Coil Design for NCSX: An Overview

by S. P. Hirshman (ORNL)

NCSX Coil Design Team

- A. Brooks, N. Pomphrey, D. Monticello (PPPL)
- P. Valanju, W. Miner (UTA)
- S. Hirshman, V. Lynch, J. Whitson (ORNL)
- M. Drevlak, P. Merkel (IPP-Greifswald), consultants

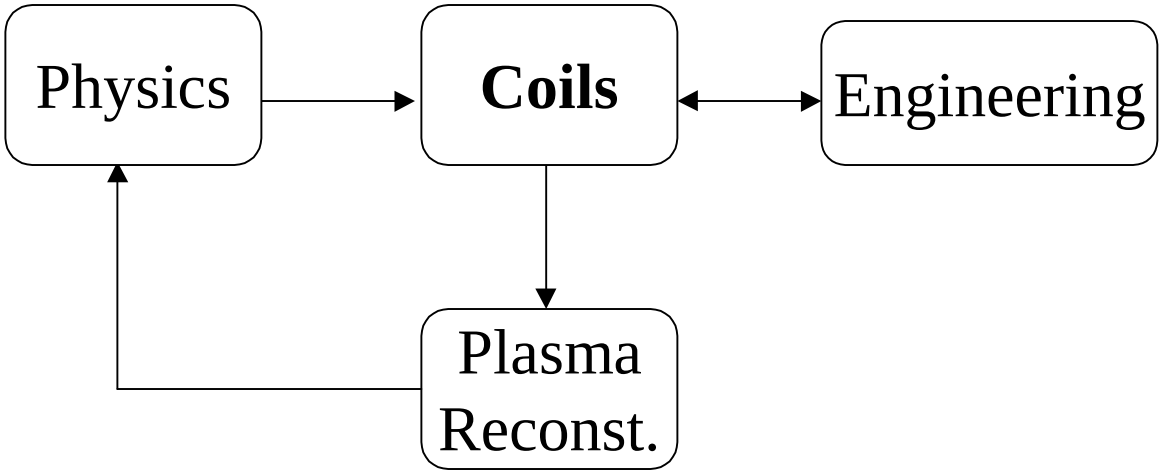
Outline of Presentation

- General consideration for the NCSX coil design (S. P. Hirshman)
- Coil design for the QAS-C10 configuration (A. Brooks)

Coil Project Goals

- Reverse-engineering of coils for NCSX
  - feasible (can be built)
  - preserve physics optimization goals (free boundary reconstruction)
- Develop error-correction coils
  - coil alignment
  - resonant error mitigation
- Coils for plasma scenario control

Context of Coil Reverse-Engineering



NCSX-Specific Developments

- NESCOIL Code (P. Merkel) extensions
  - Virtual casing principle (Shafranov/Zakharov) used for finite β (BNORM Code) and finite I_p
  - Ill-conditioning (Cauchy problem for elliptic pde) handled with **S**ingular **V**alue **D**ecomp-osition (SVD) => smoother coils at increased Δ
  - Minimize (resonant) displacement $B \bullet \nabla X = B^{\psi}$

Developments (cont'd)

- Improved coil-extraction algorithm
  - NESCOIL (current potential $\boldsymbol{K}$: $\boldsymbol{j} = \nabla s \times \nabla \boldsymbol{K}$) -> finite coils

