Power and Particle Control in NCSX

NCSX

NCSX Boundary Group:

P. Mioduszewski, J. Schmidt, A.Grossman, M. Fenstermacher, H. Kugel, D. Stotler, T. Rognlien, D. Hill, B. Nelson, M. Cole, M. Ulrickson

prepared by

Peter Mioduszewski

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Motivation and Goals of the Plasma Boundary Program

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- **Experimental evidence clearly demonstrates that control of neutrals and impurity influx is a prerequisite for enhanced plasma performance.**

  Based on this experience, the plasma boundary program has a primary and a secondary goal:

Goal 1

- **Support the mission and objectives of NCSX and provide the necessary conditions for improved confinement, high beta, and pulse length.**

Goal 2

- **Create the knowledge base for understanding divertor physics for future compact stellarators**

Magnetic Topology of the Plasma Boundary

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- **We have set up the computational tools needed to explore the complicated boundary topology of NCSX:**

- **To calculate the free boundary equilibrium required to provide the magnetics inside the LCMS, we use the VEMEC code.**

- **For the field topology outside the LCMS we use a code originally developed for W7-X (Strumberger), the 'Magnetic Field Solver for Finite Beta Equilibria' (MFBE).**

- **The MFBE code calculates magnetic fields of finite-beta, free-boundary equilibria with toroidal currents.** *(Previously, only vacuum fields outside the LCMS have been calculated.)*

- **The Gourdon code is then used for field line tracing once the MFBE magnetic fields have been calculated.**

Poincaré Plots of Field Lines Started Outside the LCMS Indicate Preservation of Initial Ordering

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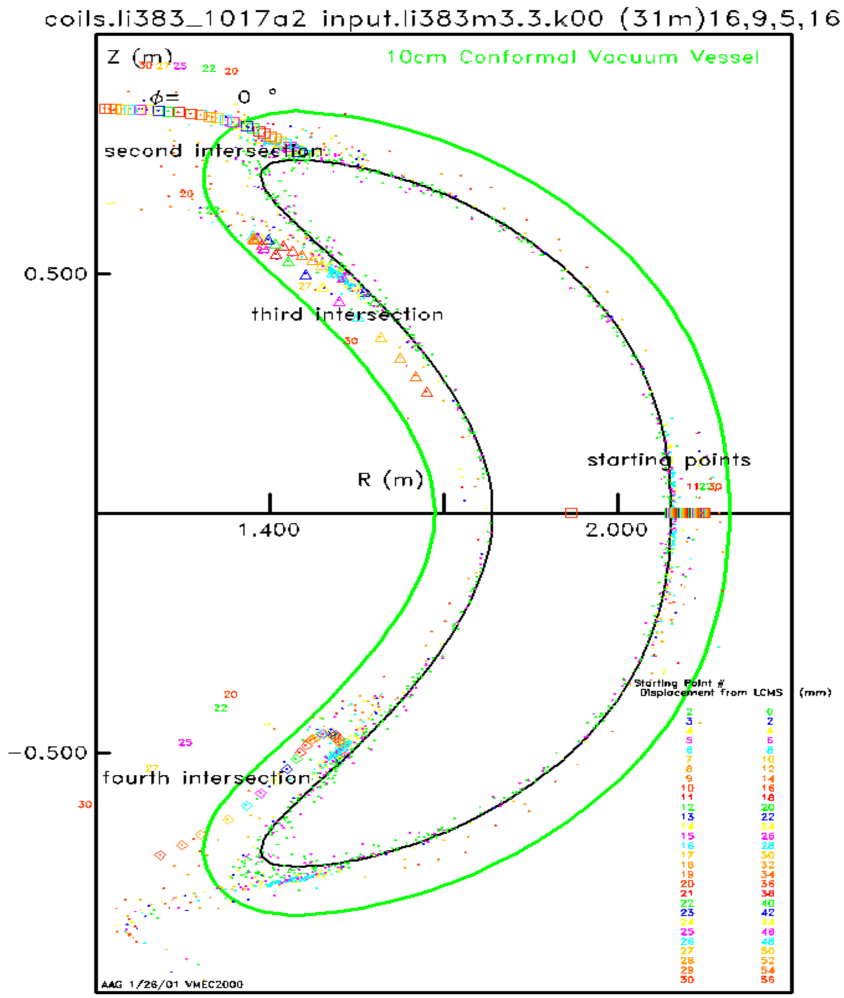

(no island-healing trim coils)

- **30 Field lines are launched at the midplane**
- **at least for the first toroidal revolution, the ordering is preserved !**
- **large flux expansion between midplane and tips of bean cross section**
- **clustering around certain locations is observed => cf. next vugraph!**

Important:

- **field lines move in and out radially**
- **conformal surface at 4 cm intercepts some field lines at the next field period => short connection lengths**
- **conformal surface at 10 cm allows many revolutions => long connection lengths**

Poincaré Plots With Trim Coils for Island-Healing Inside Reveal More-Pronounced Island Structures Outside the LCMS

