PHYSICS AND ENGINEERING DESIGN OF CHS-QA

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in cooperation with IPP Greifswald

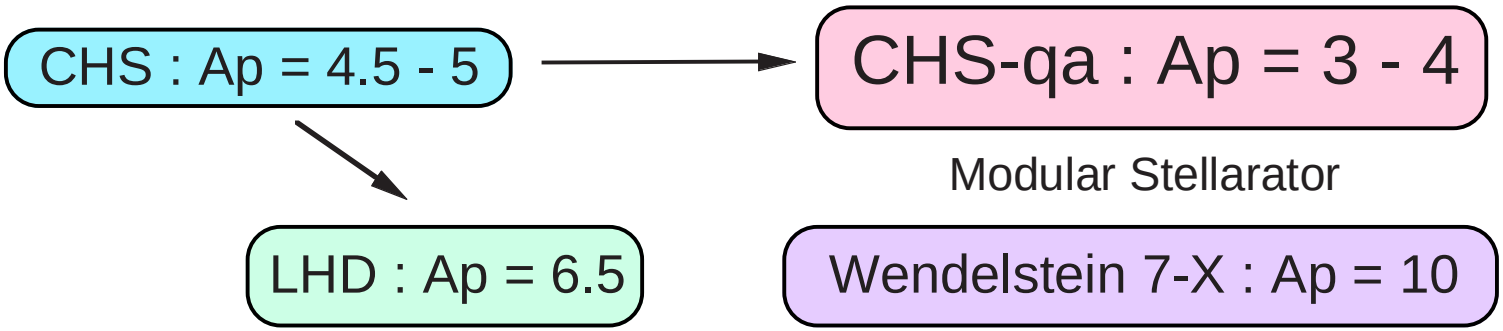
1. **Basic information of present status of CHS-qa design work in NIFS**
2. **Field error or coil miss-alignment and robustness of the configuration**
3. **How much beta will be normal running beta in the experiments ?**

STEPS TO POST CHS SATELLITE MACHINE

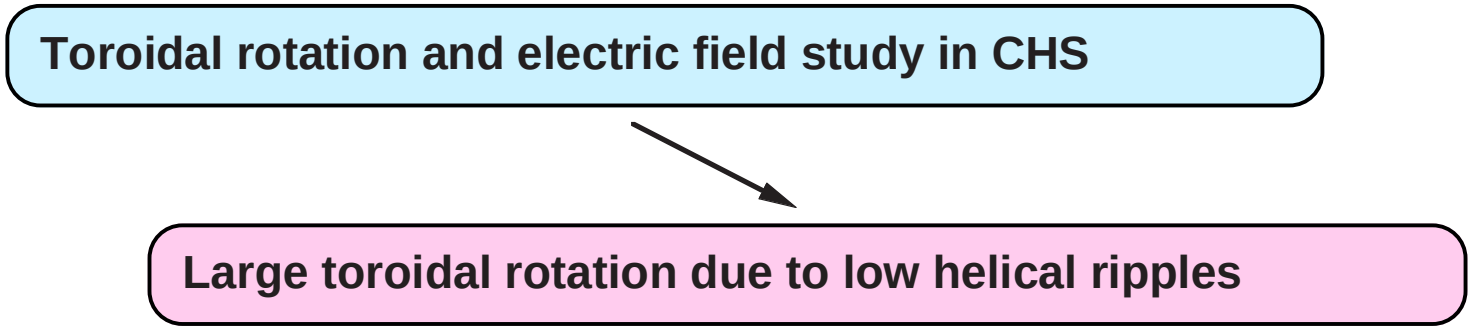
1988	CHS experiment started
1990	LHD construction started
1995 Mar.	Post CHS experiment discussion started ATS (Advanced Toroidal System) working group
1996 Aug.	Selection of low ripple modular stellarator as a candidate for post CHS experiment
1998 Mar.	LHD experiment started
1999 Mar.	Finished CHS experiment in Nagoya site
1999 Aug.	Transported CHS to Toki site
2000 Jan.	Restart CHS experiment in a new exprimental hall with upgraded utilities

