MAGNETIC FITTING OF HELICITY-INJECTED PLASMAS IN NSTX

M.J. Schaffer,[1] L.L. Lao,[1] S.A. Sabbagh,[2] D.A. Gates,[3] J.E. Menard,[3] D. Mueller,[3] R. Raman,[4] and the NSTX Team

[1] General Atomics, San Diego, CA, U.S.A.
[2] Columbia University, New York, NY, U.S.A.
[3]Princeton Plasma Physics Laboratory, Princeton, NJ, U.S.A.
[4] University of Washington, Seattle, WA, U.S.A.

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GENERAL ATOMICS

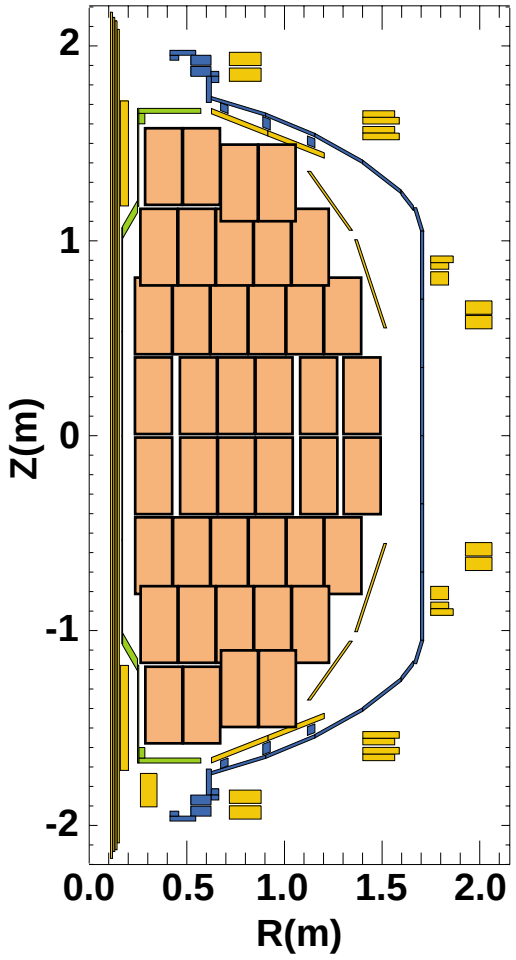
Helicity Injection is Important for NSTX

- STs have little or no space for an inductive drive coil.
  - They can benefit greatly from efficient non-inductive current drive.
- Coaxial helicity injection (CHI) is demonstrated on small STs.
- NSTX is designed and built with helicity injection in mind.
  - NSTX is a large scale up from previous small experiments.
  - NSTX committed to test, study and develop CHI.
- Almost 400 kA toroidal current has now been driven by CHI in NSTX from a “cold start”.
  - Directly relevant to noninductive startup.
- It is still not clear if closed magnetic surfaces are produced during CHI.
  - Closed flux necessary to contain beam ions and hot plasma.
  - Presence of closed flux is still an open question.

MFIT and EFIT Calculate Magnetic Flux Distribution

- EFIT uses external magnetic data plus MHD equilibrium constraints.
  - EFIT can handle large scrape-off layer (SOL) currents,
  - but EFIT fails without a sufficiently large closed flux volume.
- MFIT uses only external magnetic data to fit currents to a set of toroidal current loops representing plasma.
  - MFIT works for both closed and open flux surfaces.
  - MFIT calculates and displays fitted flux surface geometry.
    - Especially useful to guide CHI startup experiments.
  - No mathematical guarantee that fit approximates the real current distribution.
- EFIT upgrade is being attempted, to fit J parallel to B even with no closed surfaces.