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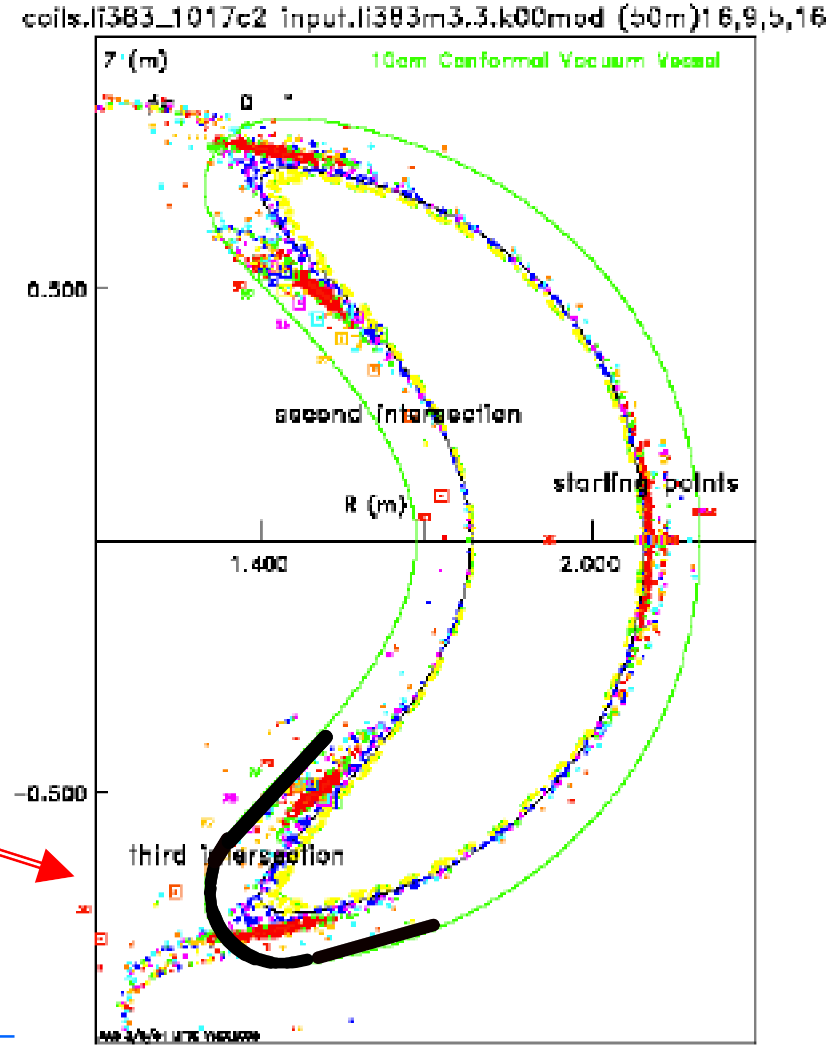
The clustering of field lines observed in the previous vugraph evolves into island structures favorable for efficient interception of power and particle fluxes.

Baffles designed to intercept the islands in the top and bottom of the bean-shaped cross-sections should enable effective divertor operation.



Sufficiently Long Connection Lengths are Potentially Very Important for Good Confinement

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- Long connection lengths between the LCMS and the divertor plate are important in order to maintain high separatrix temperatures simultaneously with low divertor target temperatures.
- The relation between the two can be calculated with the "2-point-model", which assumes 3 balance equations along the field line:
  - 1. Momentum balance:
  - 2. Power balance:
  - 3. Sheath condition:

$$2 n_t T_t = n_u T_u$$

$$T_u^{7/2} = T_t^{7/2} + \frac{7}{2} \frac{q_{//} L_c}{\kappa_{0e}}$$

$$q_{//} = \gamma \, n_t T_t c_{st}$$

- With these equations we can calculate the following parameters:
  - upstream- and target temperature and density for given input power and upstream density

Target- and Upstream Temperatures as Functions of Input Power and Separatrix Density

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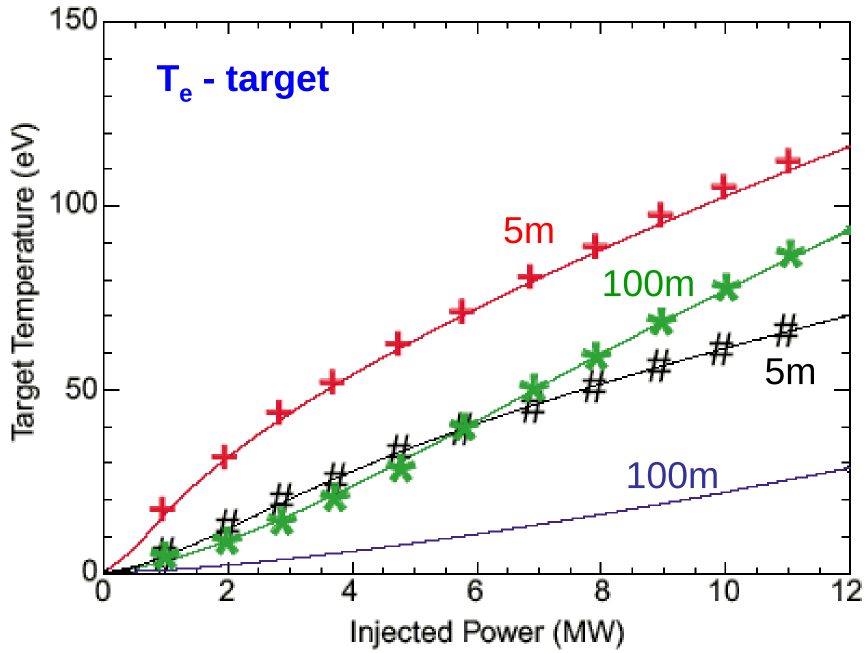

