The Stellarator Effort in the PPPL Theory Group

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The Stellarator Effort in the PPPL Theory Group

- Played a major role in guiding design of NCSX.
- Addressing key issues for CDR.
- Has also contributed to design of other domestic experiments.
- Planning to increase focus on tool development and on fundamental stellarator physics issues, and to increase participation in ongoing stellarator experiments.

NCSX Design and PVR

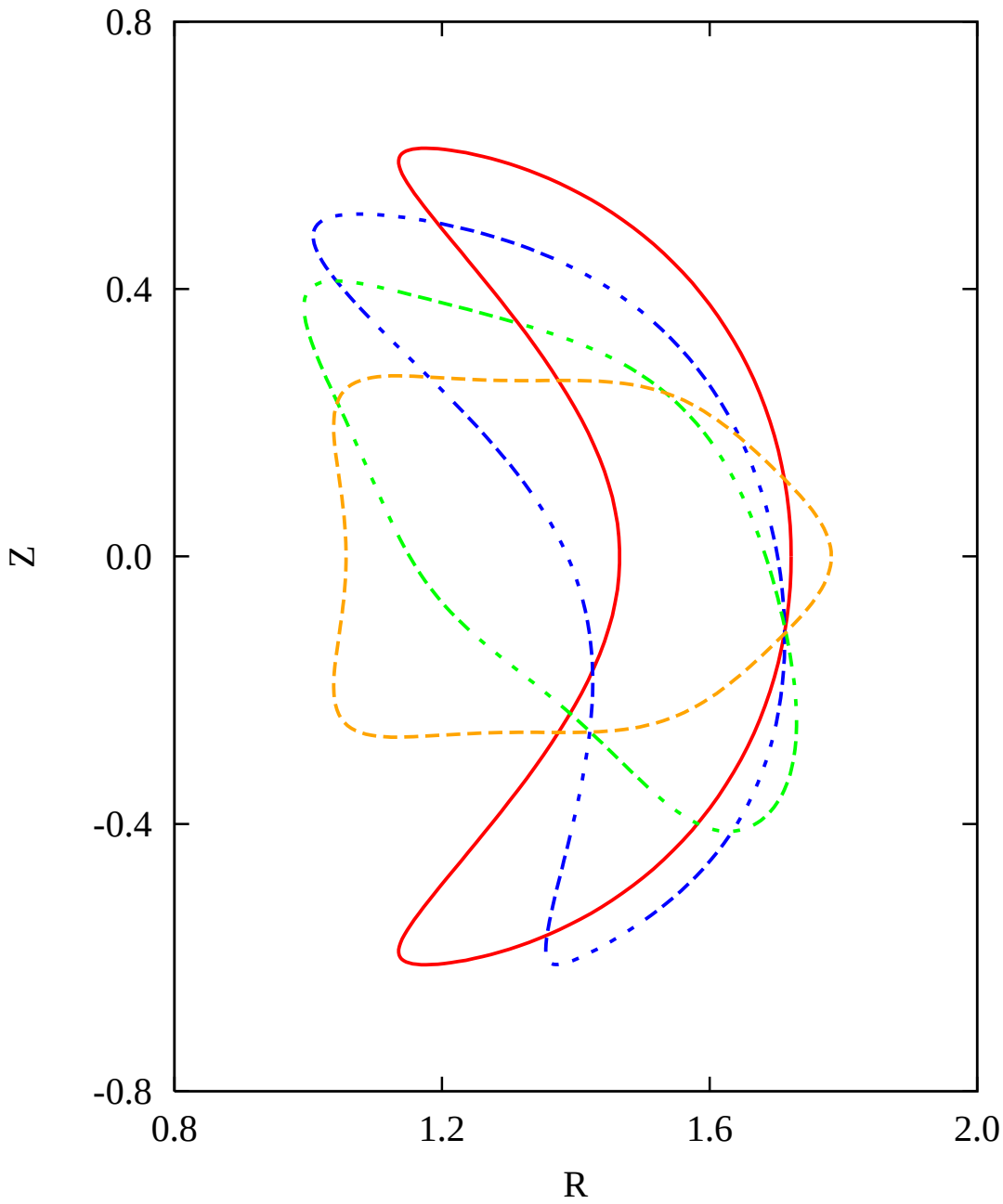
G. Fu, S. Hudson, J. Lewandowski, Z. Lin, D. Monticello, H. Mynick, N. Pomphrey, A. Reiman, R. White