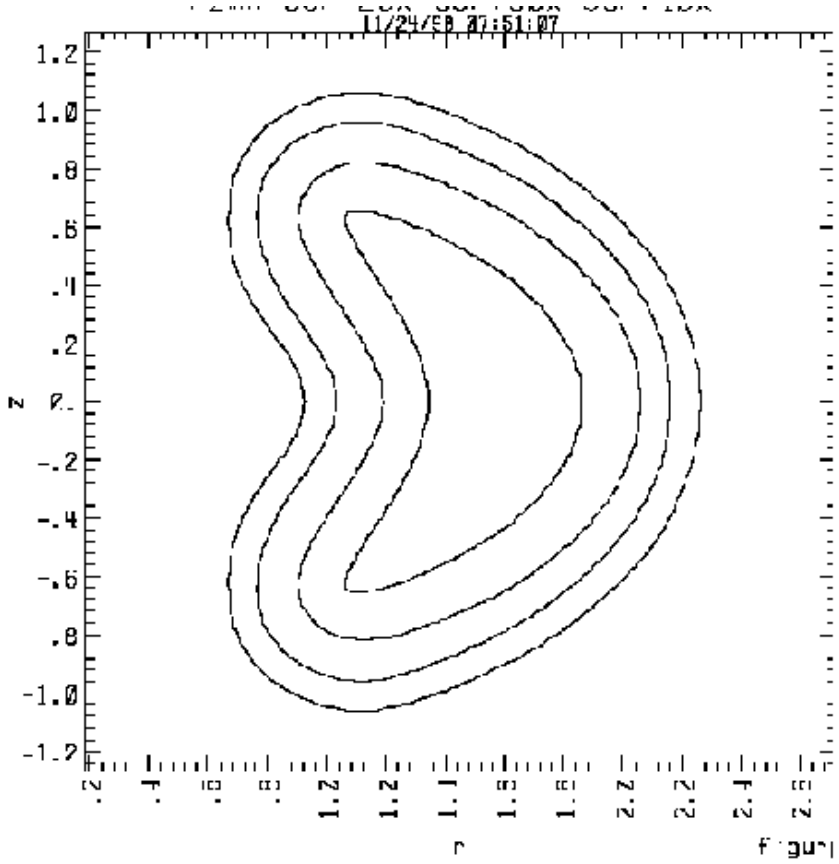
- Allowing coil properties to influence physics optimization
  - Complexity measure $|\nabla \times \boldsymbol{K}|^2$ (realizability:avoid Swiss-cheese effect)
  - Coil-to-plasma separation, $\boldsymbol{j}$, B_{coil}/B_{plasma}

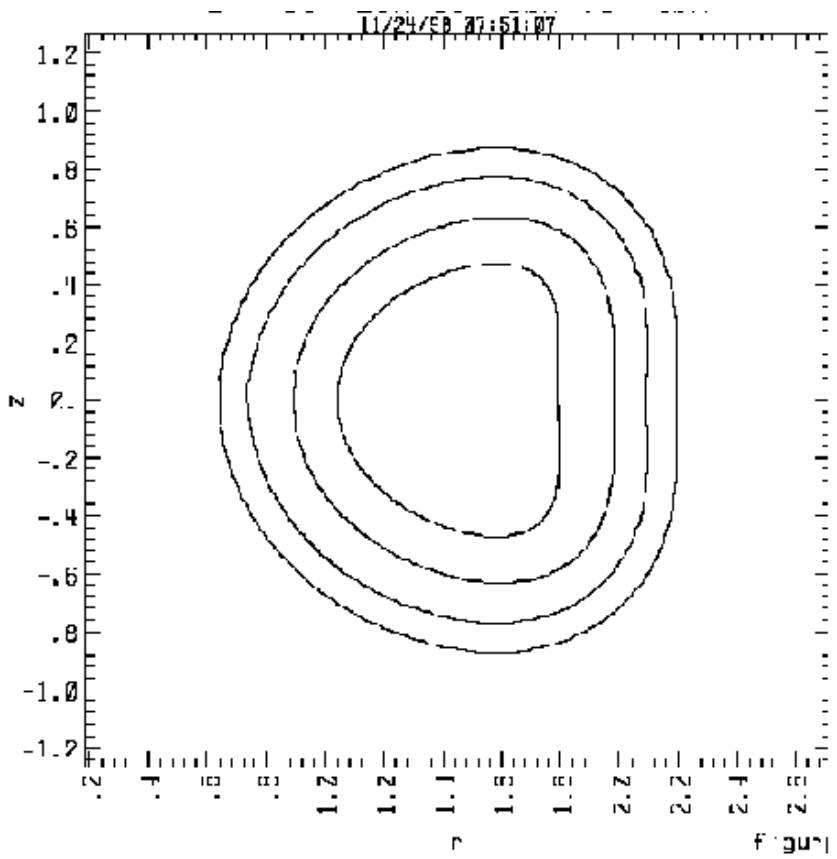
Sample Saddle Coil Calculation for QAS3_C10