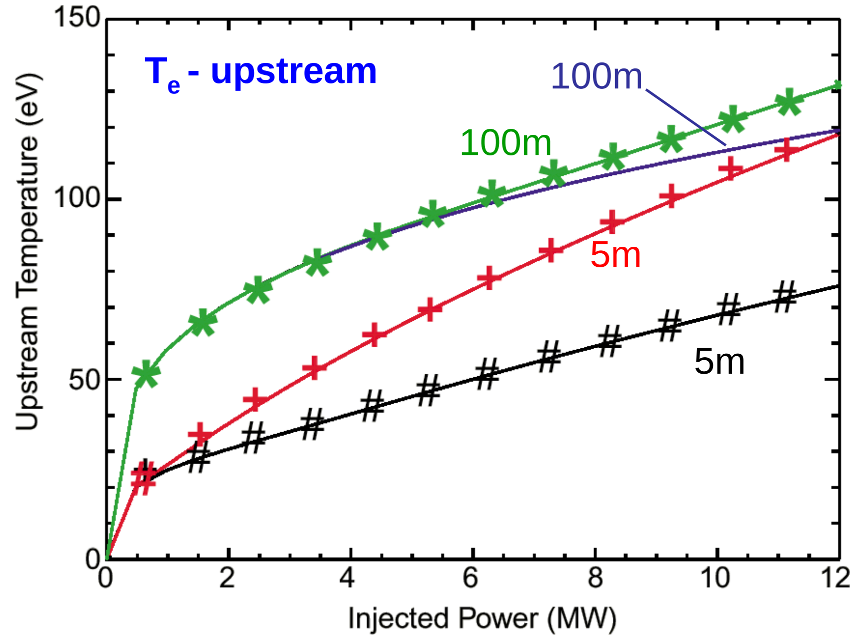

Fig. 1 Target temperature vs injected power for four deuterium plasma cases:

(a) (+) symbols use L_c = 5 m, n_u = 3.e19,
(b) (#) symbols use L_c = 5 m, n_u = 6.e19,
(c) (*) symbols use L_c = 100 m, n_u = 3.e19
(d) (_) plain line uses L_c =100m, n_u =6 e19

Fig. 2 Upstream temperature vs injected power for four deuterium plasma cases:

(a) (+) symbols use L_c = 5 m, n_u = 3.e19,
(b) (#) symbols use L_c = 5 m, n_u = 6.e19,
(c) (*) symbols use L_c = 100 m, n_u = 3.e19
(d) (_) plain line uses L_c =100m, n_u =6 e19.

Initial 2-D Neutrals Calculations with DEGAS-2: Limiter at the Outboard Side or Baffle at the Bottom

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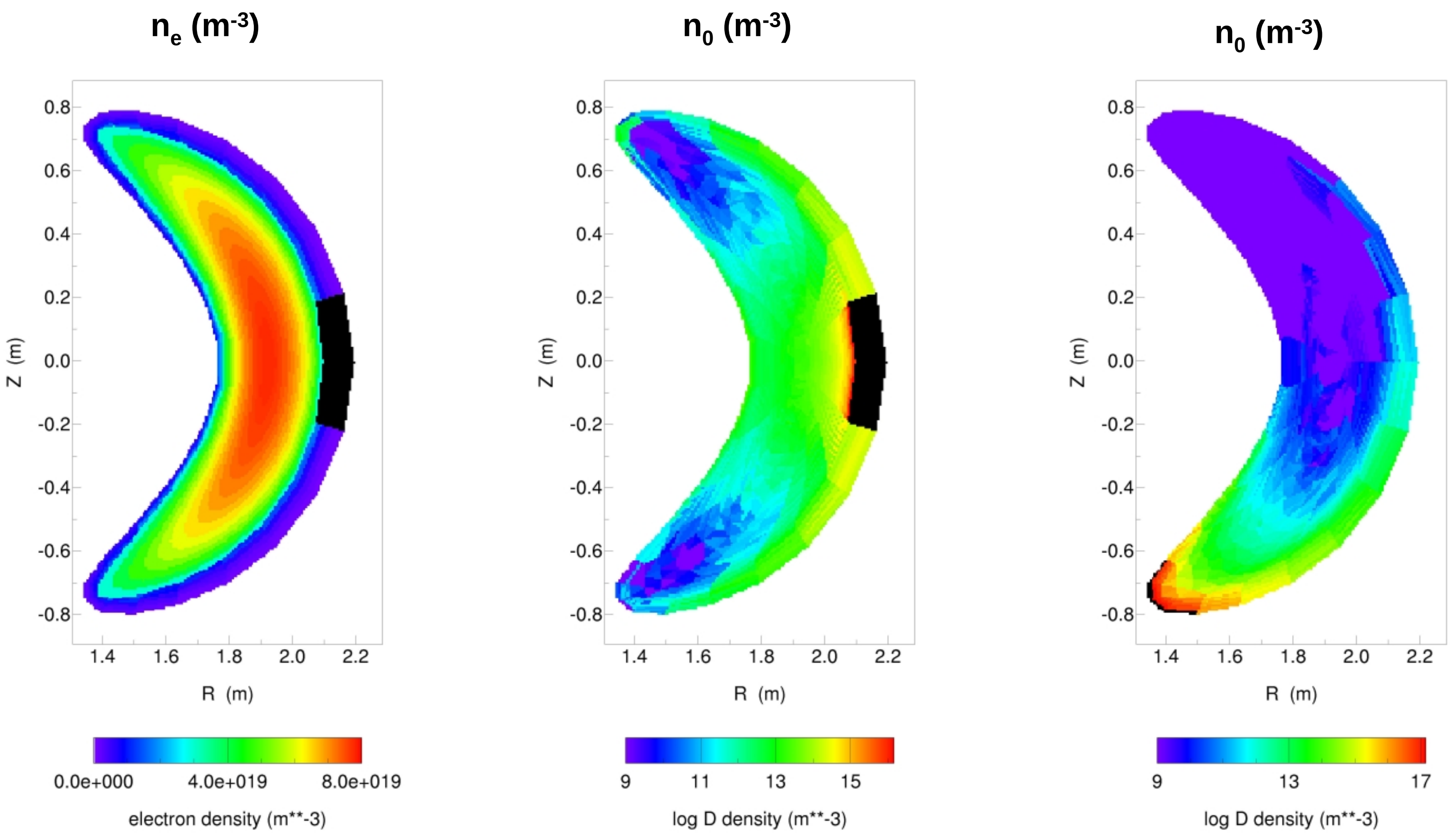