PPPL theory group played major role in guiding design of NCSX and addressing key physics issues for PVR.

- Ballooning stability
  - β limits of previous quasi-symmetric designs < 2%.
    Lack stabilizing mirror term of W7X-like devices.
  - Problem solved by development of innovative quasi-axisymmetric design with strong axisymmetric shaping.
- Design strategy: Morph advanced tokamak to quasi-axisymmetric stellarator, preserving good ballooning stability.

Configuration LI383

Axisymmetric components of shaping give good ballooning stability properties.



NCSX Design (continued)

- Kink stability
  - Large tokamak-like bootstrap current a problem.
  - Systematic studies of stabilization via externally generated shear.
  - Introduced stabilizing corrugation via Furth-Hartman coils, and later through optimizer.
- Neoclassical confinement: PPPL codes GCC, GTC and Orbit (as well as ORNL codes) used in assessing adequacy of quasi-axisymmetry for thermal and energetic particle confinement.
- Coil design: contributions to ORNL activity.
- Free-boundary configuration flexibility studies. (Pomphrey talk)
- Flux surfaces. (Reiman talk)
- Continuing contributions to CDR.

The Theory Group Has Also Contributed to the Design of Domestic Stellarator Experiments other than NCSX

- QPS – Guoyong Fu and Don Monticello shared in ORNL Scientific Research by a Team Award.
  - MHD stability calculations – Fu.
  - PIES calculations – Monticello.
- CTH stability calculations – Fu.
- Nonneutral confinement device being proposed by Pedersen at Columbia. Pomphrey – contributions to optimization of coil design.

Stellarator Theory Plans

Development and application of computational tools and fundamental theory for stellarators.

A. Development and application of major codes.

- PIES
- Transport codes
- M3D
- HINST

B. Development of fundamental 3D theory.

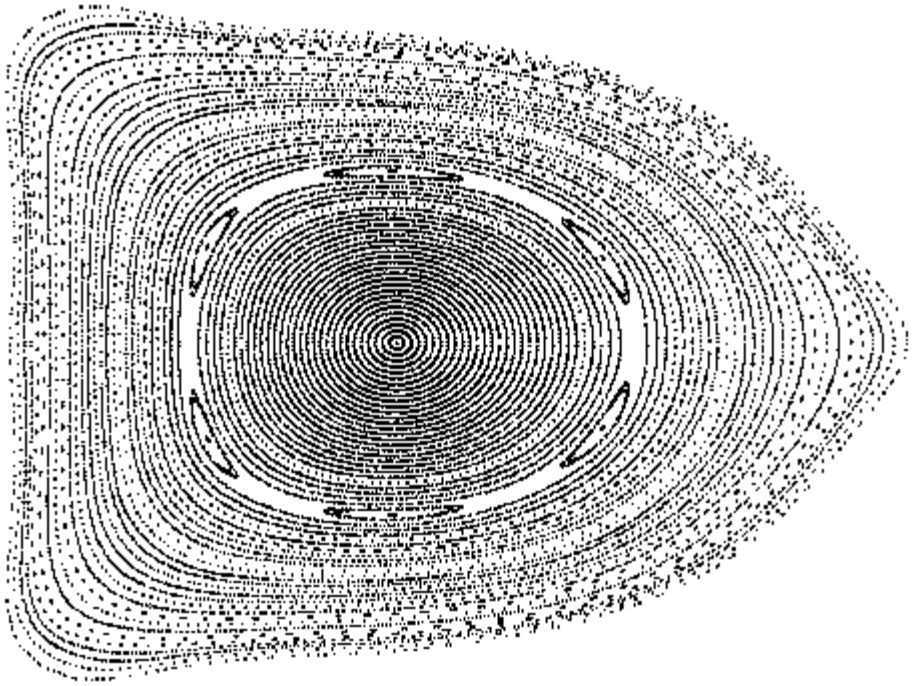
- Collaboration with Wisconsin on ballooning and island physics.
- Profile reconstruction from experimental data.
- Topography of stellarator design space and global optimization.

