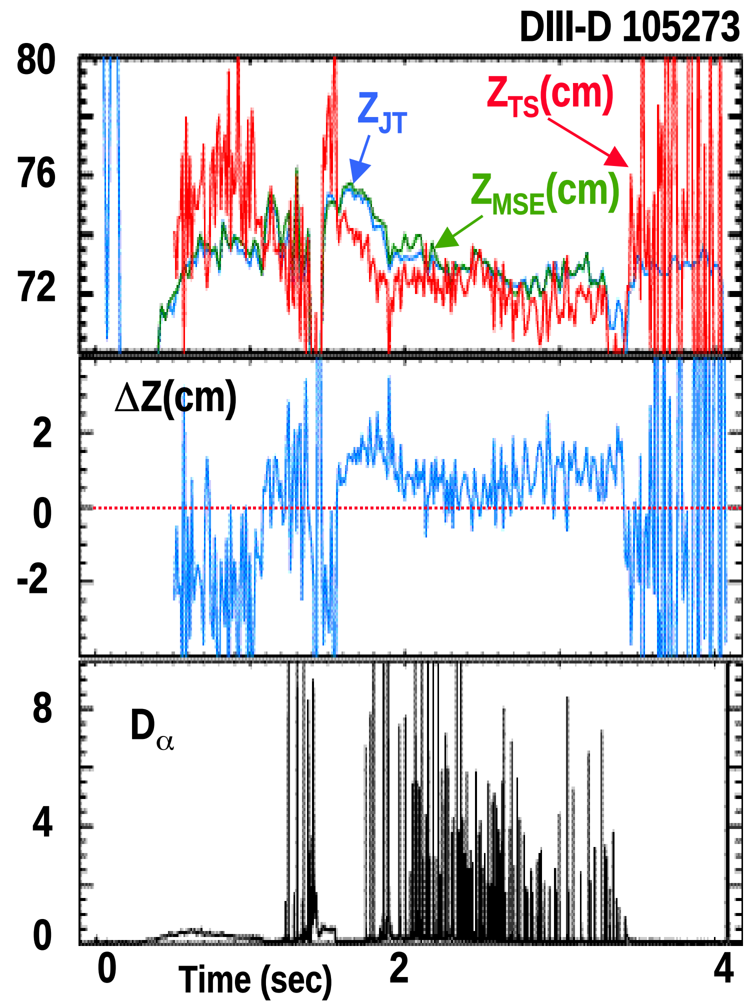
SEPARATRIX LOCATIONS FROM EFIT AND THOMSON CAN DIFFER BY 1-2 cm IN DOUBLE-NULL DISCHARGES

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







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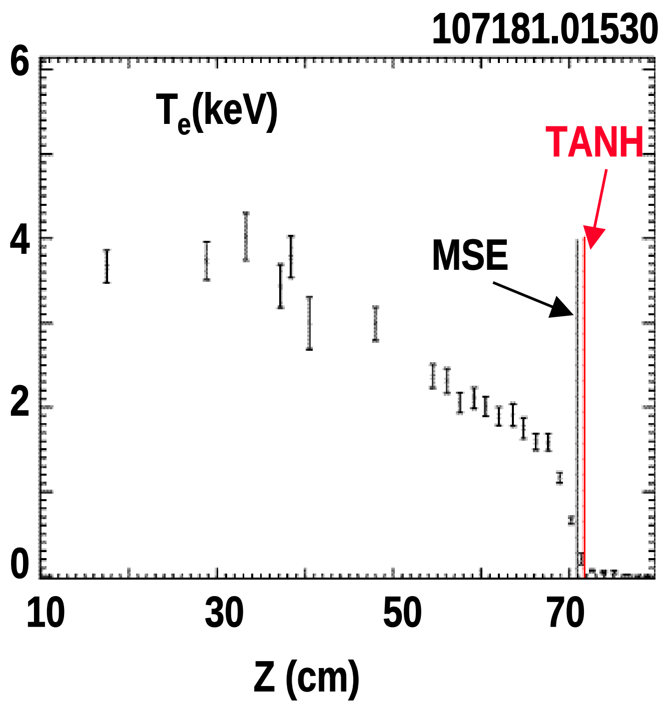
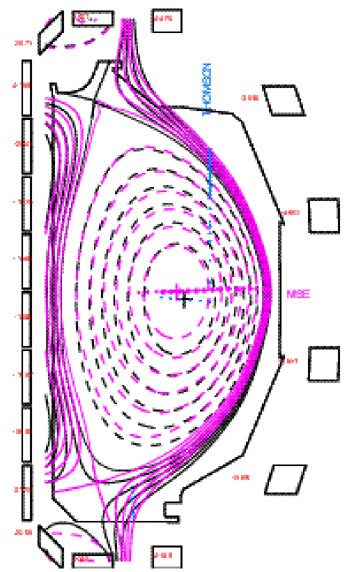
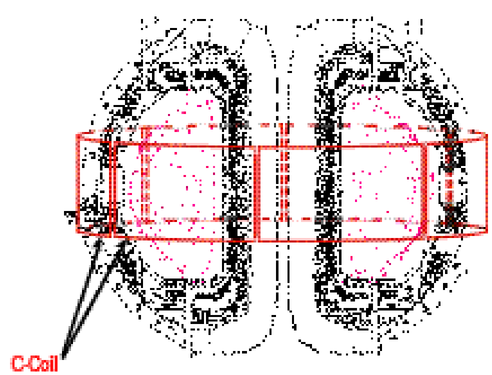
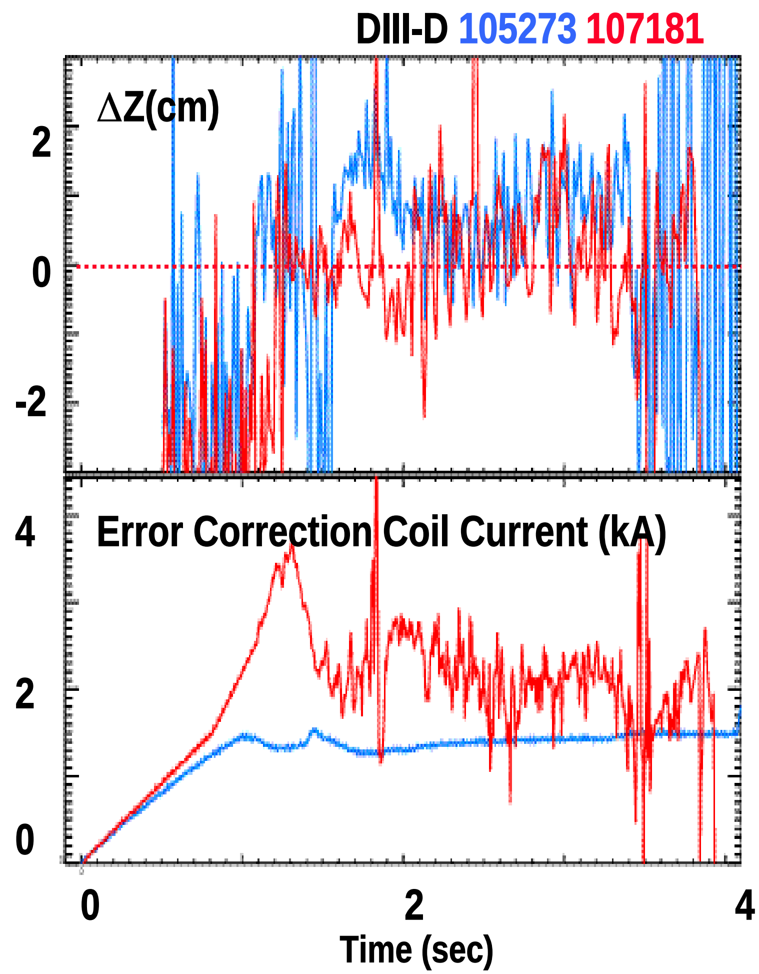
ERROR FIELD CORRECTION COIL CURRENT APPEARS TO PLAY A ROLE IN THE EFIT-THOMSON SEPARATRIX LOCATION DIFFERENCE