(assuming plasma profiles with: Te(0) = 3 keV, Ti(0) = 2 keV, ne(0) = $8 \times 10^{19} m^{-3}$)

Divertor- vs. Limiter Configuration in Stellarators

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- Due to their three-dimensional topology, stellarators don't necessarily have the ordered magnetic field structure outside the separatrix found in axisymmetric tokamaks.
- To accommodate the 3-D nature of the magnetic topology outside the LCMS, the plasma-facing components have to be designed with the corresponding 3-D shapes.
- Depending on shape and location of the PFCs , we distinguish limiter- from divertor operation in the following way:
  - in limiter operation the PFCs "scratch" closed magnetic surfaces and are in direct contact with the confined plasma
  - in divertor operation the PFCs intercept open field lines only and there is usually (edge) plasma between the main confined plasma and the PFC
- In NCSX we will be able to operate in divertor- as well as limiter mode.

Phased Approach to Power and Particle Handling:
Phase I Vacuum Vessel and Plasma-Facing Components

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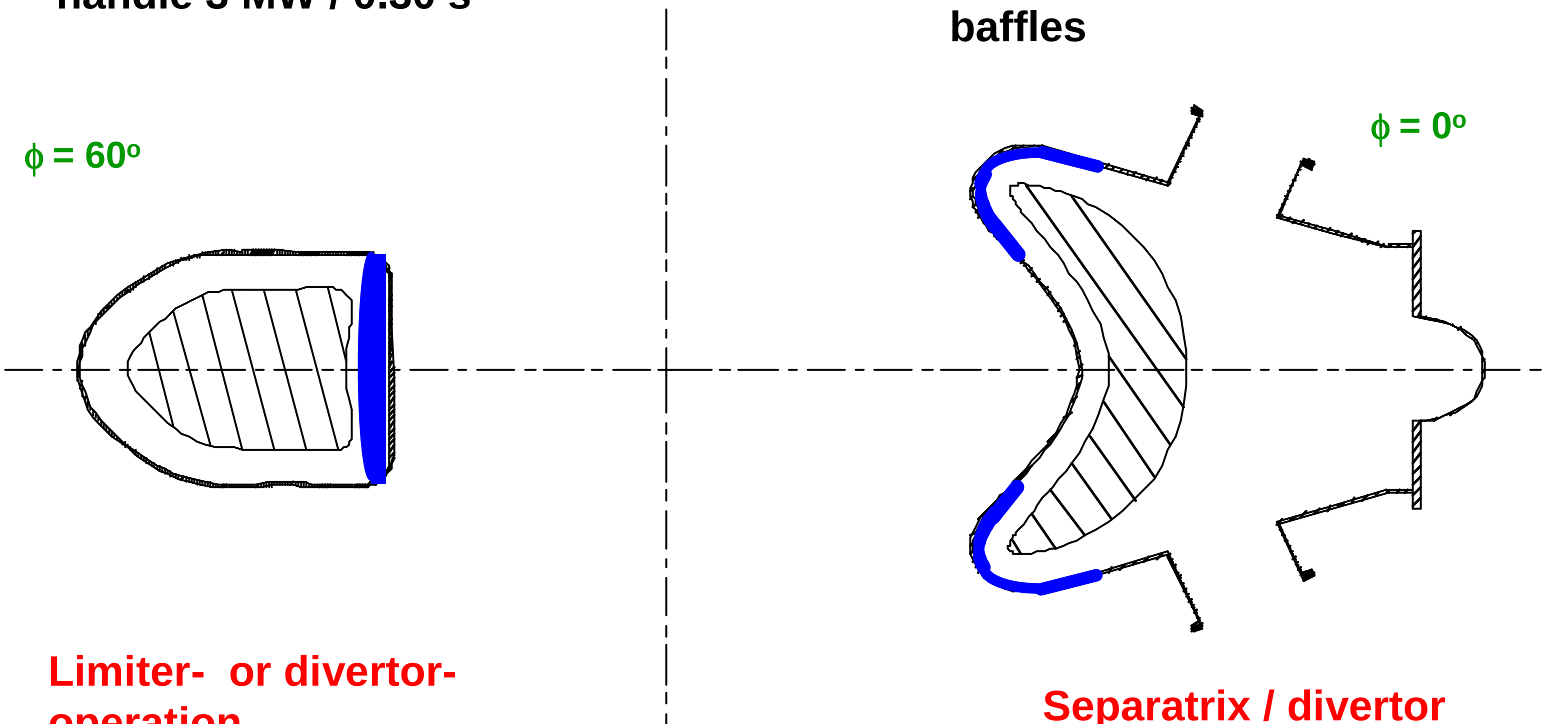
3 inboard limiters to handle 3 MW / 0.30 s