C. Application and benchmarking of tools via LHD collaboration.

(Nazikian talk)

The PIES Code (Monticello, Hudson, Reiman)

Near term focus: CDR (coil design, robustness of surfaces).



Over next year:

- Island physics studies. (collaboration with Hegna)
- Improvement to free-boundary calculations to facilitate comparison with experiment and edge modeling.
  - Capability to move reference surface further from plasma
  - Support for users wanting to do comparison with experiments (e.g. Nakamura – Heliotron-J, Merkel – W7AS, Salas – TJII)
  - Support for edge modeling (Grossman, Koniges)

The PIES Code (continued)

Over next year:

- Benchmarking: HINT, M3D
- Support for users wanting to apply and to help develop the code: Drevlak (Germany), Deshpande (India)
- Algorithm improvements.
  - Speeding up subroutines (e.g. by splining new diagnostics)
  - Accelerated convergence via improved underrelaxation scheme.
  - Modification of grid for calculating current – to smooth and accelerate convergence.

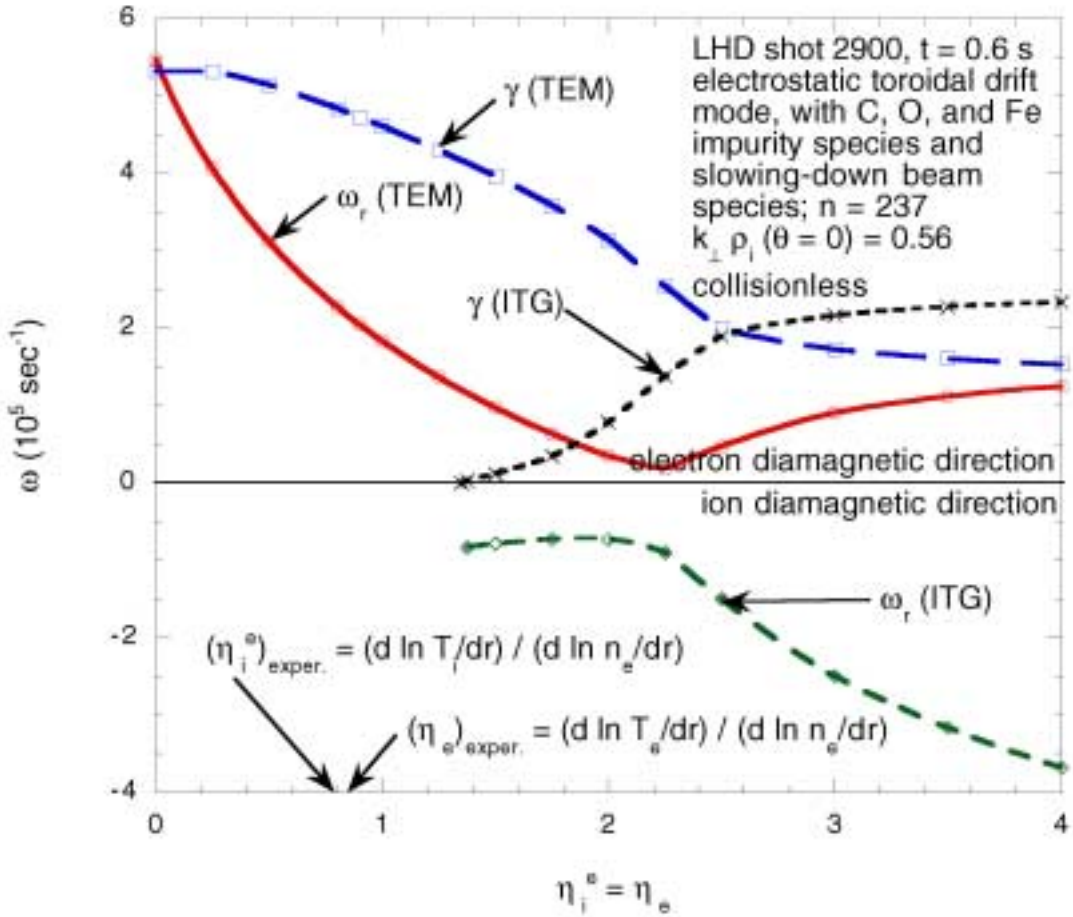
Longer term:

- Neoclassical effects. Benchmark against DIII-D, LHD, etc.
- Parallelization – May be necessary to make full torus calculations practical.

Transport Codes

Full (Rewoldt)

- Electrostatic, linear microinstability code.
- Being applied to LHD. (Nazikian talk)



Transport Codes (continued)

GS2

- Flux tube, gyrokinetic code.
- Bill Dorland's code, converted to stellarator geometry by E. Belli, graduate student working for G. Hammett.
- To be applied to LHD by D. Mikkelsen. (Nazikian talk)

GTC (Lin, Lewandowski)

- Global gyrokinetic code.
- Neoclassical version has been used in NCSX design.
- Version capable of studying turbulent transport being converted to stellarator geometry. To be completed within 1 year.
- To be applied to LHD by Rewoldt. (Nazikian talk)

Plans for Development and Application of Major Codes (continued)

M3D (Strauss, Park, Jardin, Fu, Hudson)

- Resistive time-dependent MHD code being converted to stellarator geometry primarily by H. Strauss (NYU).
- G. Fu to contribute to studies of nonlinear MHD instabilities.
- S. Hudson to benchmark equilibrium island calculations against PIES.

HINST (Gorolenkov, Cheng, Nakajima)

- Kinetic ballooning capability to be converted to stellarator geometry in collaboration with Nakajima (NIFS, Japan).