- From 2001 AT stability experiment, $\beta_N \sim 3.8$, $q_{95} \sim 5.1$, higher C_{79} current









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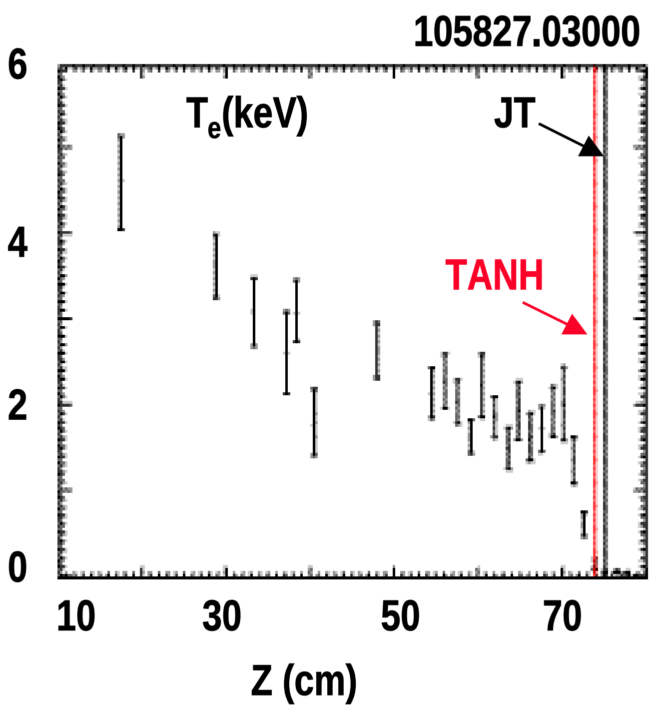
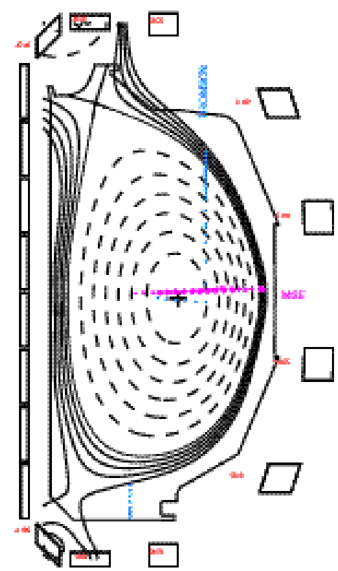
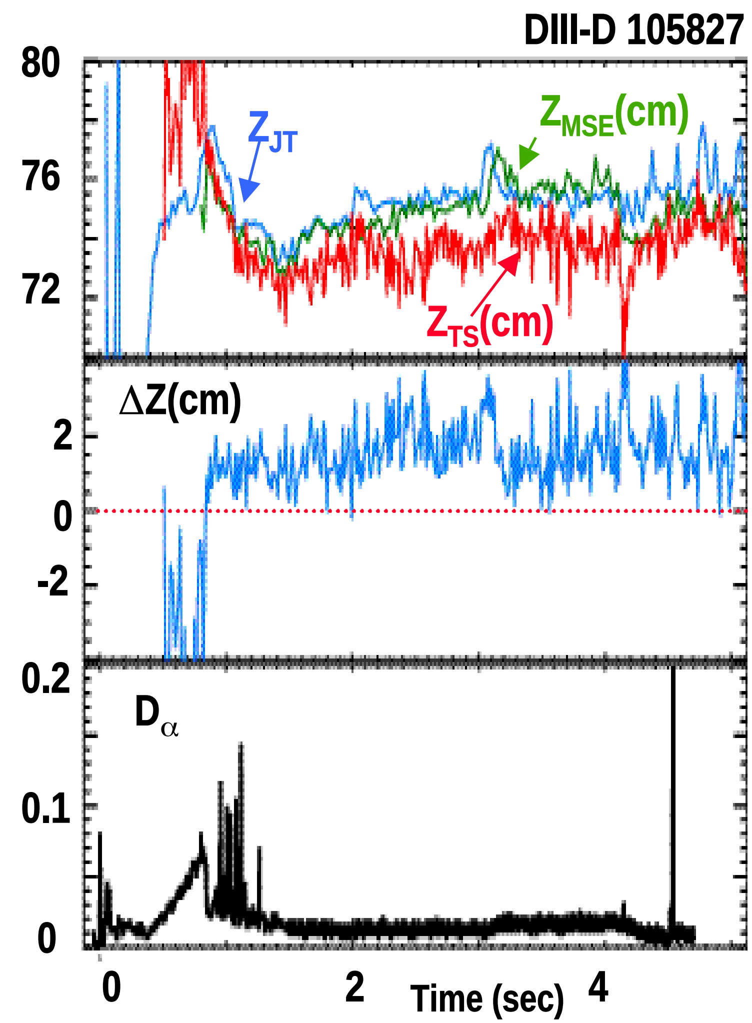
SEPARATRIX LOCATIONS FROM EFIT AND THOMSON CAN DIFFER BY 1-4 cm IN UPPER SINGLE-NULL DISCHARGES

