NCSX
Physics Configuration Development

M. Zarnstorff
PPPL

NCSX PAC-4
1 August 2000

Outline

- Goals $\rightarrow$ Requirements
- Previous status - C82
- New Configurations
  - Characteristics
  - Decisions
- Further developments and Plans

NCSX Goals

- Test high-beta disruption-free operation, compatible with bootstrap & external transform, at low aspect ratio
- Determine beta limits and limiting mechanisms
- Reduce neoclassical transport by quasi-axisymmetric (QA) design
- Reduce anomalous transport by flow-shear control, using reduced flow damping by QA design
- Stabilize neoclassical tearing-modes by design of magnetic shear
- Test compatibility with power and particle exhaust methods

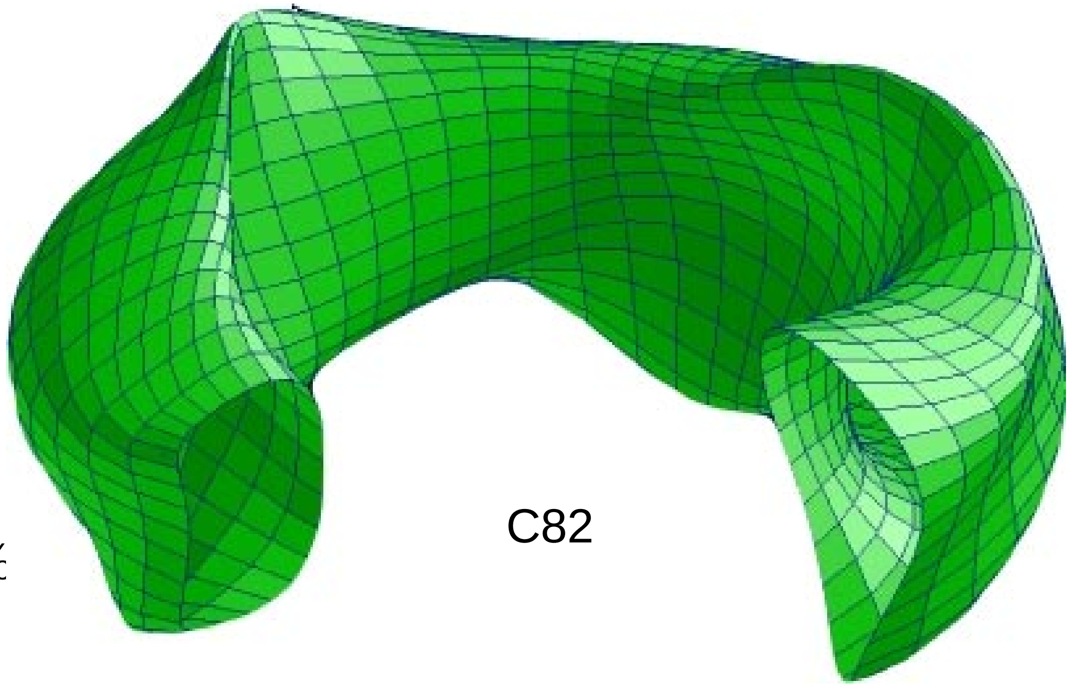
Requirements

- MHD stable design (up to β ~ 4%)
- Adequate power & confinement to access beta limit
- Good flux-surfaces
- Flexible coils
  - Coils must allow a range of operation: profiles & physics flex.
  - B range 1 – 2 T, for scaling studies
  - ~0.7 sec flattop at 2T
  - ~1.5 sec flattop at 1T, ultimate capability

  Based on previous experiments and simulations

$\Rightarrow$ Need low coil current density to allow flexible operation

Previous Configuration Stable at $\langle\beta\rangle = 4\%$



- 3 periods, $\langle A \rangle$=3.4
  Quasi-axisymmetric
- Stable to ballooning, kink, vertical, mercier modes without conducting wall or feedback control at $\langle\beta\rangle$=4% (limited by kink)
- Bootstrap-like current profile, increases iota.
- Stellarator shear ($dq/dr < 0$), for neoclassical island stabilization
  - Without need for ECCD feedback