MFIT Was Improved in 2000–2001

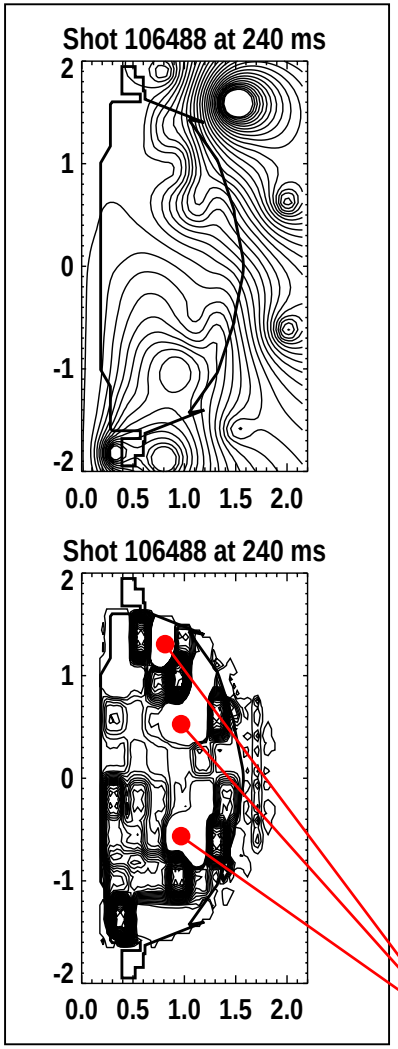


42 Ring Elements now used

- NSTX MFIT puts currents in fictitious large-cross-section toroidal rings to fit magnetic data, using singular value decomposition (SVD).
  - Old fitting showed tendency to spiky current distributions, including large local negative current spikes.
  - Greatly improved since 2000 Sept by:
    - Spikiness ($\sqrt{\Sigma I^2} - I_{avg}$) is penalized.
    - User-adjustable SVD condition number.
- Can now use more ring elements than before with little or no spikiness.
- MFIT is now well developed; used routinely to display flux geometry of CHI experiments.