- **From 2001 QH mode experiment using 1.3 MA shape control panel**

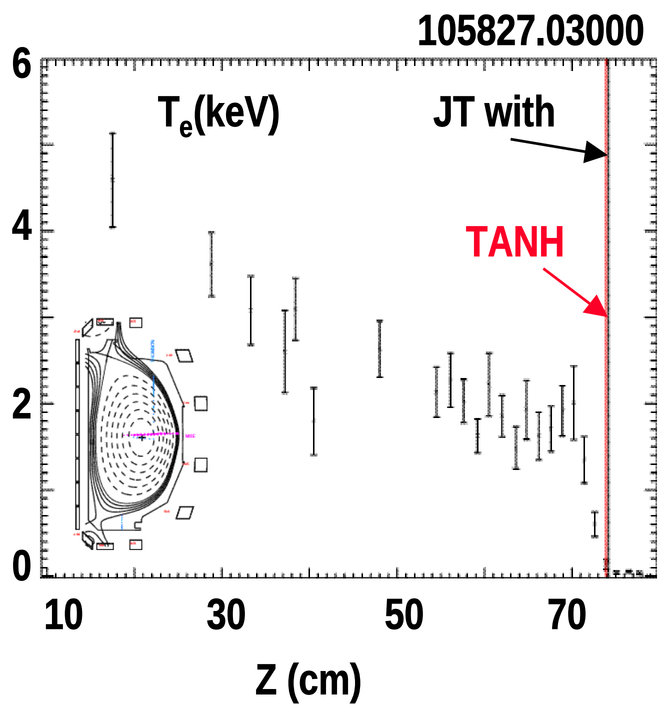


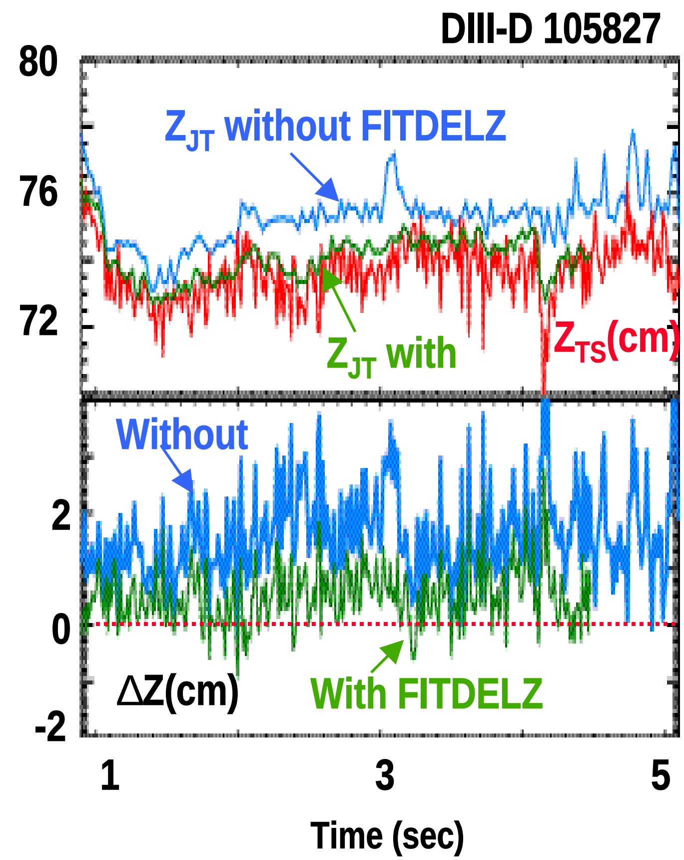




VERTICAL POSITION FITTING SWITCH SOMETIMES HELPS FINDING A BETTER NUMERICAL SOLUTION

- From 2001 QH mode experiment using 1.3 MA shape control panel
- Z dependence only enters Grad-Shafranov equation implicitly
- ψ is allowed to have a rigid body shift during iteration $\psi^{n} = \psi^{n-1} + \delta Z\, \psi_Z^{n-1}$
  - When effective both χ^2 and convergence are usually improved





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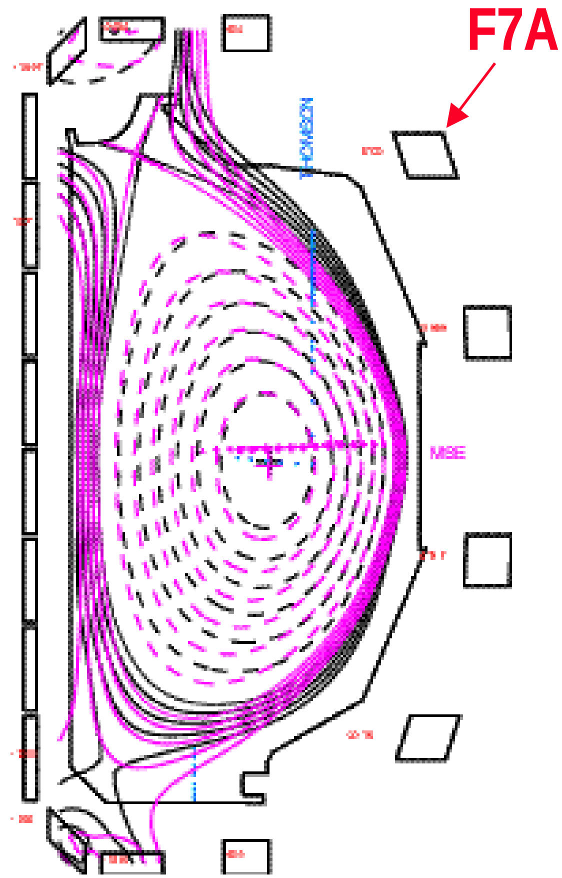
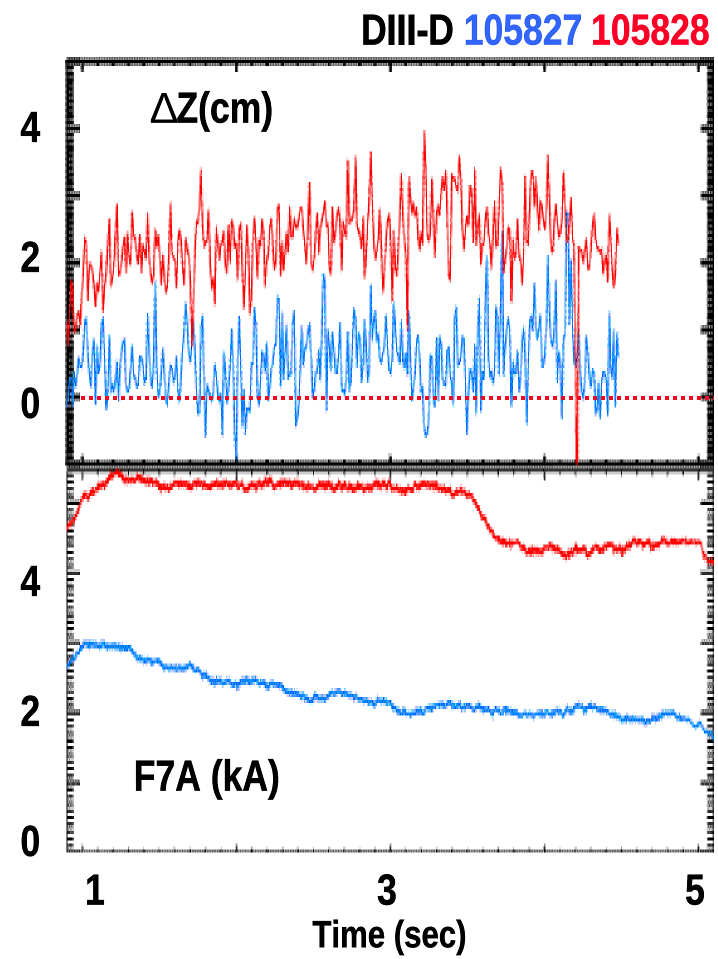
CURRENT IN F7A APPEARS TO PLAY A ROLE IN THE EFIT-THOMSON SEPARATRIX LOCATION DIFFERENCE