- Illustrating effects of numbers of coils and SVD-smoothing (reduce $P = \lambda_{max}/\lambda_{min}$)
  - Current sheet (reconstructs well)
  - 11 coils/period : about same as CS
  - 5 coils/period: feasible, not reconstructing well

- Cases shown here are for 40 cm separation

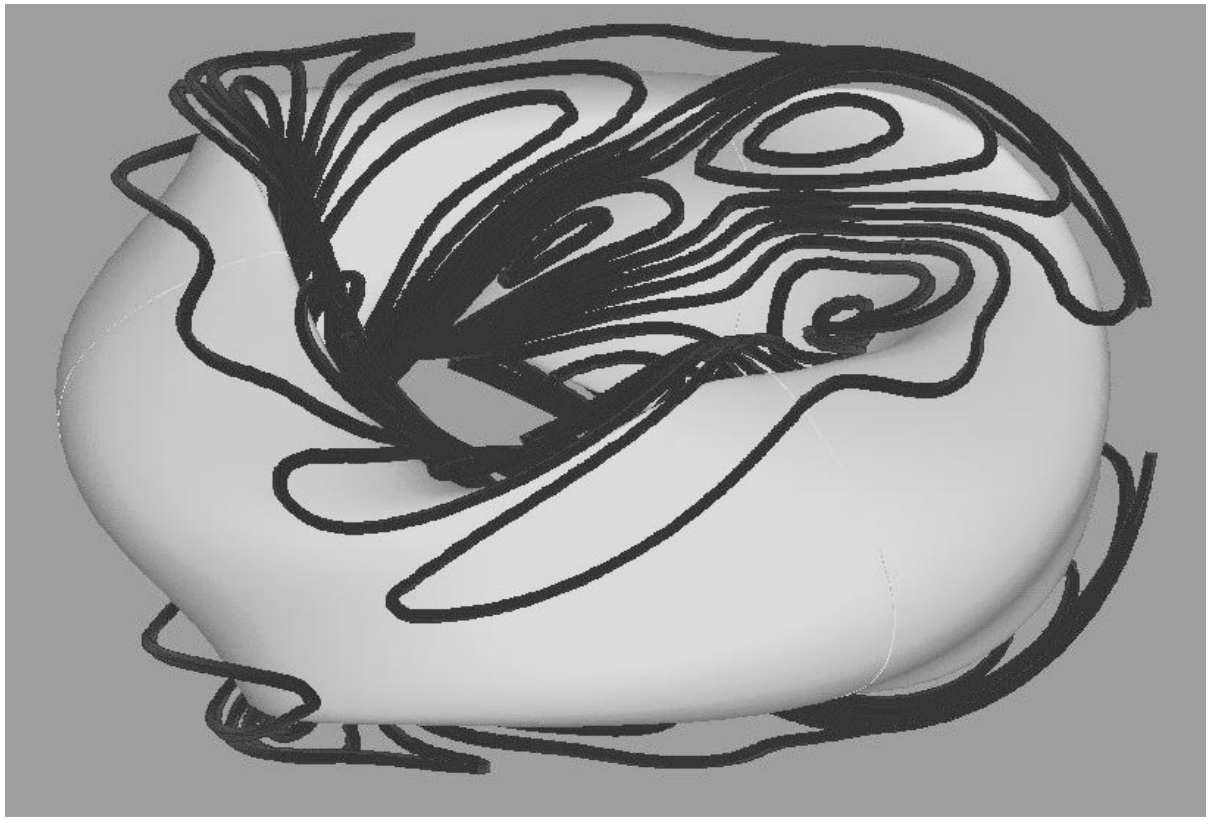
Winding surfaces at 20,30,40 cm. separations from plasma