GENERAL ATOMICS

Illustrative MFIT Plots of Poloidal Flux and Toroidal Current Density

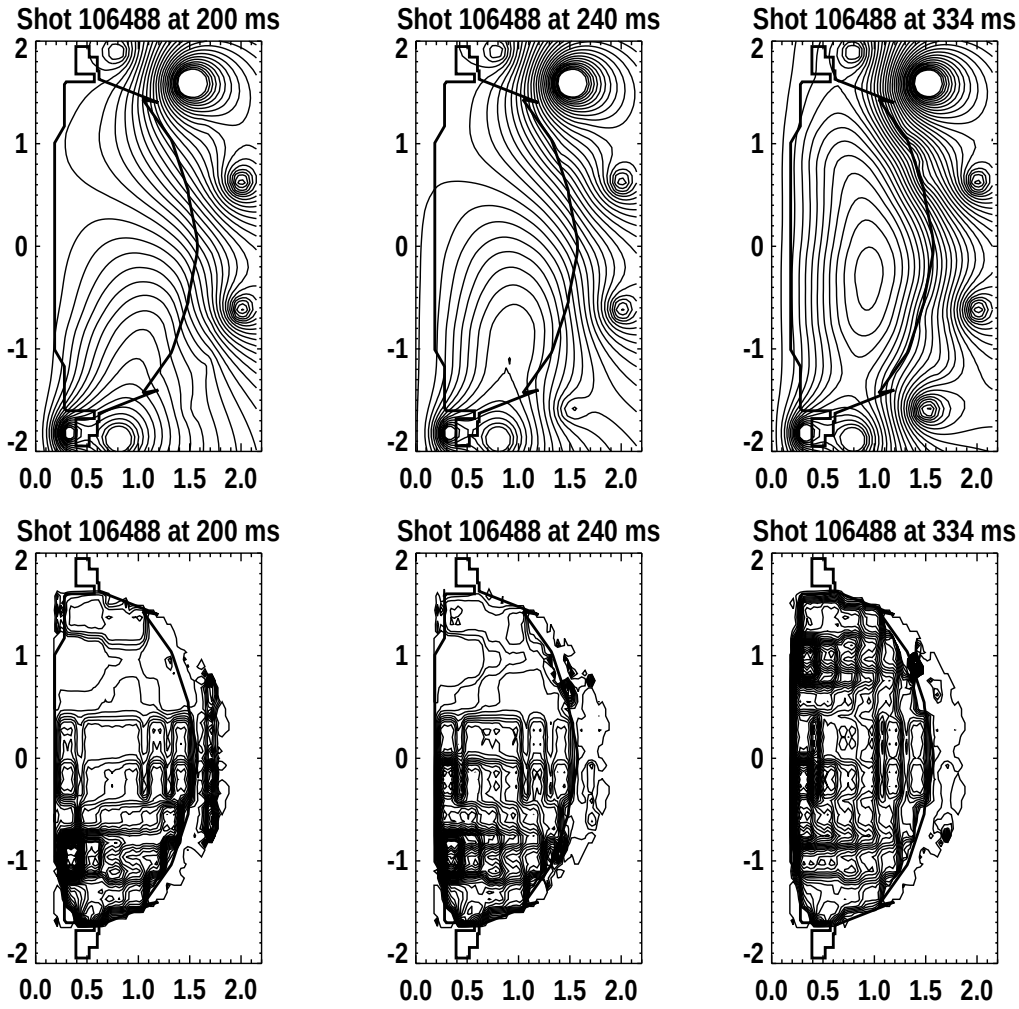


Improved MFIT ⇒

Flux contours

J_ϕ contours (J = const. in a ring)

Old ⇐ MFIT (gets negative currents)



GENERAL ATOMICS

Relevance of MFIT to Physical Flux - 1

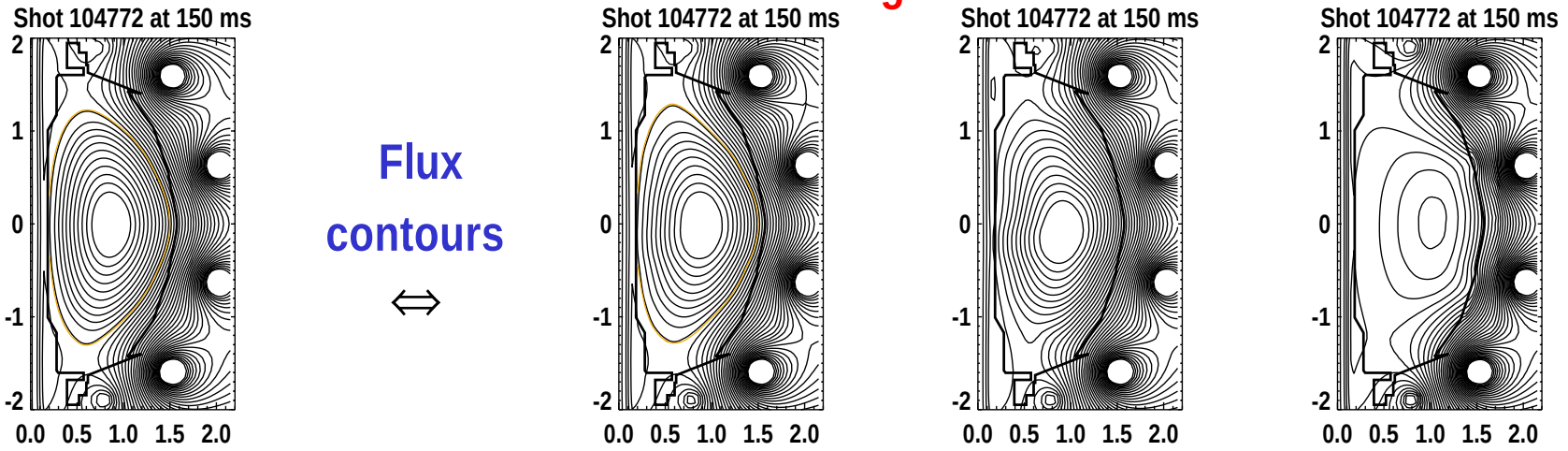
- Vacuum flux surfaces: Can compute them from a sufficient set of external magnetic data. Equivalent to projection from measurement points by solving Laplace equation.
  - Do not need to know current distribution in interior regions.
  - Can calculate shape of last closed flux surface (LCFS) by MFIT or EFIT.
- Current-carrying (plasma) surfaces: An infinite set of current distributions satisfies a given set of external magnetic measurements, by virtual casing theorem.
  - External data cannot determine a unique internal current distribution, J(R, z).
  - Current smoothing, as in MFIT, is a weak, but physics-based, constraint.
    - Smoothing might be wrong, if actual current is very peaked or hollow.
    - In MFIT, fits suddenly jump to unrealistic "flat" current distributions if smoothing parameters are increased too much; as illustrated for Ohmic shot on next page...