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



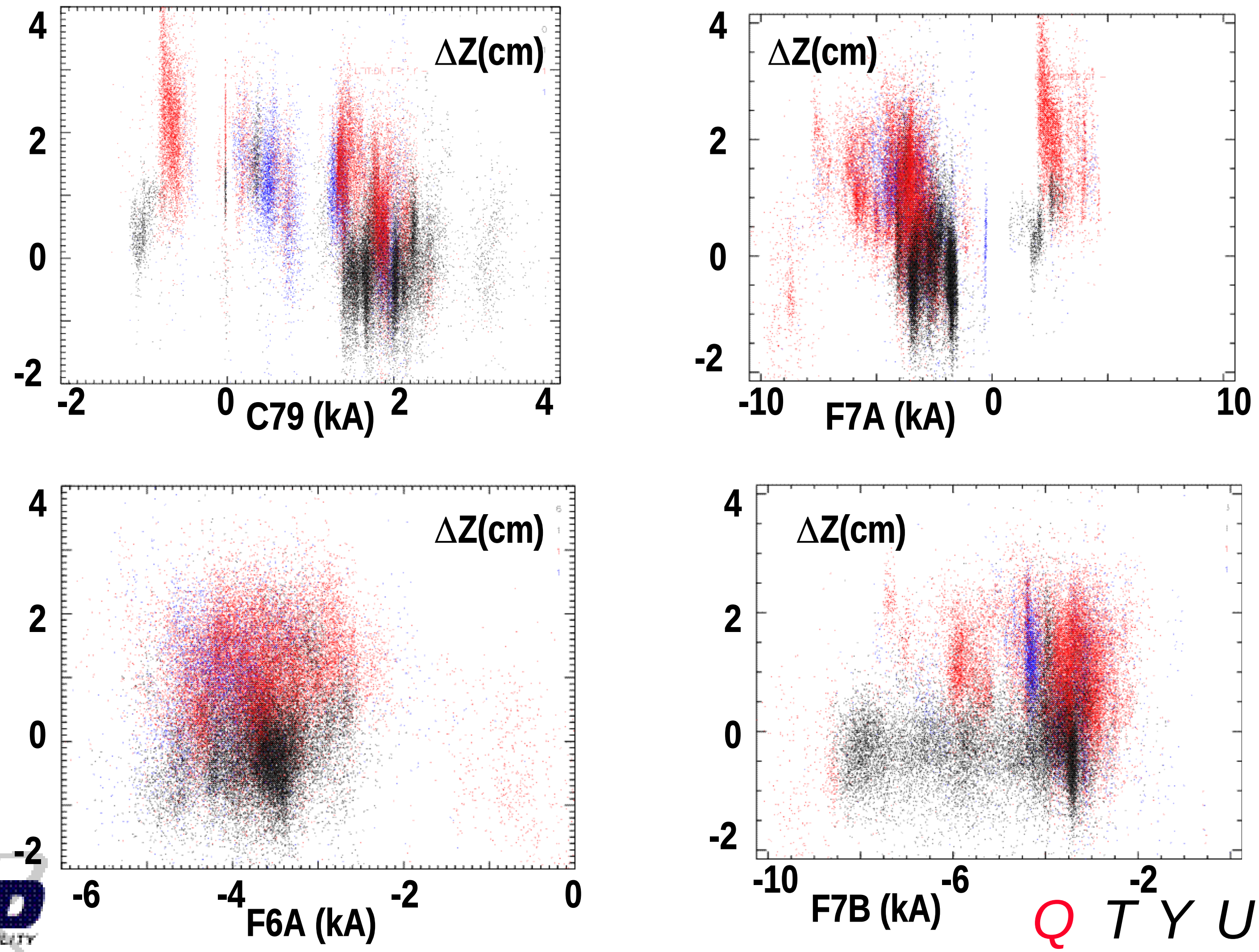


DATABASE SURVEY

- 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), $\delta R_{SEP} < -1$ cm
  - Double null (DND), -1 cm < $\delta R_{SEP} <$ 1 cm
  - Upper single null (USN), $\delta R_{SEP} >$ 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}

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**



DIVERTOR HEAT FLUX ANALYSIS

- To determine if the upstream T_e along the separatrix implied by the IR camera heat flux measurement (ϕ ~ -225 °) is consistent with that from Thomson scattering based on EFIT mapping
- Approach
  - — Use upper single-null discharge 104274 from Thrust 2 experiment in 2000
  - — Assumed SOL in sheath-limited regime

$$n_{eu} \approx \frac{18.2 x q}{\gamma x [T_{eu}]^{1.5} \; x\{1 + \frac{T_{iu}}{T_{eu}}\}^{0.5} x [\frac{B_z}{B}]_t}$$

  - — γ = sheath heat transmission coefficient
  - — Assume peak $q_\perp$ is at separatrix location