Conformal wall armor serving as initial divertor baffles



Limiter- or divertor-operation

Separatrix / divertor operation

(Note: the shown structures are 3-dimensional!)

Phased Approach for Plasma-Facing Components: Initial Configuration and Future Upgrades

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Phase I :

- **3 divertor baffles = conformal wall armor around ϕ = 0° cross-section and**
- **3 inboard limiters 'centered' around ϕ = 60°**

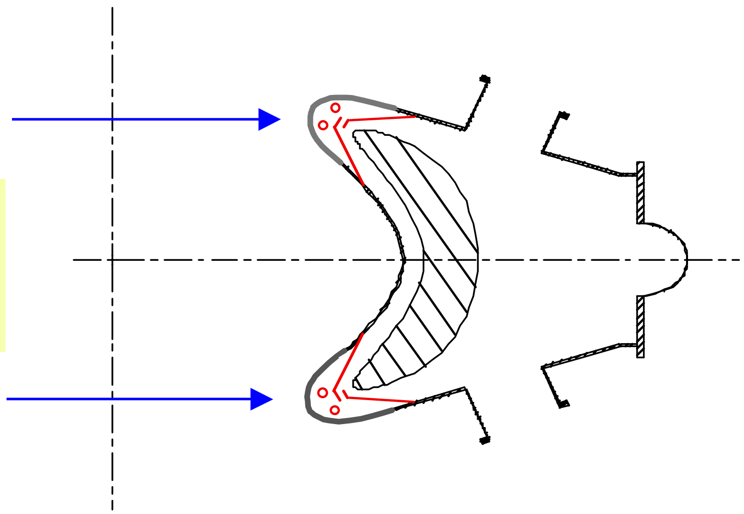
Phase II

- **baffles optimized for recycling control and impurity control, based on detailed neutrals and impurity transport modeling**

Phase III

- **divertor upgrades include optimized divertor baffling and divertor pumping, if needed**

Neutrals control via optimized baffles and divertor pumping



Neutrals- and Impurity Control Will Initially Be Accomplished With Wall Conditioning

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- **For proper conditioning, the graphite plasma-facing components are designed for baking at 350 ^{o}C.**
- **The primary wall conditioning technique will be glow-discharge with one fixed electrode in each field period.**
- **This system will be used for the following wall cond. techniques:**
  - **Hydrogen glow-discharge for chemical cleaning of the s.s. vacuum vessel or pre-loading of surfaces with selected H-isotope**
  - **Helium glow discharge for hydrogen isotope depletion of CFCs**
  - **Boronization for impurity and recycling control**
- **Various techniques of lithium wall conditioning, pioneered on TFTR, are envisioned for future upgrades**

Plasma Boundary Tasks Between PVR and CDR:

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- **Tasks 1: maximize the plasma-wall gap**
  - **To achieve the necessary connection length, the gap between vacuum vessel and plasma needs to be sufficiently large to allow the field lines to make many revolutions before intercepting the wall.**
  - **We will run more complete sets of field line plots, especially analyze excursions inboard and outboard.**
  - **We will assess optimization/modification of the vacuum vessel.**
- **Task 2: design of plasma-facing components**
  - **Location and shape**
  - **Power flux capability**
  - **Neutrals recycling and impurity control aspects**
- **Task 3: estimate power flux densities**
  - **Foot prints on the (actual) vessel**
  - **Field line plots with added diffusion**
  - **Estimates of power fluxes due to fast particles**

Summary

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- The goal of the Power and Particle Control task is
  - To provide optimum boundary conditions in support of the NCSX mission
  - To create the knowledge base and understanding of the plasma-wall interface of compact stellarators
- We have begun to study the features of the NCSX plasma boundary
  - Magnetic topology
  - Connection length and plasma-wall gap
  - Penetration of recycling neutrals
  - Energetic particles
- The phased approach will establish a sound scientific base
  - Initial phase: configurational flexibility needed for initial operation
  - Model validation of different configurations => upgrades
  - Later phase: advanced divertor configuration for optimized power and particle handling

=> The following vugraphs are back-up material !