Ohmic Plasma Illustrates Effect of MFIT Current Smoothing

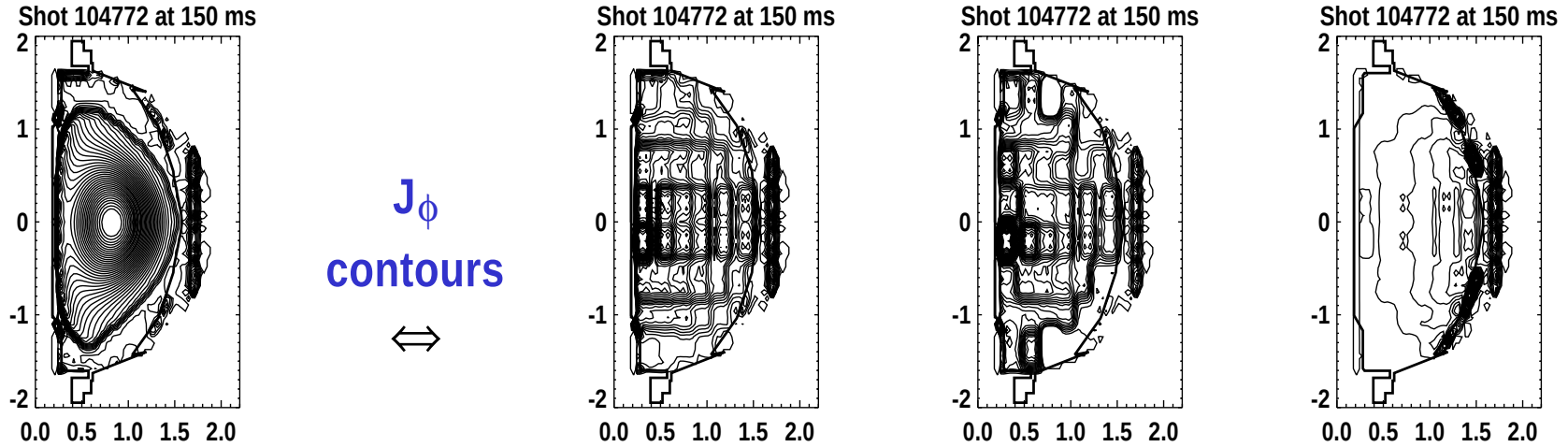
NSTX

EFIT | MFITs: Good Smoothing | Too Little | Excessive

Flux contours ⇔



J_ϕ contours ⇔

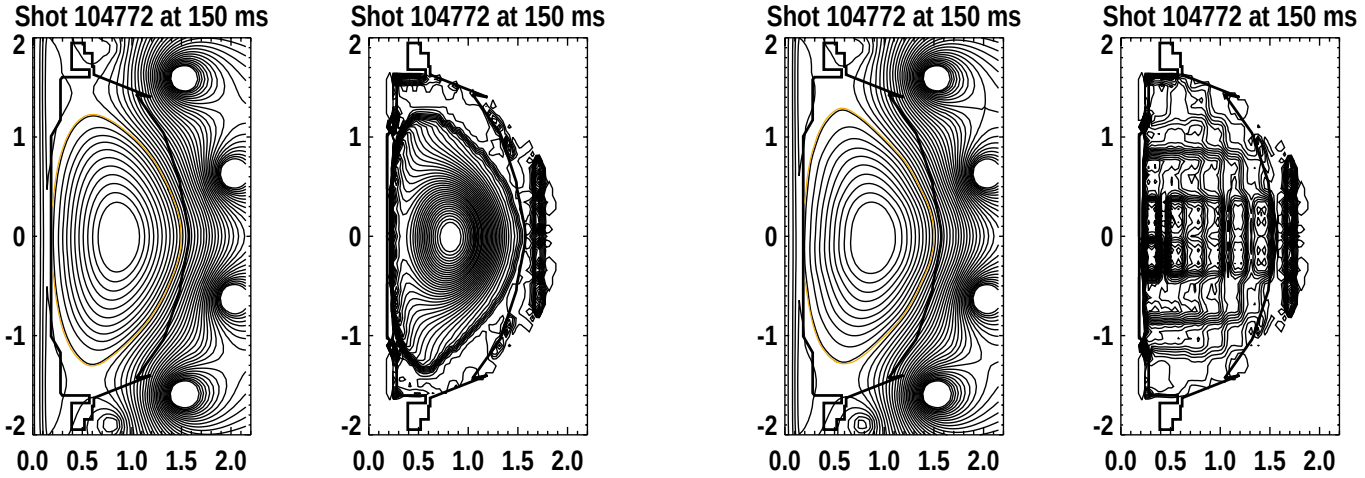


GENERAL ATOMICS

Relevance of MFIT to Physical Flux - 2

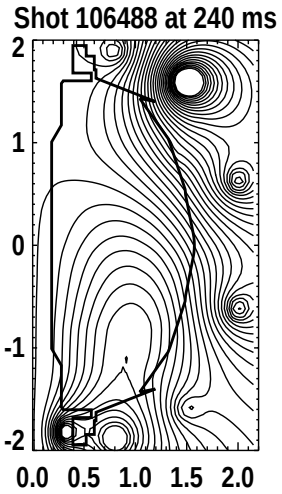