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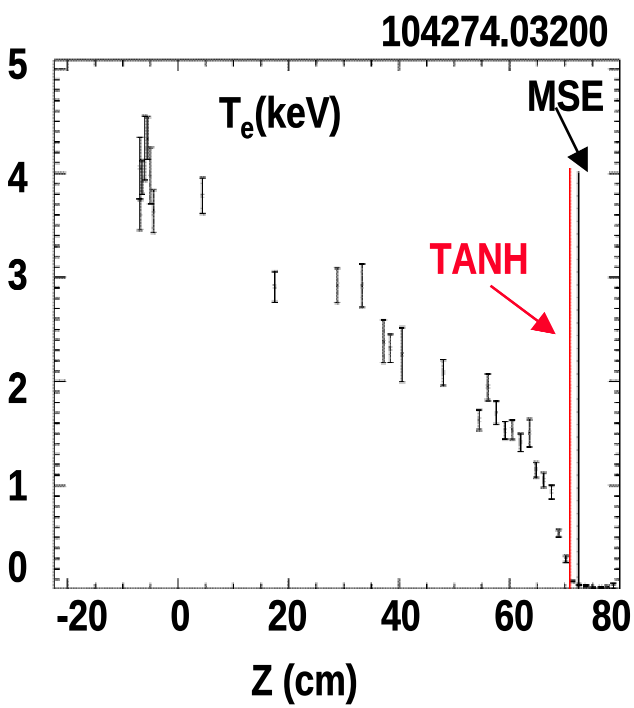
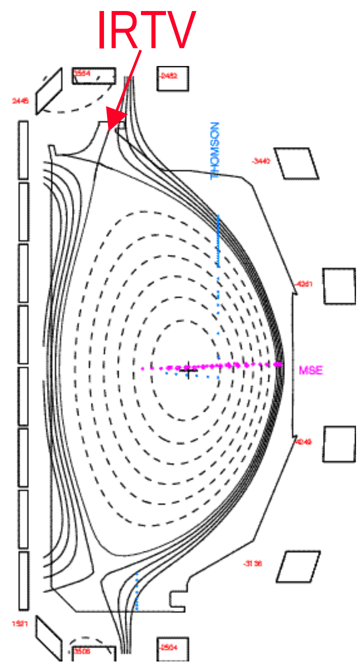
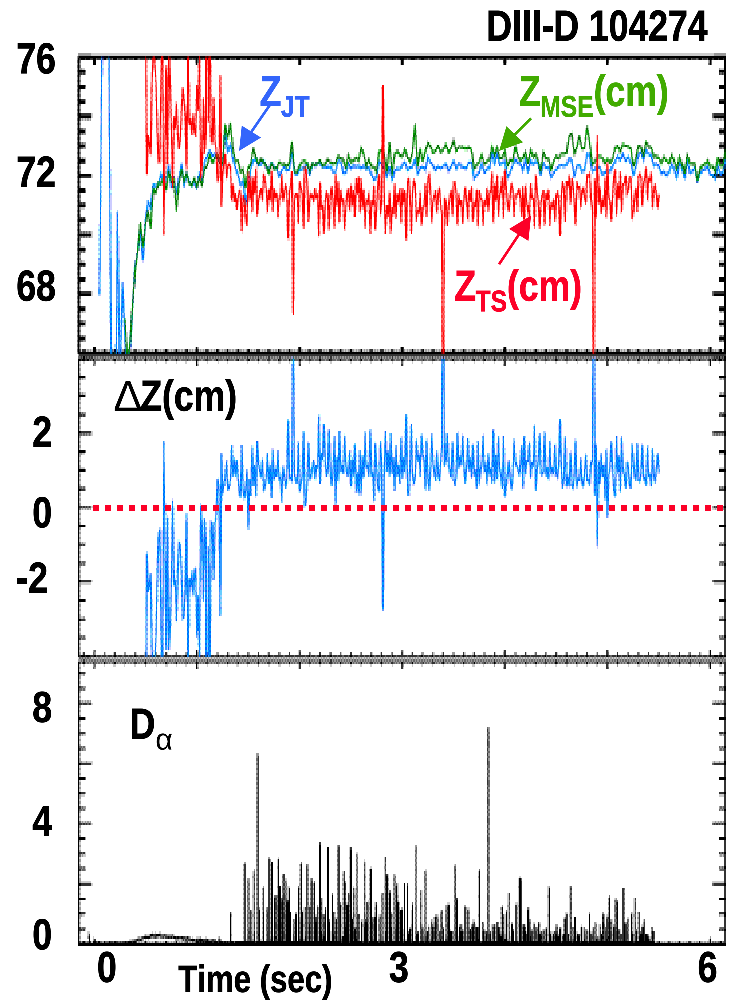
SEPARATRIX LOCATIONS FROM EFIT AND THOMSON DIFFER BY ~ 1-2 cm IN THIS USN DISCHARGE