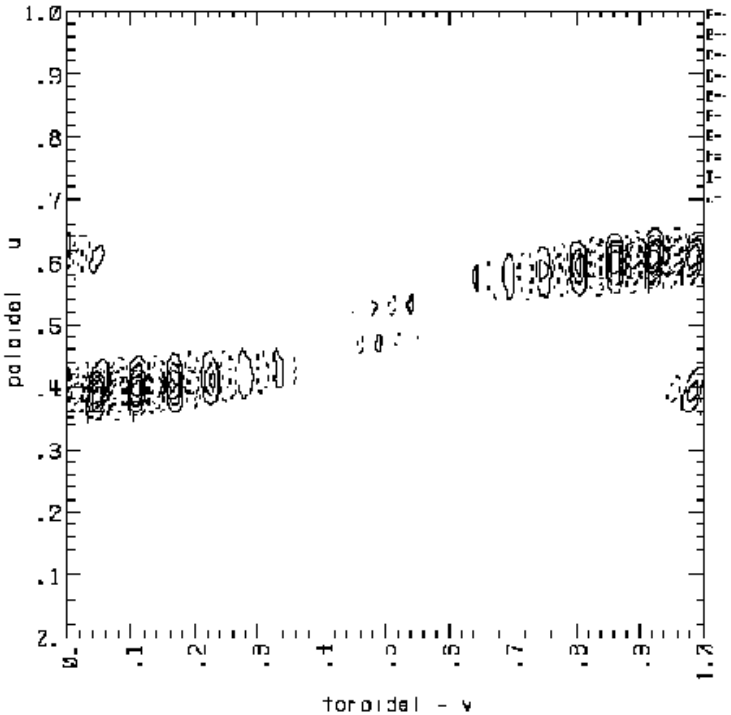
What are saddle coils?

- No net TF, PF currents: PBX-M option



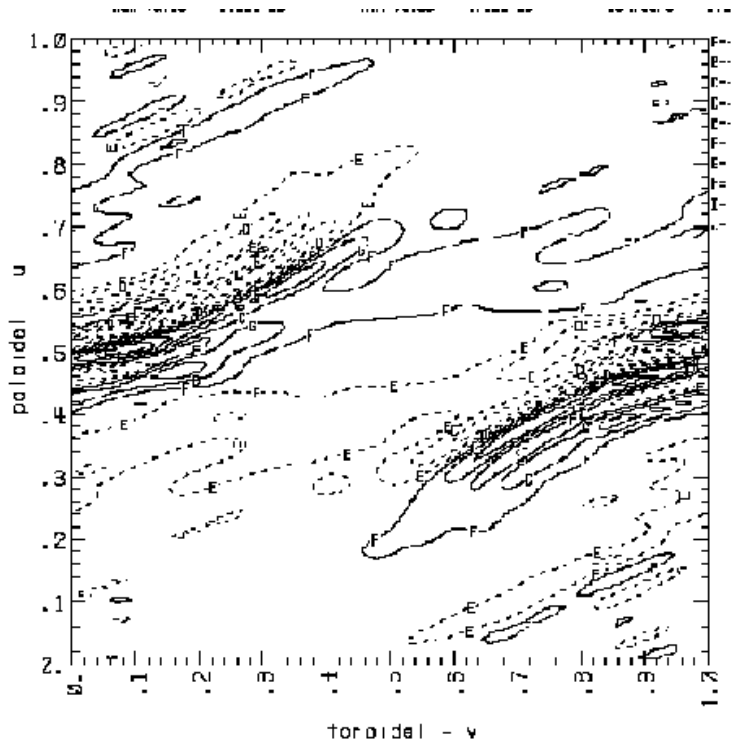
Current Sheet (P_{cond} = 4 X 10^9)