- MFIT run with current smoothing yields broad current profiles.
- In general, broader current distributions yield less closed flux.
  - Cf. MFIT vs. EFIT fits to OH plasma.

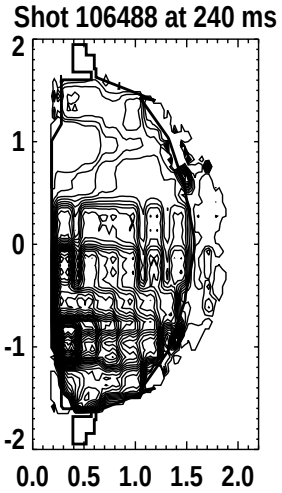
EFIT **MFIT**



GENERAL ATOMICS

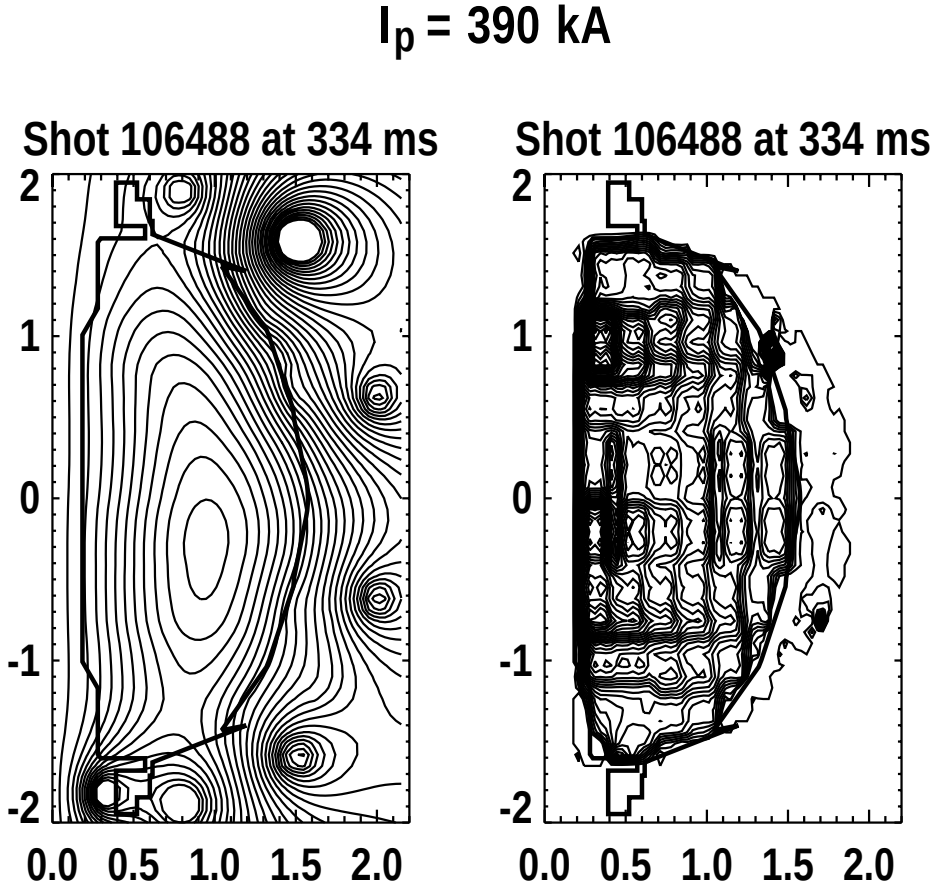
What Does MFIT Tell Us About Existence of Closed Surfaces in CHI? - 1