C82 – Is Marginal

- Coil current densities large $\Rightarrow$ limited flexibility
  - Saddle coils: 27 kA/cm^2 for 2T
  - Modular coils: 15 kA/cm^2 for 2T
- Flux surface quality – poor
  - Good surfaces for vacuum and low beta, full current
  - Field-lines stochastic outside r/a ~ ¾ for $\beta \geq 3\%$
- Transport optimization – marginal
  - significant NBI orbit losses and thermal ion neoclassical transport
  - transport optimization marginal to access β-limit 6MW

Improved Tools to Target Issues

- PIES 3D Equilibrium code
  - Vastly faster (10x) -- now part of design process
  - Improved free boundary implementation
  - Incorporation of neoclassical-island effects being benchmarked
- VMEC 3D Equilibrium code
  - Greatly improved convergence vs. number of modes (2½x)
  - Improved force balance in 3D
- Optimizer
  - Added NESCOIL, to target coil characteristics
    J_{max}, Coil-complexity, B-normal error
  - Improved transport targets
    DKES, ε_{eff}, fast-ion confinement, J contour alignment.

A Large Region has been Explored

C. Kessel, L.-P. Ku, A. Reiman

- Aspect ratio, A: 3 – 5 (outside PBX-M constraint)
- Average elongation up to 3 (exploiting robust vertical stability)
- 2, 3 periods
- edge iota $\iota(a)$: 0.47 – 0.78
- vacuum magnetic well – suggestions from P. Garabedian

→ β-limits up to 7%

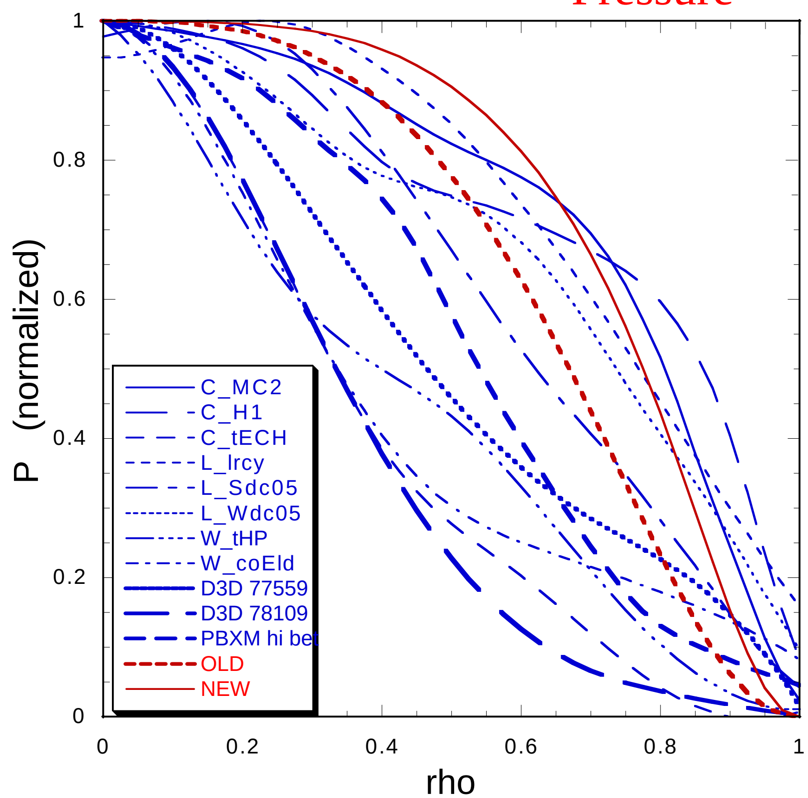
→ external transform fraction at β-limit: 60% – 81%