Neutrals: Initial 2-D Calculations with DEGAS 2

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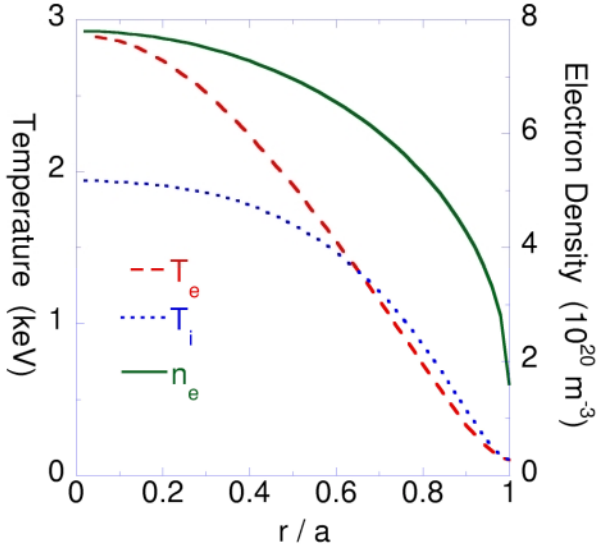

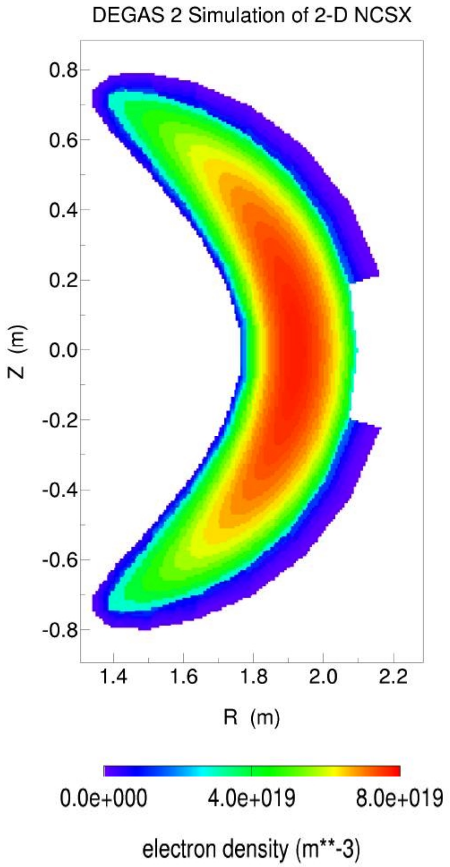

Divertor Baffles / Limiter Configuration

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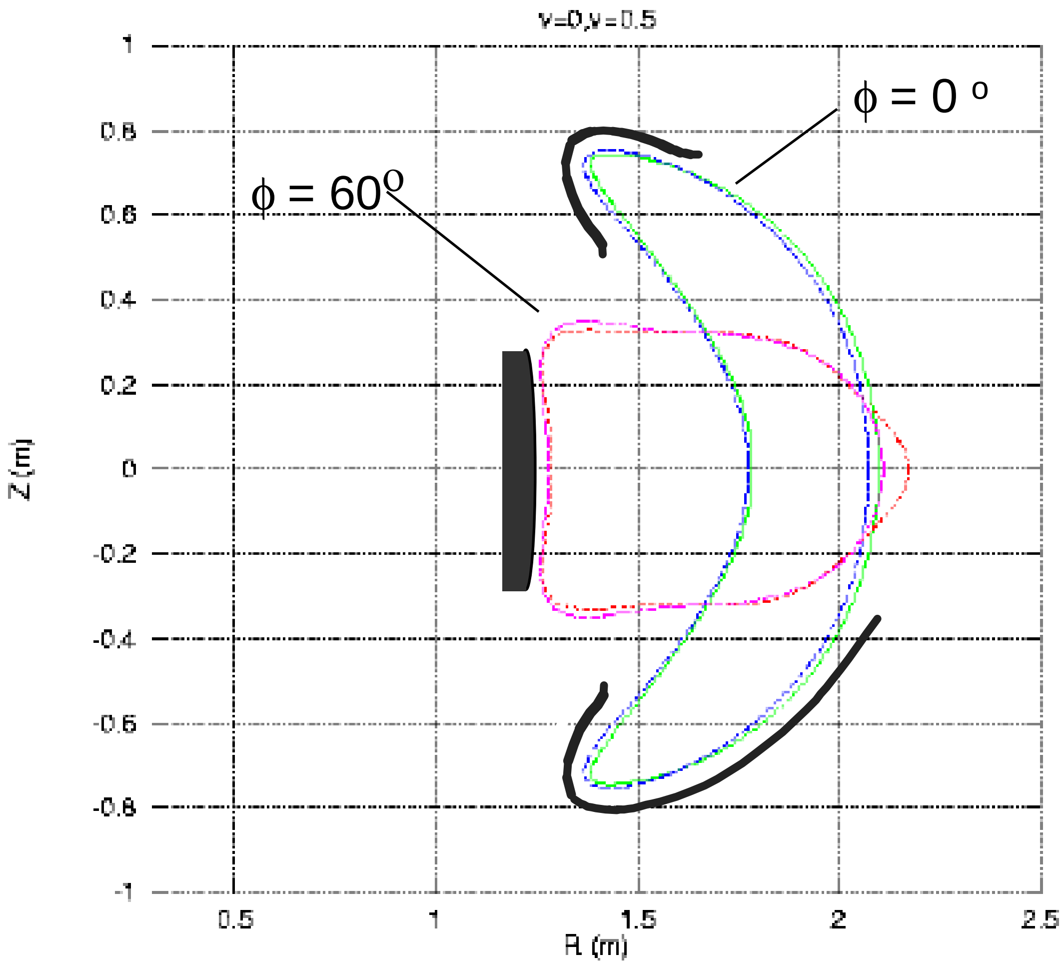