- No SVD smoothing (δB_{max} = 0.34 %)



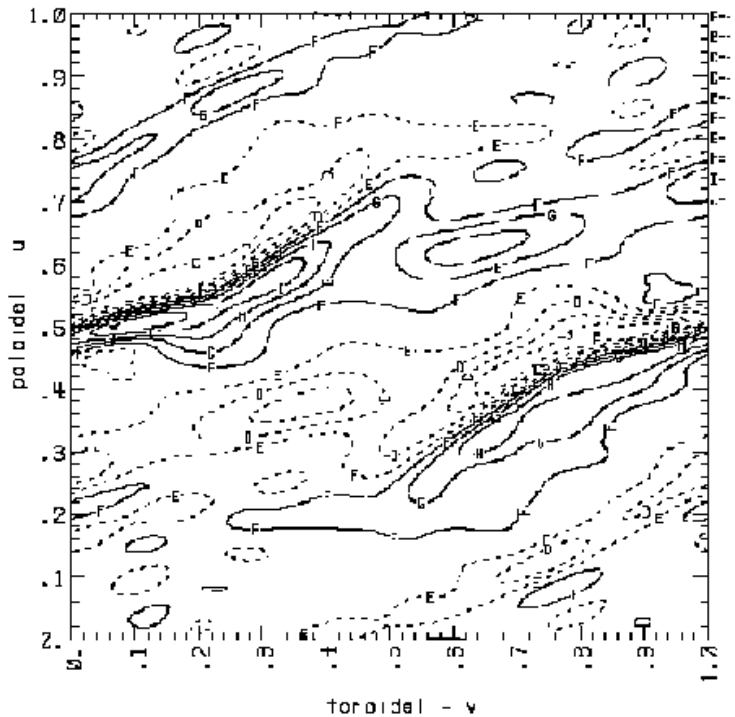
Current Sheet: (P_{cond} = 140)

- SVD Smoothing (δB_{max} = 1.60%)



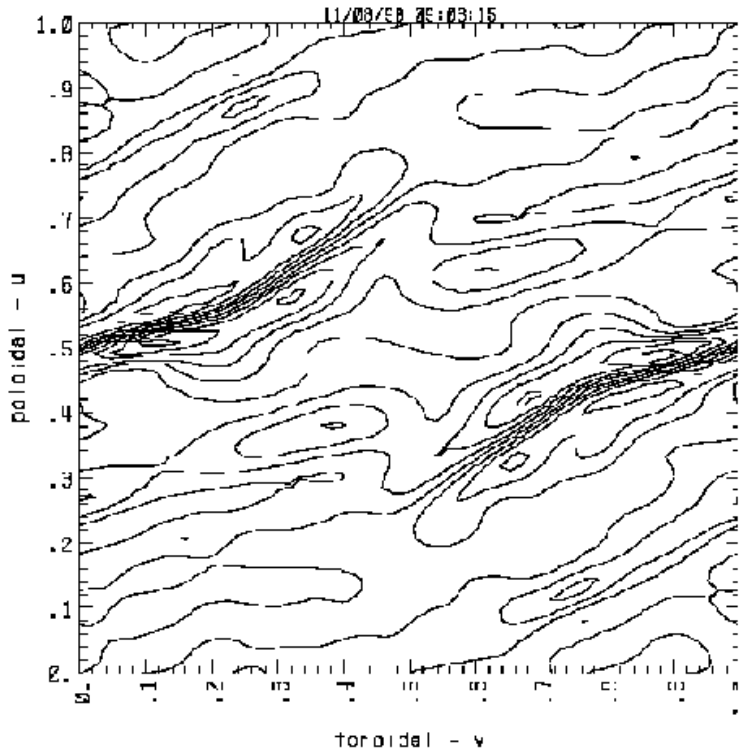
Current Sheet (P_{cond} = 20)

- More SVD Smoothing (δB_{max} = 3.18%)