- Major distinguishing characteristics: flux-surface quality & Coil J_{max}

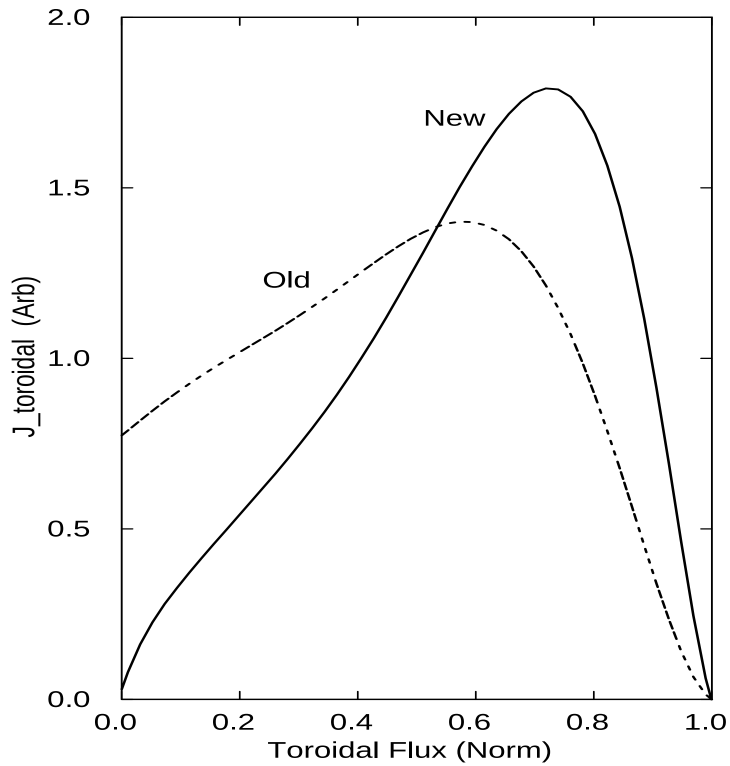
- Two promising configurations have been identified

Slightly Broader Profiles Used

Pressure



Toroidal Current



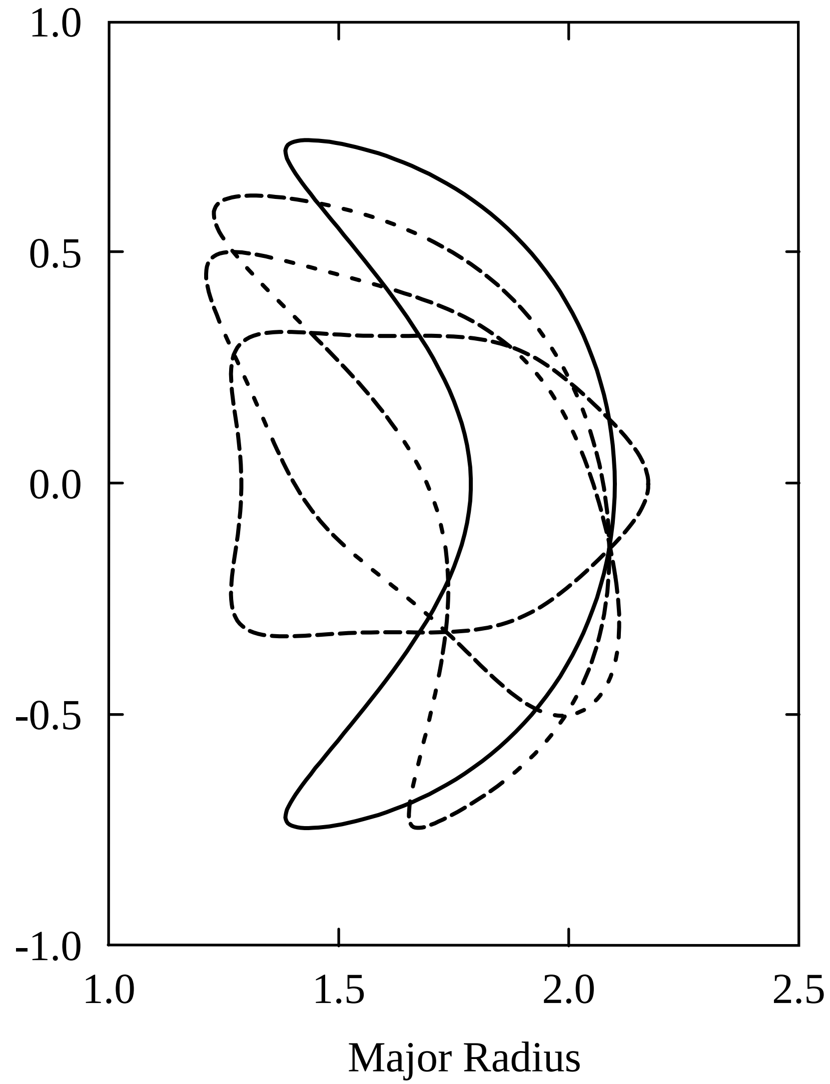
- Both pressure profiles within observed range
- Old pressure and current from Aries, needed seed & edge CD
- New current profile shape consistent with bootstrap current from new pressure profile