The limiters at φ = 60 º can also act as divertor plates if the plasma is sufficiently removed

The baffles at φ = 0 º can act as mechanical baffles for neutrals in phase I; later they can be modified for pumping

(Note: these are 2-D cuts; the actual PFCs are 3-D)

Plan View of Plasma and Vacuum Vessel

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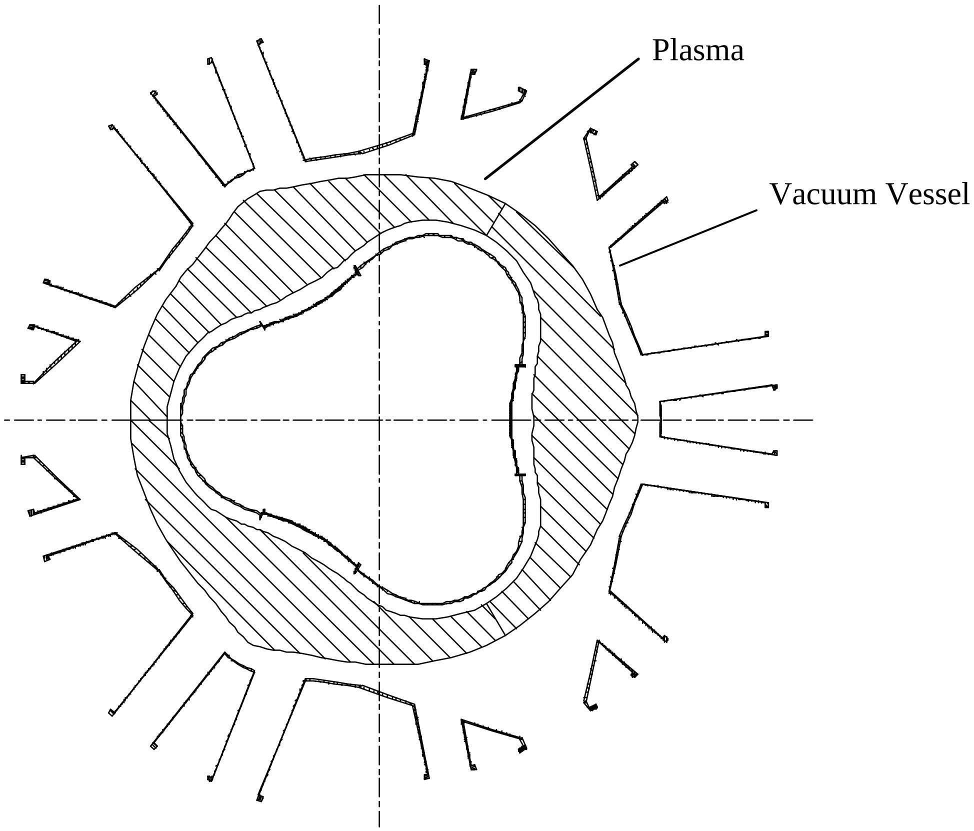

Views of the Inboard Limiters

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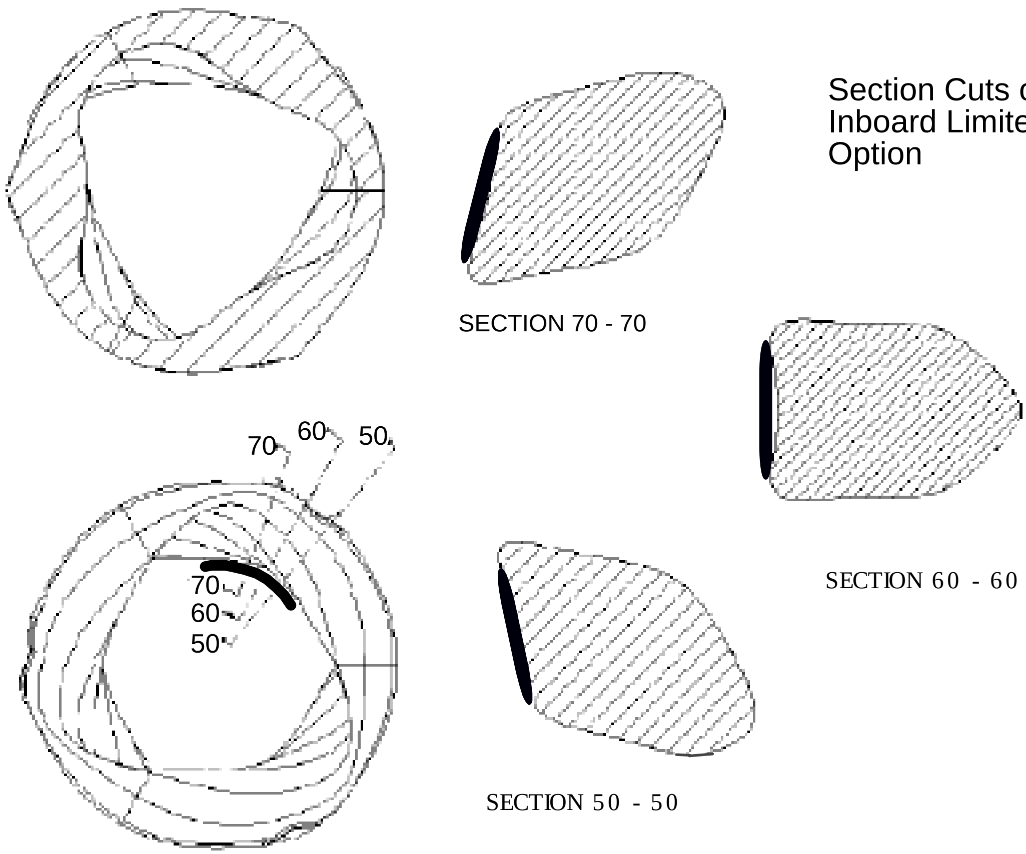