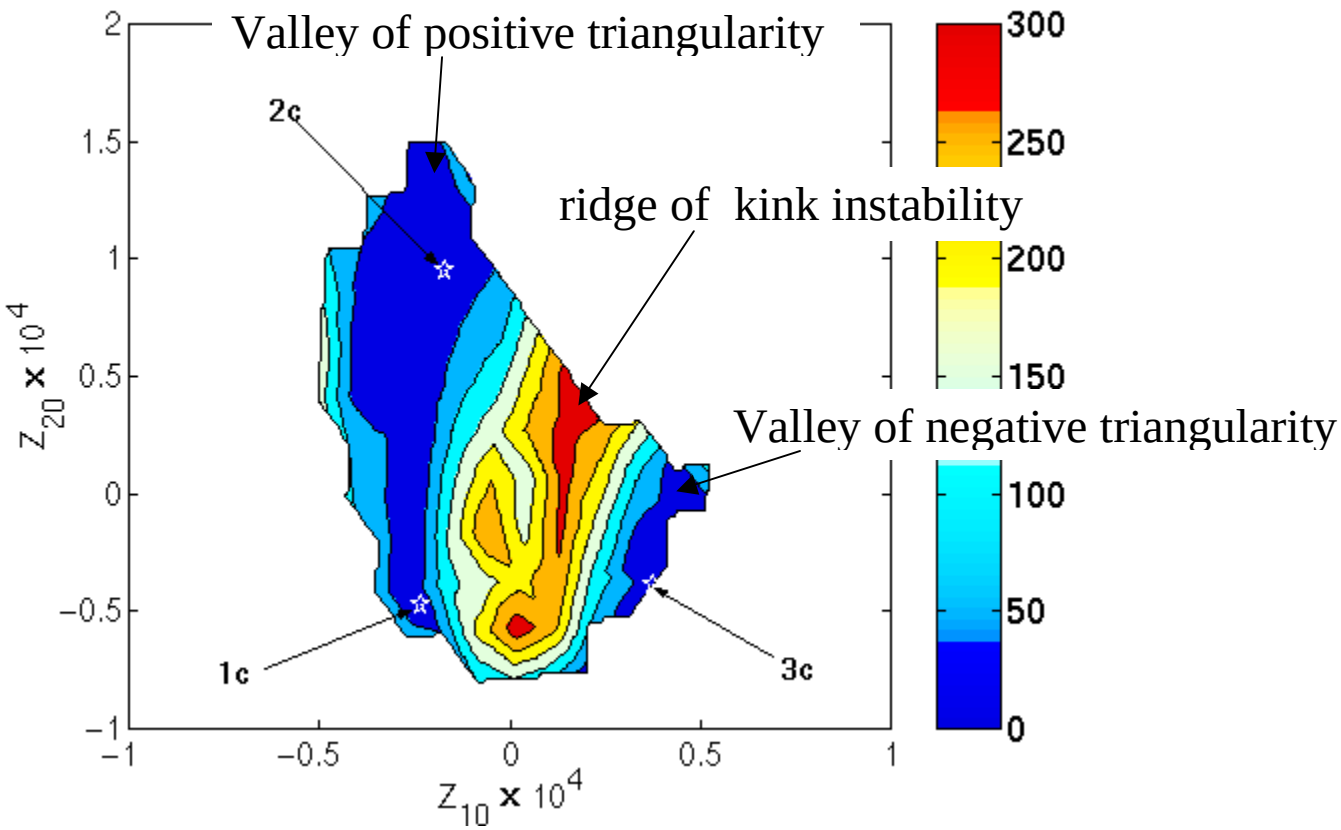
  Expected completion: this spring.

Longer term – Energetic particle calculations via HINST and NOVA.

Development of Fundamental 3D Theory

- Collaboration with Wisconsin (Hegna et al)
  - Ballooning (Hudson): continuation of work initiated as postdoc at Wisconsin
  - Island physics (Hudson, Monticello, Reiman): Comparison of PIES calculations with analytic models of Hegna et al.
- Current and pressure profile determination from information about the shape of the flux surfaces. (Mynick and Pomphrey)
  - Generalization of 2D work of Christiansen and Taylor to 3D.
- Stellarator optimization. (Mynick and Pomphrey)
  - Feasibility of global optimization.
  - Topography of stellarator design space.

- GLOBAL SEARCH provides map of stellarator configuration space :
- Contour plot of target function shows relations among wide range of QASs:



- Previously identified attractive QAS configurations fall into small number of 'basins'
  - 1c = contains configurations LI383 and II75
  - 2c = contains configuration PG2
  - 3c = contains configurations C82 and A4k2

LHD Collaboration

- Transport modeling
  - Microinstability calculations with FULL code
  - GTC calculations planned
- Kinetic ballooning – HINST code
- Energetic particle calculations via HINST and NOVA planned
- MHD
  - PIES provides true free-boundary calculation of flux surfaces (unique).
  - PIES to be applied to LHD equilibria and compared with HINT and VMEC calculations.

Further details in Nazikian talk.

Conclusions

- Theory group has played crucial role in NCSX design effort, solving critical problems and defining some key features of the configuration.
- Has also contributed to the design of other domestic experiments.
- Near term priority: CDR.
- Beyond CDR: Planning to increase focus on tool development and on fundamental stellarator physics issues, and to increase participation in ongoing stellarator experiments.