Attractive 3-Period Configuration

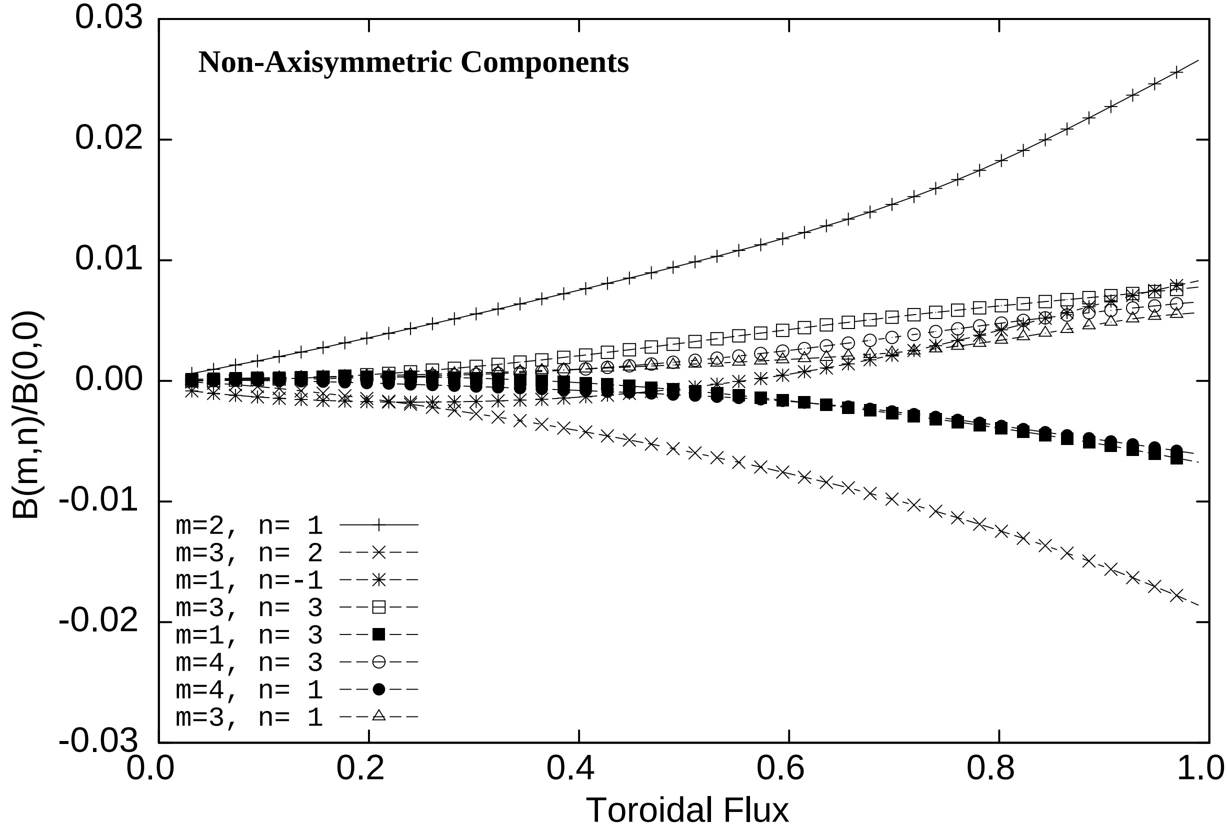
- 3 periods, ⟨A⟩=4.4, ⟨κ⟩~1.7
- Stable to ballooning, kink, vertical, Mercier at β=4.1%
- Limited by ballooning, should be able to optimize profiles
- Good flux surfaces, except one significant island chain
- Saddle-coil current density ~ ½ of C82, less complex
- Narrow waist in elongated cross-section (32 cm FW)