Fast Particle Exits on the Last Close Magnetic Surface: Helical Stripes on the Lower/Outer Vessel Surface

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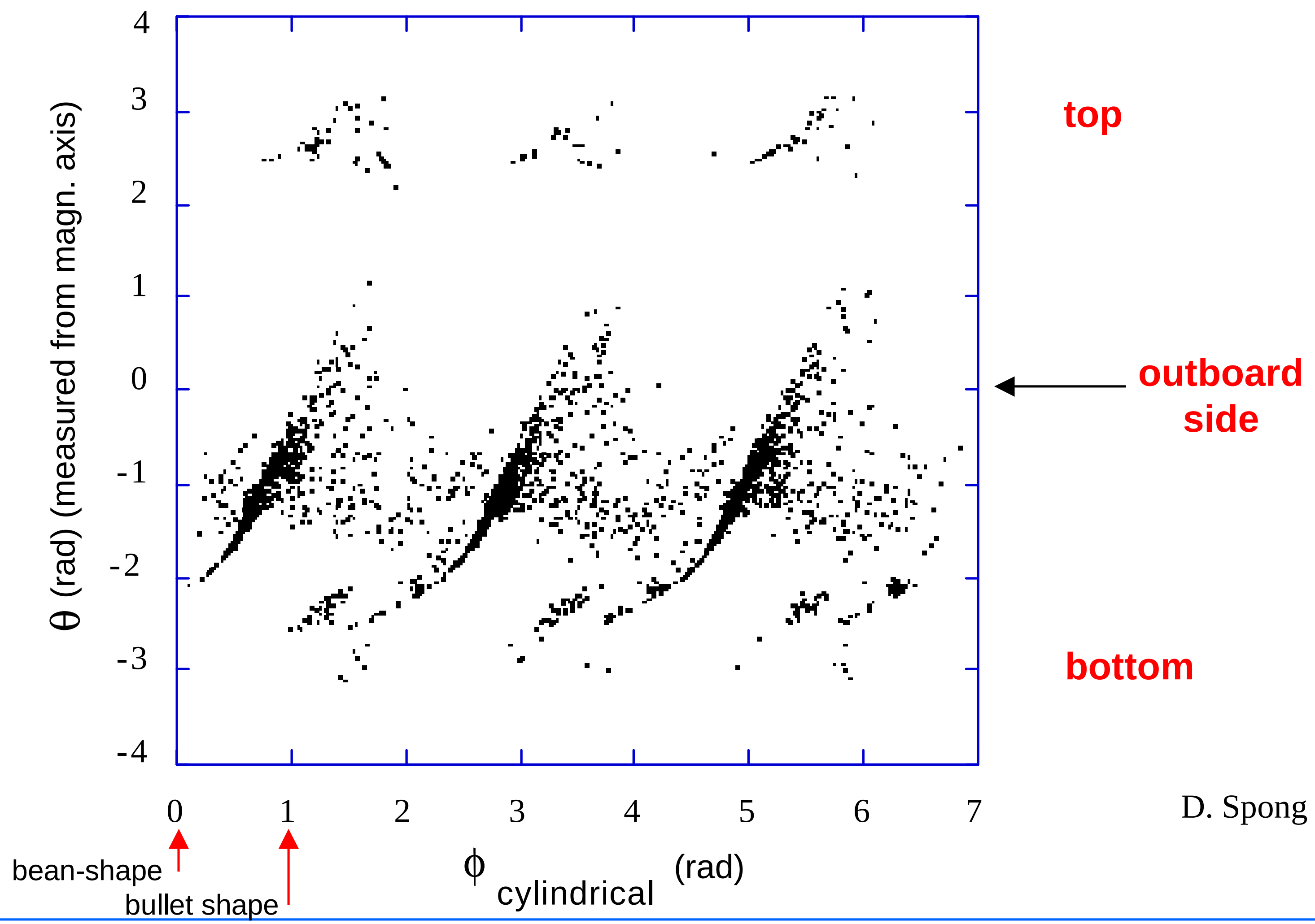

D. Spong

Modelling Efforts Make Use of International and Domestic Developments in the Stellarator Program

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- **<u>Magnetic Boundary Topology</u>**

VEMEC:	equilibrium with nested surfaces inside LCMS
MFBE:	finite-beta, free-boundary, with toroidal currents
Gourdon:	field-line tracing code for Poincaré plots

- **<u>Neutrals modeling</u>**
  - start with 2-D and DEGAS 2 with given plasma background; this provides first estimates of neutrals

- **<u>3-D plasma edge code</u> development**
  - collaboration with Greifswald (BoRiS-code)
  - we will adapt the BoRiS-code to the NCSX geometry and perform self-consistent edge plasma calculations

- **<u>Turbulent transport</u>**
  - 3-D turbulence code for tokamaks: BOUT-code; Greifswald group plans to help modify BOUT for stellarators