- Flux is 2nd integral of current. Flux is quite insensitive to current distribution details.
- Smoothing reduces excessively peaked current profiles.
  - Peaked J would make more flux, yield false closed surfaces.
- Therefore, smooth-J MFIT reduces possibility of false closed surfaces, EXCEPT when ACTUAL current is much more hollow.
  - However, hollow J (large current on open surfaces, where J is directly driven by biased electrodes) IS precisely the axisymmetric, classical transport expectation.
- ∴ MFIT can only suggest that, if the physical current distribution is not too hollow, then there might be mean-field closed surfaces.

What Does MFIT Tell Us About Existence of Closed Surfaces in CHI? - 2



- MFIT consistently returns modest closed flux regions when CHI-driven current is sufficiently high.
- Together with observations of simultaneous n=1 MHD activity,* this gives a tentative indication that CHI plasmas with mean-field closed surfaces are produced.
  - But cannot draw firm conclusion, as discussed in preceding slides.

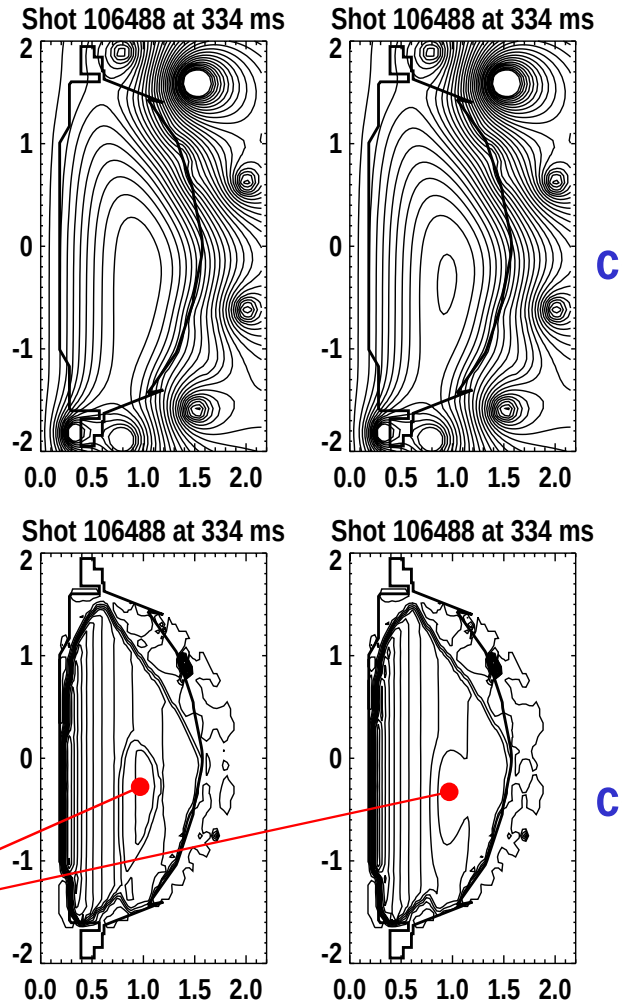
*B.A. Nelson et al., oral GO1.007, this meeting.