⇒ need neutral control & analysis.

LI383



3-Period has Improved Transport

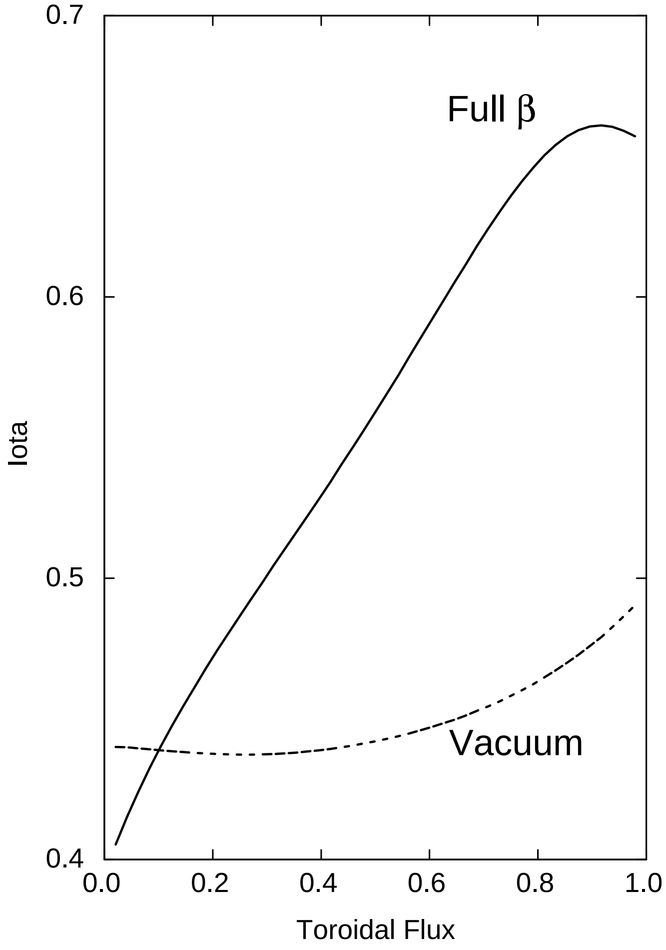


- Effective ripple reduced 40% at r/a~0.7 from C82
  $\Rightarrow$ < ½ the helical neoclassical transport.
- Neutral beam fast ion losses ~19% at 2T vs. 23% for C82