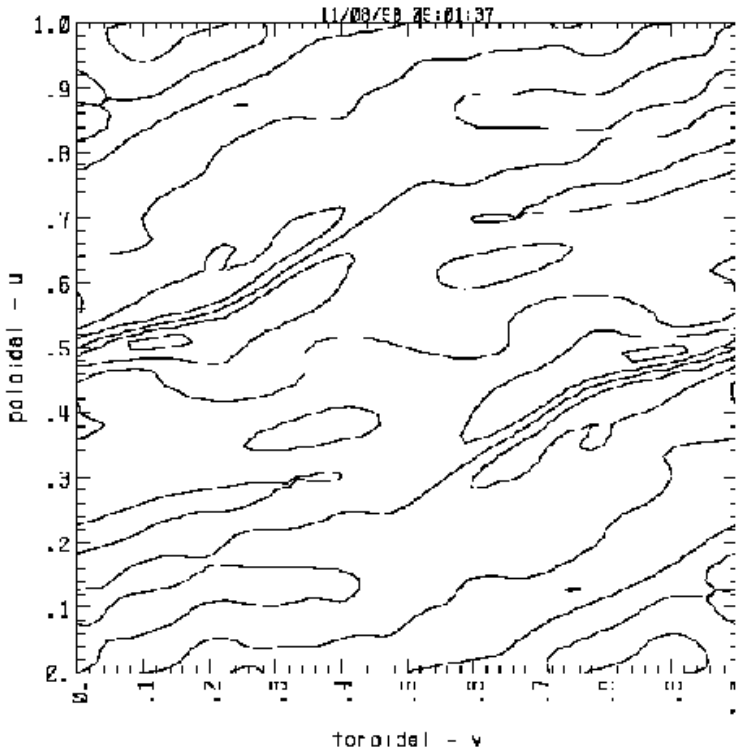
11 Coils/Period (P_{cond} =)

- SVD Smoothing (δB_{max} = 3.99%)



5 Coils/Period (P_{cond} =)

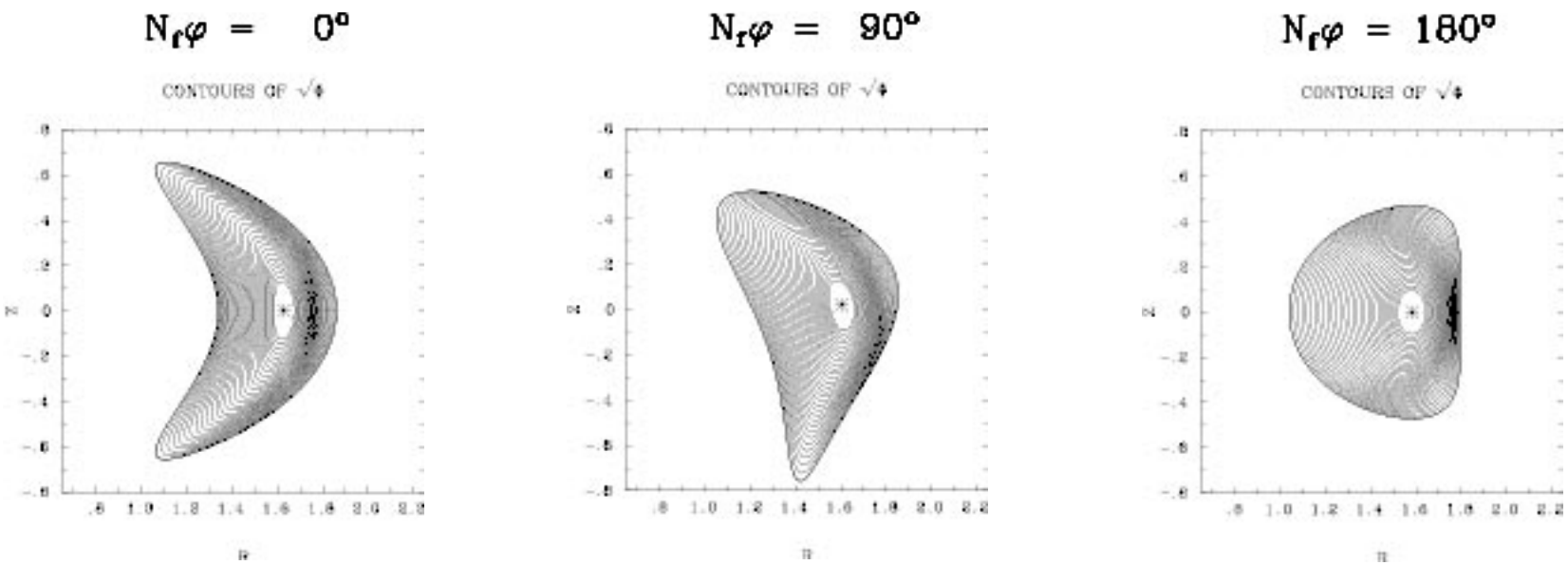
- SVD Smoothing (δB_{max} = 14.55%)