- **From 2001 AT experiment, β_N ~ 2.7, q_{95} ~ 4.3**



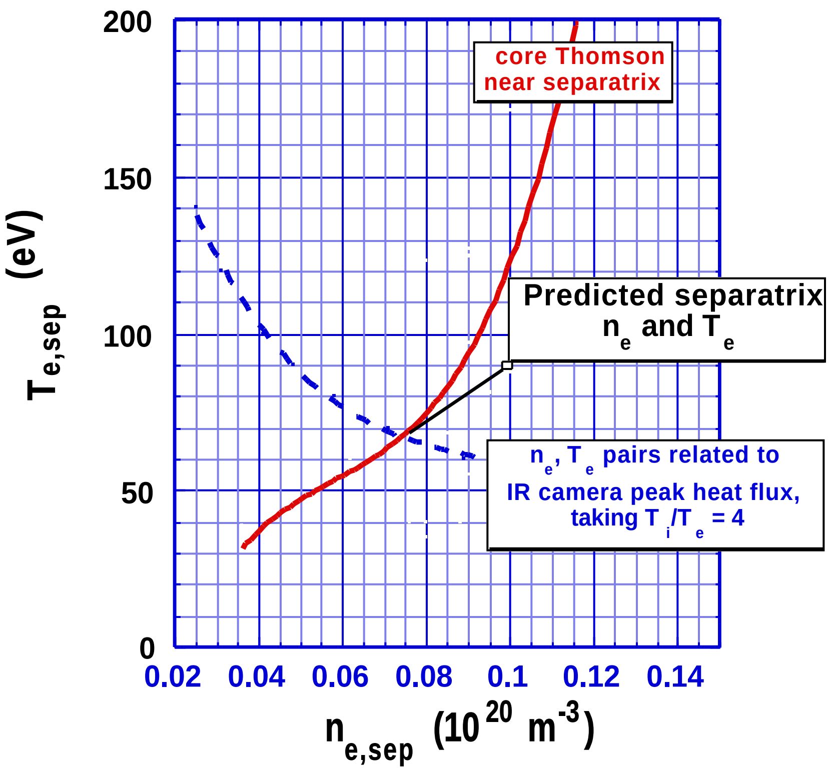




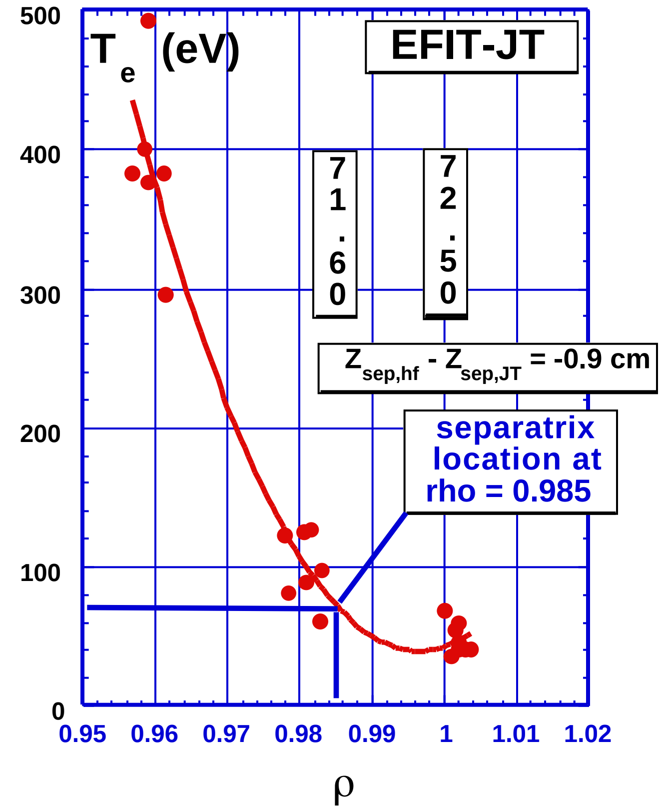
HEAT FLUX ANALYSIS RESULTS ARE CONSISTENT WITH A 1-2 cm DIFFERENCE SEEN BETWEEN EFIT AND THOMSON

- Using JT-like EFIT for mapping

UPSTREAM ELECTRON DENSITY AND TEMPERATURE ALONG THE SEPARATRIX MUST SIMULTANEOUSLY SATISFY BOTH THOMSON SCATTERING AND HEAT FLUX CONDITIONS