3-Period iota crosses ½

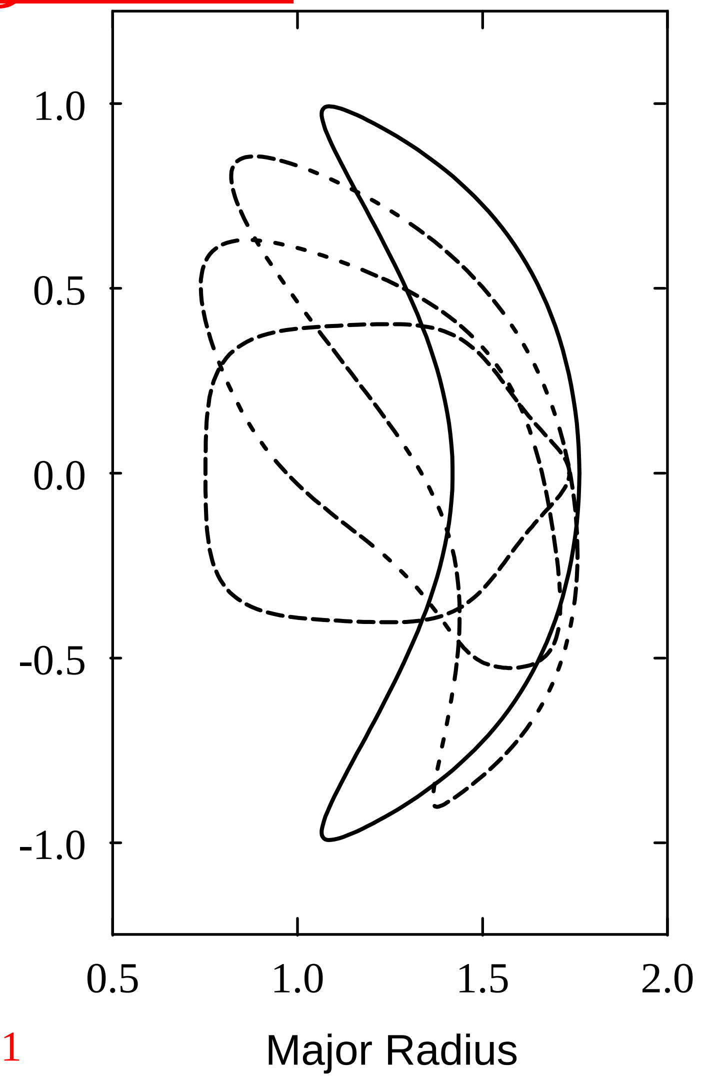
- Full-β, full current iota crosses ½
  - Can produce disruptions in W7-AS, Especially when crossing near edge
- Δ′ calculations (Knowlton) show tearing stability (cylindrical approx.)
- Vacuum iota everywhere below ι = ½ ⇒ edge will pass thru ½ (q=2) during ramp up, may be disruption prone