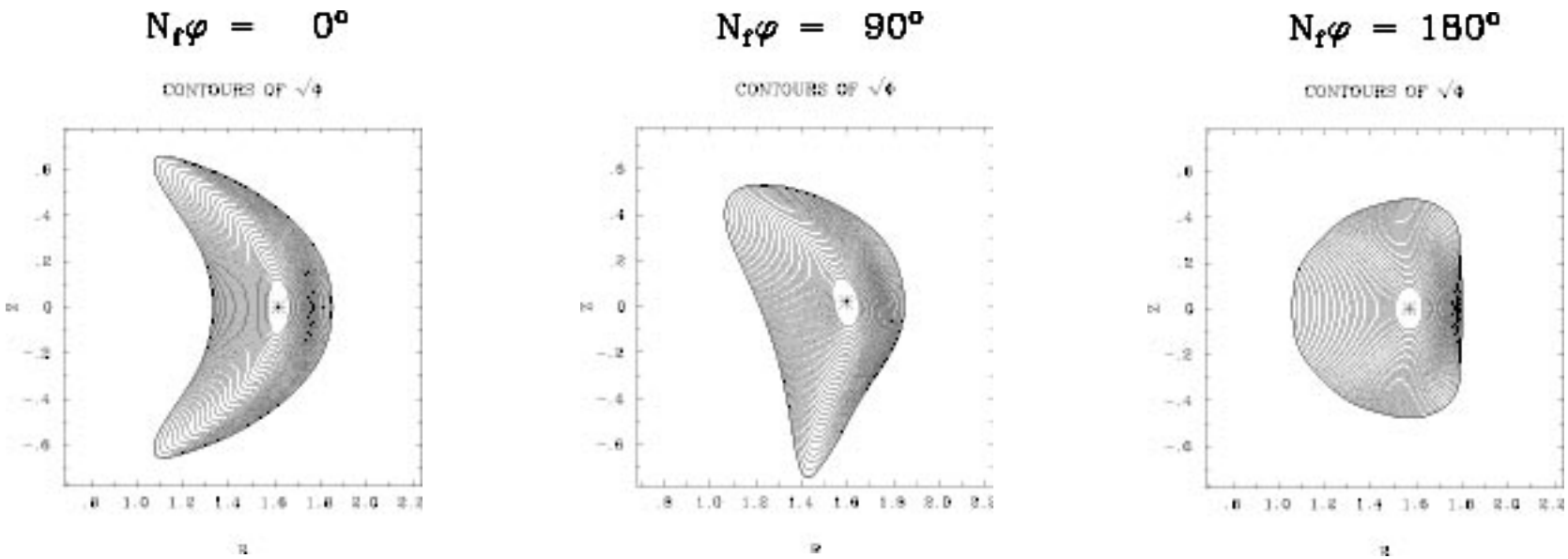
Plasma Physics Reconstructions

- Free-boundary *VMEC* code using coils
  - Match B^2 across plasma/vacuum interface
  - Uses *NESCOIL* (Green's function) module
    - find B_{vac} with $B_{norm} = 0$ at interface