GENERAL ATOMICS

EFIT Obtains Fits with Small Closed Flux When CHI Current is Large

- Two example EFITs are shown here: shot 106488 at 334 ms, $I_p \approx 380$ kA.
- EFIT was run with parallel current throughout the thick SOL.
  - EFIT puts no current in private flux.
- These are poor fits ($\chi^2 \approx 750$ and convergence error ~0.05).
- EFITs much like MFIT (preceding page).
  - Modest closed flux.
  - J hollow in closed flux region.
  - MFIT $\chi^2 \approx 650$.

EFIT current is hollow here



EFIT

Flux contours

J_ϕ contours

GENERAL ATOMICS

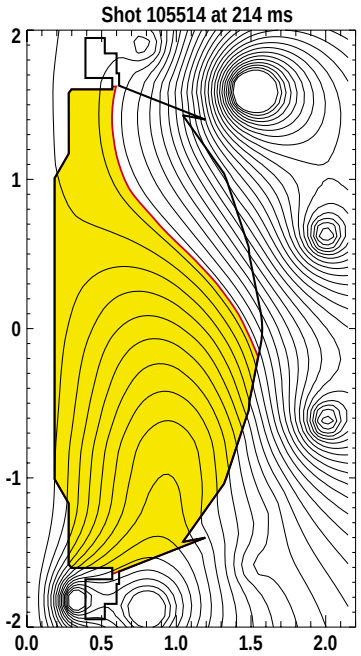
What Does EFIT Tell Us About Existence of Closed Surfaces in CHI?

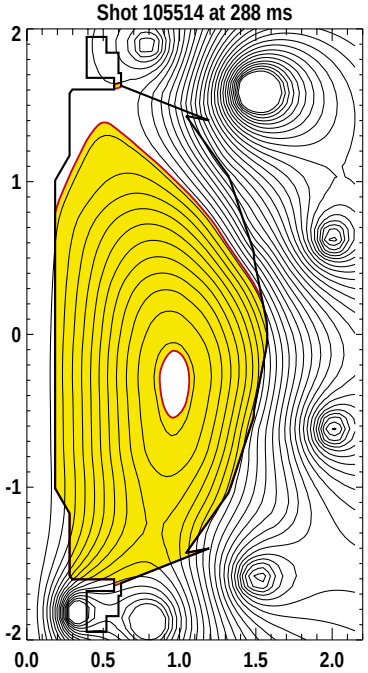
- EFIT has been run with large, force-free current in a thick SOL.
  - With SOL current extended out to 2nd (upper) X–point.
- EFIT is constrained by Grad-Shafranov equation.
- However, these fits during CHI are of very poor quality compared with the usual EFITs.
- As with MFIT, the evidence is weak, and we can only draw a tentative conclusion that mean-flux closed surfaces have been produced by CHI in NSTX.

We Need an EFIT That Works for ALL Open Surfaces, Where: Open Lines → Low β Plasma → J || B

- Method being developed uses the insulated gaps to define the minimum and maximum flux values that bound the current-carrying flux.

Examples:





- This works for some common topologies and geometries.
- It does not work once the closed flux is large; but then regular EFIT works.

Conclusions

- MFIT was improved.
  - Much less susceptible to spiky current distributions than before.
  - Well developed and in routine use for control room analysis.
- MFIT consistently shows modest closed mean-field flux during high-current CHI.
  - There is reason to believe that MFIT is pessimistic about flux closure.
  - Together with observations of n=1 MHD activity, this gives a tentative indication that CHI plasmas with mean-field closed surfaces are produced in NSTX. But cannot firmly conclude that there are closed surfaces.
- EFIT shows closed mean-field flux similar to MFIT at the highest attained toroidal plasma currents. EFIT does not work well at lower currents.
- EFIT is presently being modified to fit current in fully open configurations and in private flux and large SOLs.