⇒Need flexibility to start above ι = ½



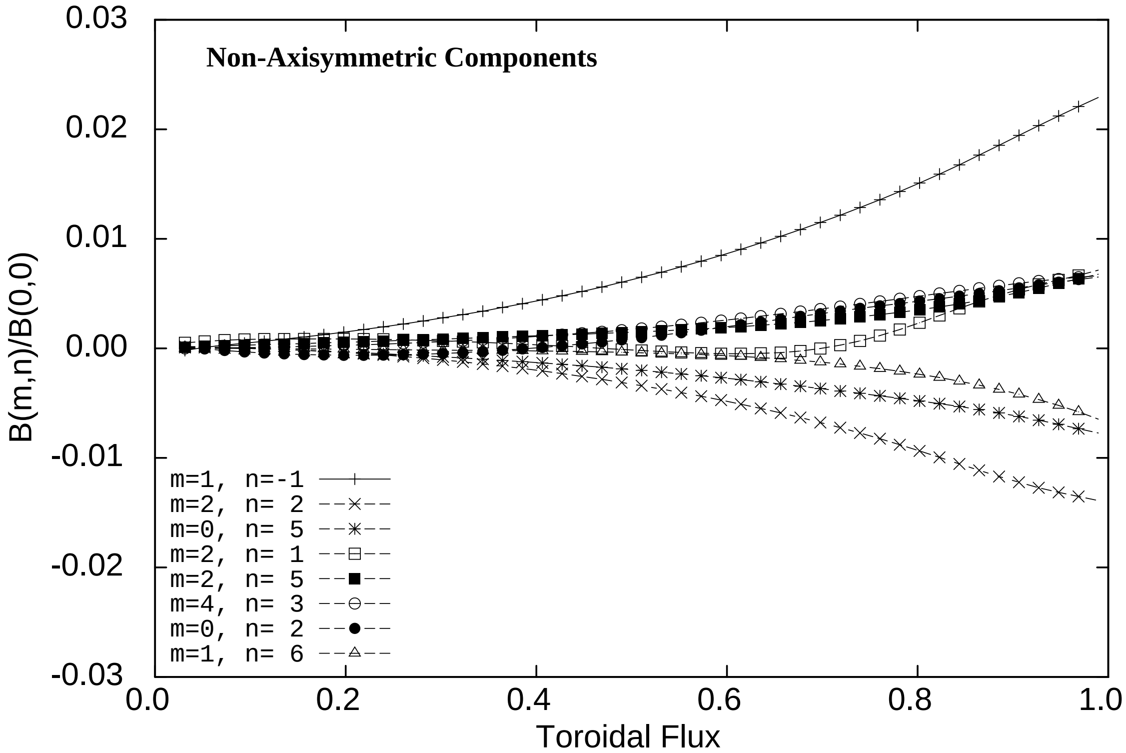
Attractive 2-Period Configuration

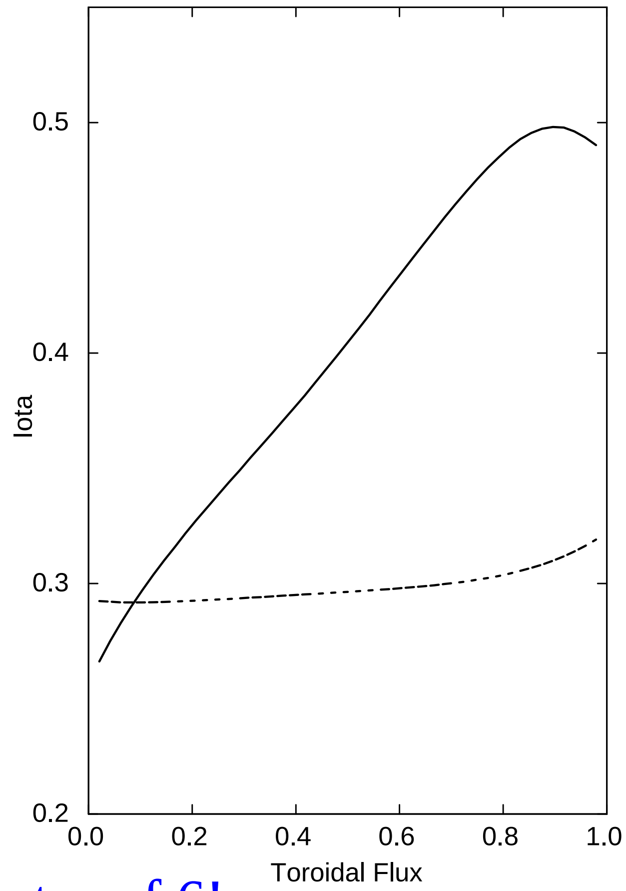
- 2 periods, ⟨A⟩=2.96, ⟨κ⟩~2.1
- Stable to ballooning, kink, vertical, Mercier at β=4.0%
- Limited by ballooning, should be able to optimize profiles
- Good flux surfaces, except one significant island chain
- Sheet-currents less complex than C82 Coils?



II2101

2-period: Extraordinarily Low Transport





- Effective ripple ~0.3% at r/a~0.7, 1/3 of C82
  ⇒ helical neoclassical transport reduced by factor of 6!
- Neutral beam fast ion losses reduced by factor 2!
- Iota < ½ everywhere

Near-Term Decisions & Activities

- Decision between 2 & 3 period configurations
- Decision between coil topologies

- Remove remaining islands in configurations
  - Effect on physics and coils
- Coil design for 2-period configuration
- Free-boundary PIES reconstruction from coils
  - Flux surface quality and robustness
- Flexibility assessment of coil designs

Conclusions

- Two exciting new configurations have been identified
  - 3 period: higher iota, low coil current density
  - 2 period: very compact, extraordinary quasi-symmetry
- All of the issues with the old configuration have been addressed
  - Flux-surface quality, coil currents, transport optimization
- Will investigate coil designs, free-boundary flux-surface quality, and flexibility to decide between them.