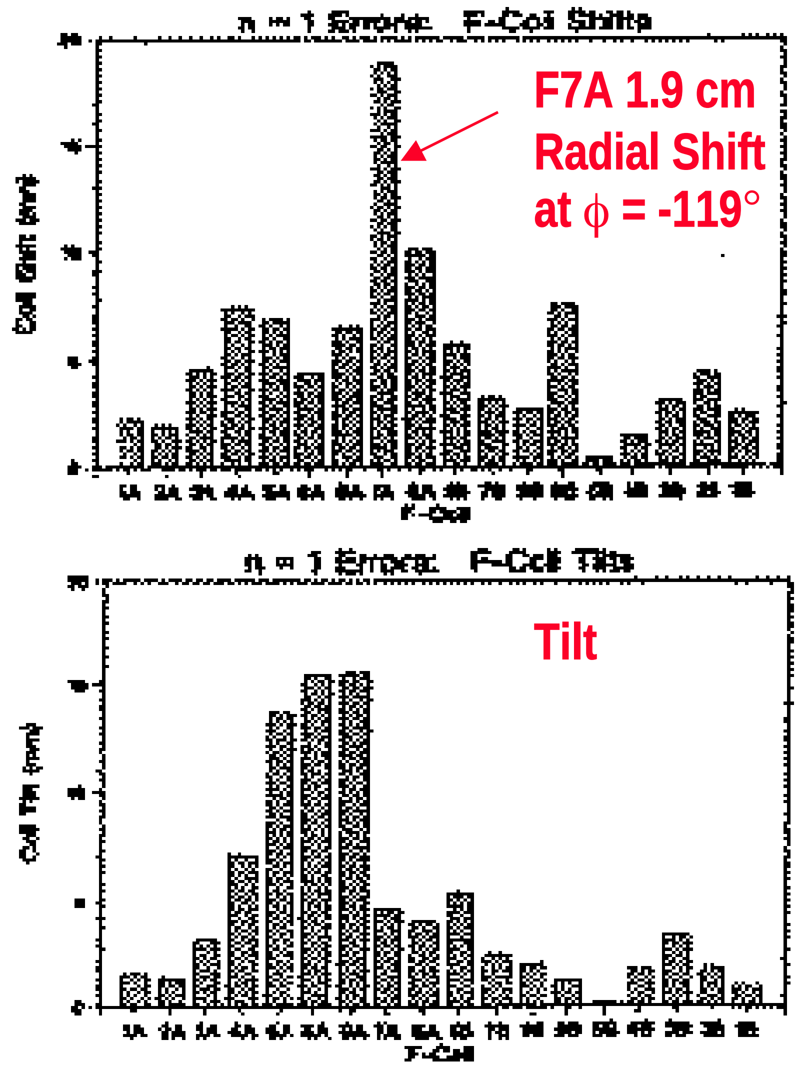


SHEATH-LIMITED ESTIMATE OF SEPARATRIX LOCATION IS SLIGHTLY AT VARAIANCE WITH EFIT-JT



3-D DISTORTION OF MAGNETIC SURFACES DUE TO TOROIDALLY ASYMMETRIC EXTERNAL COILS

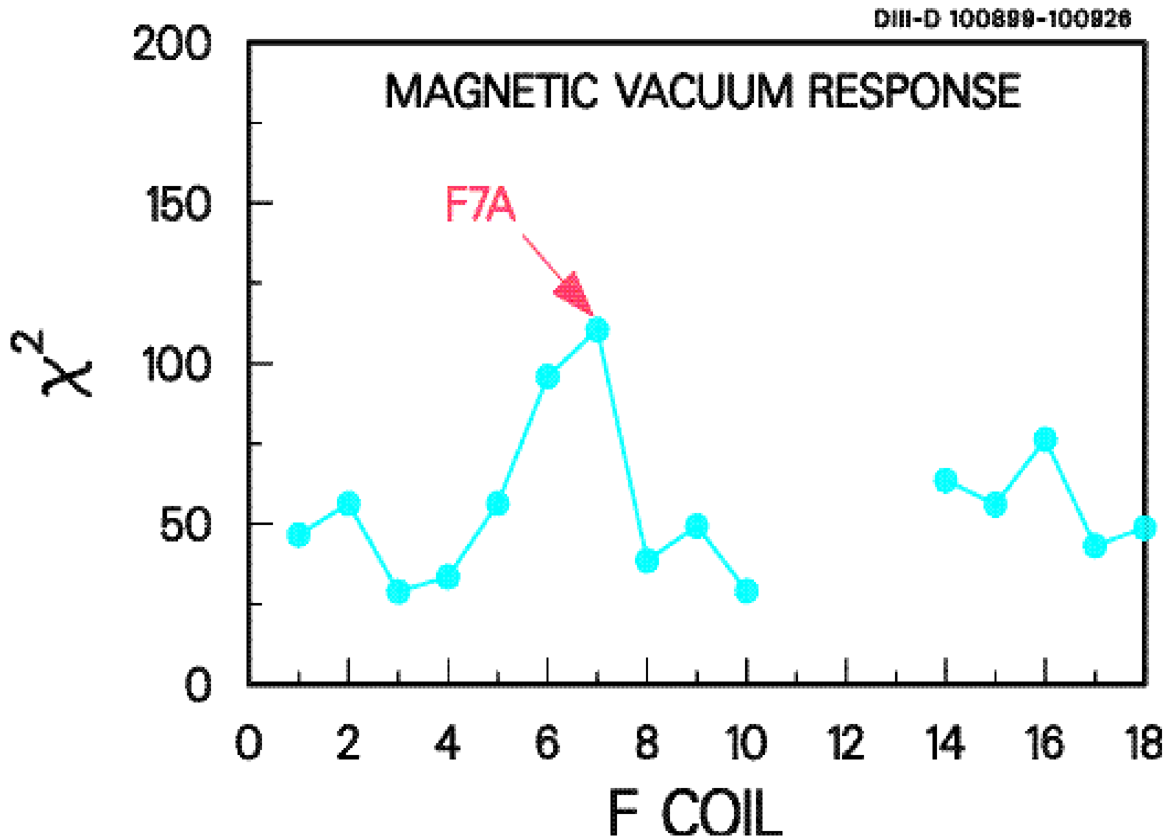
- **Previous measurements indicate that F-coil irregularities exist [1]**
  - — **F7A 1.9 cm radial shift + tilts**
- **Perturbative 3-D calculations**
  - — **3-D effects taken to be small, plasma assumed to remain in a 2-D axisymmetric equilibrium state**
  - — **3-D corrections to the magnetic surfaces are then computed by super-imposing the asymmetric external magnetic field onto the background toroidally symmetric magnetic field due to the plasma using the Green's function approach**



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

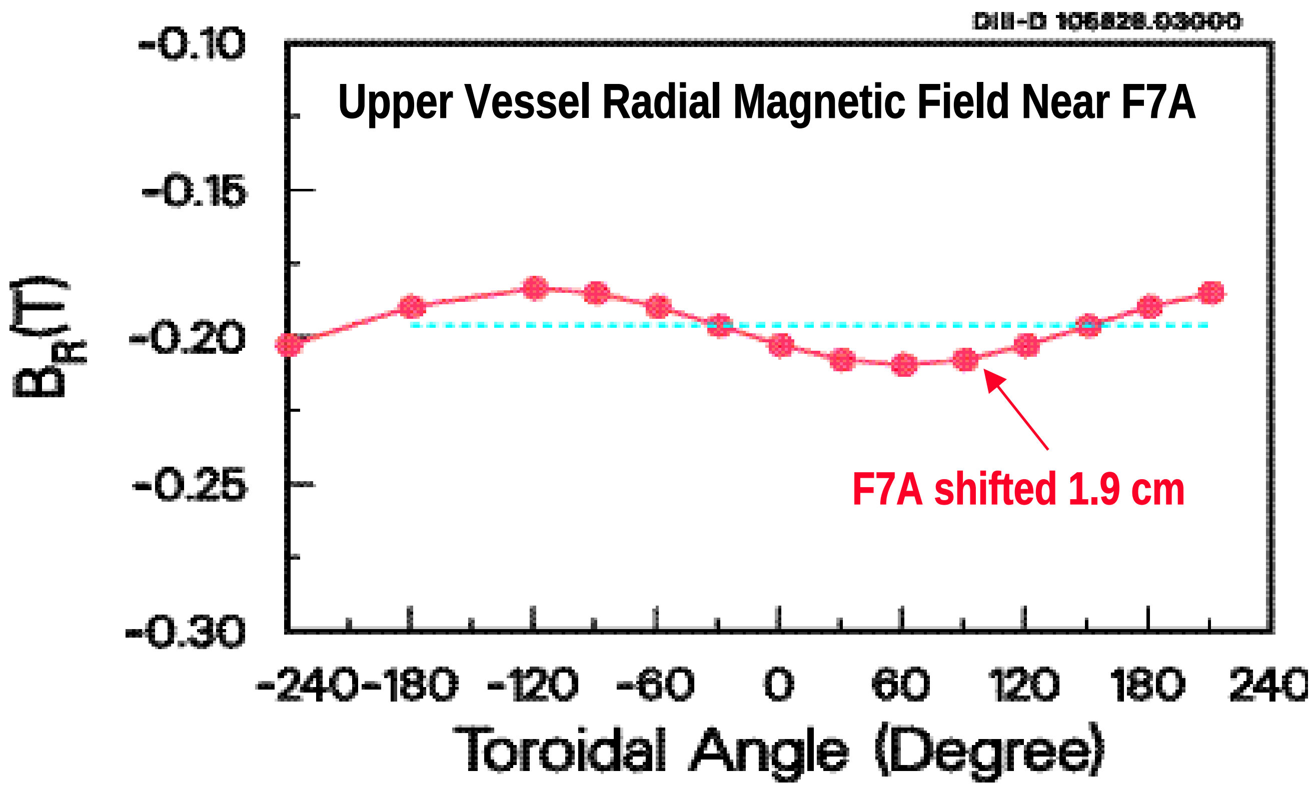
VACUUM MAGNETIC TESTS INDICATE THAT ERROR MAGNETIC FIELDS ARE LARGEST FOR UPPER OUTER COILS

- Magnetic measurements from a series of vacuum shots are compared against EFIT calculations using
  - measured F-coil currents
- F -coils are energized individually in separated discharges



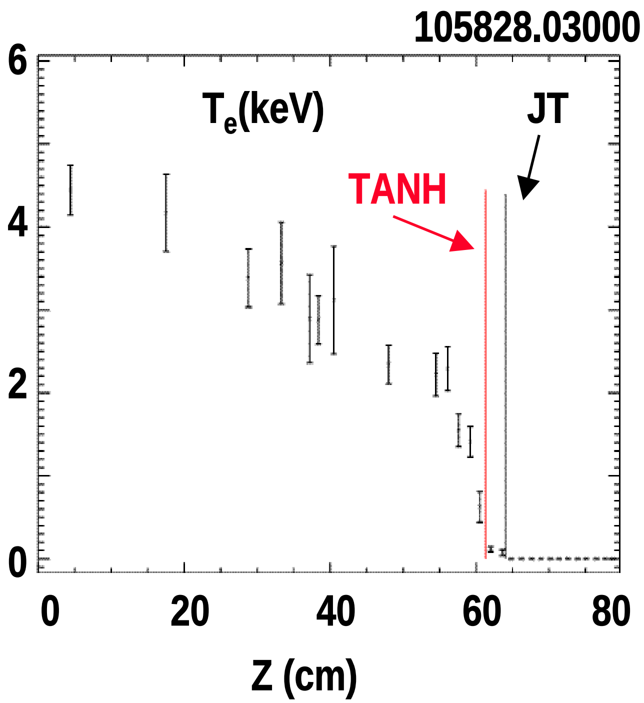
PERTURBED RADIAL MAGNETIC FIELD FROM F7A DUE TO A RADIAL SHIFT EXHIBITS A *n* = 1 PATTERN