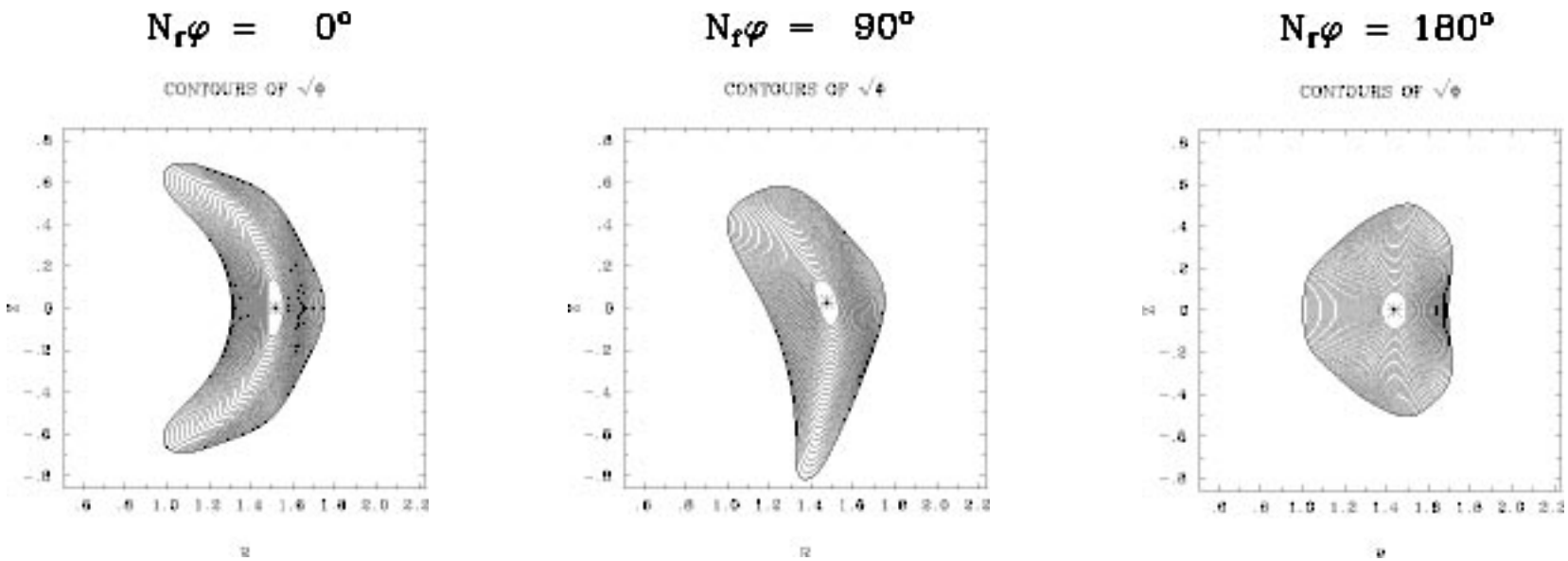
Original QAS Equilibrium



QAS Reconstruction Using 11 Coils Per Period (40 cm)



QAS Reconstruction Using 5 Coils Per Period (40 cm)



Accomplishments

- Extended standard NESCOIL suite to deal with current, pressure
- Successfully coupled discrete coil codes and free-boundary *VMEC*
  - Reconstruction and preservation of physics demonstrated for current sheet solutions
  - Error reduction with finite coils (< 11 / period): work in progress

Future Directions

- Finite radial builds
  - Impact on reconstruction and field errors
- Control resonant errors
  - correlate *PIES* to free-boundary reconstruction
- Compute forces in low *A* geometry
  - German codes, support available (Kisslinger)
- Reactor-relevant coil designs