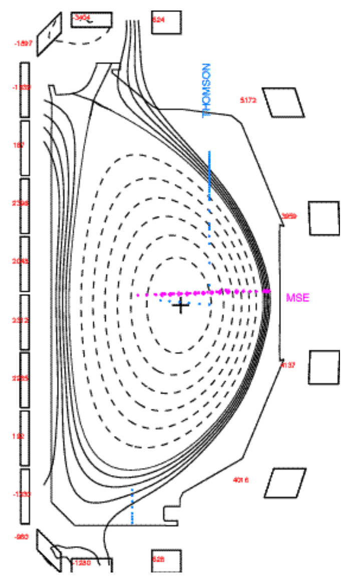
- **Calculations done using measured F7A current from a QH-mode discharge**

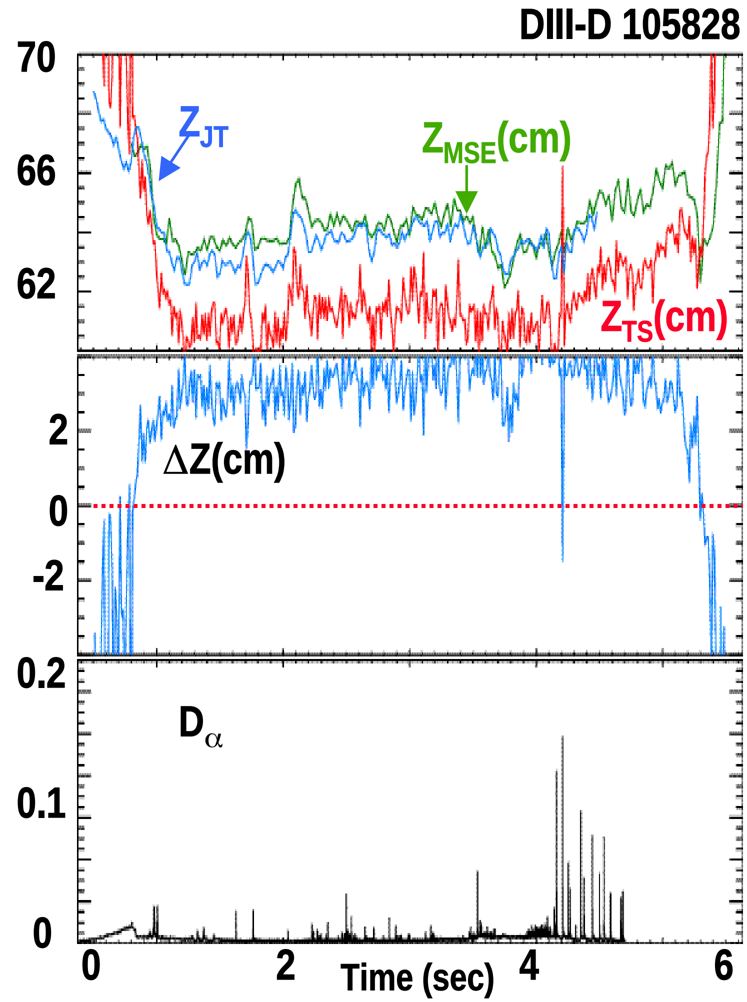


SEPARATRIX LOCATIONS FROM EFIT AND THOMSON DIFFER BY 2-4 cm IN THIS UPPER SINGLE-NULL DISCHARGE

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

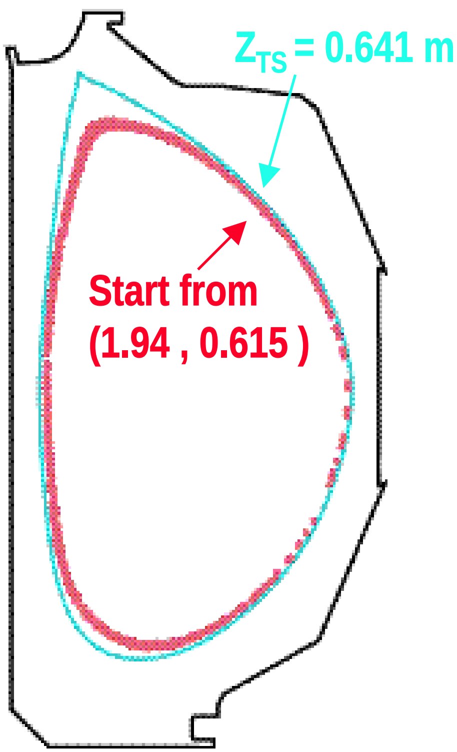




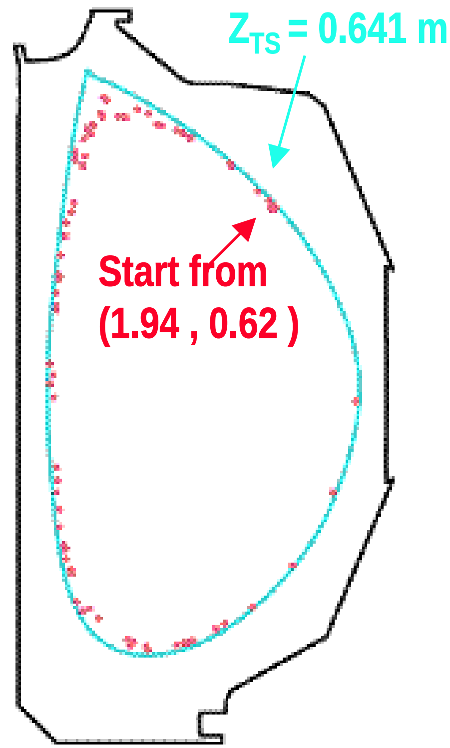


A 1-2 cm RADIAL SHIFT IN F7A CAN LEAD TO FORMATION OF AN EDGE STOCHASTIC REGION

- **3-D perturbative calculations based on QH-mode discharge 105828**
- **Magnetic surfaces remain closed at (R, Z) = (1.94m, 0.615m), but become open and stochastic at (R, Z) = (1.94m, 0.620m)**



F7A shifted radially by 1.9 cm at ϕ = -119°



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- A leading explanation for this difference is the toroidal asymmetry of the external magnetic field