Basic Policy for Post CHS Satellite Machine

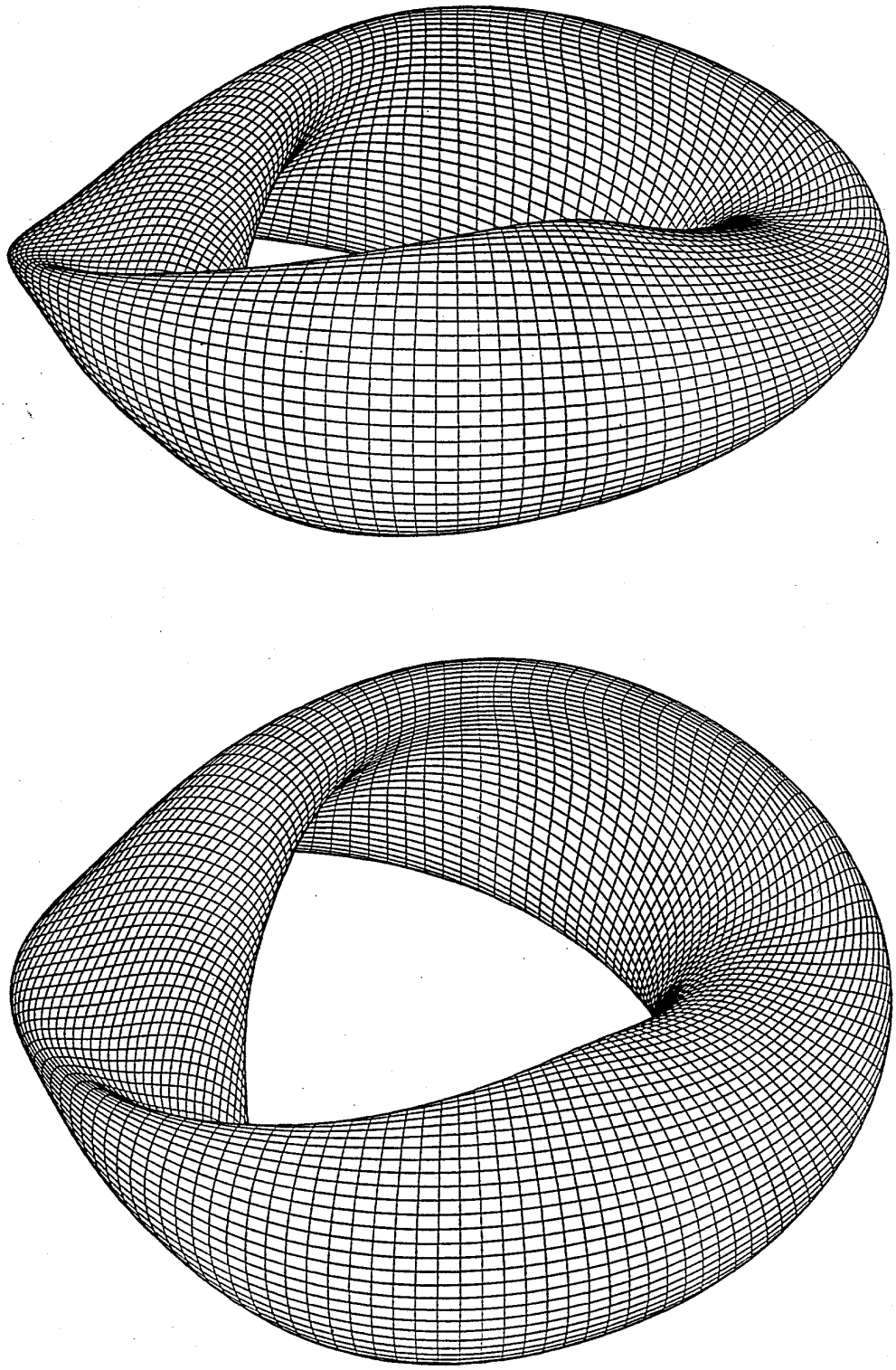
1. **Proceed to the direction of low aspect ratio helical system research established in the CHS experiment**



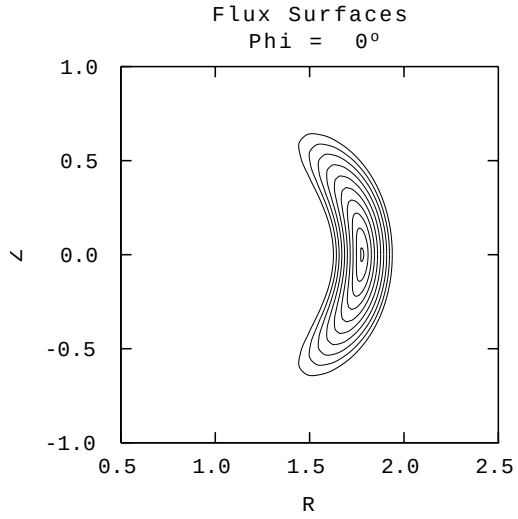
2. **Provide experimental scenario to suppress anomalous transport as well as the orbit optimization**

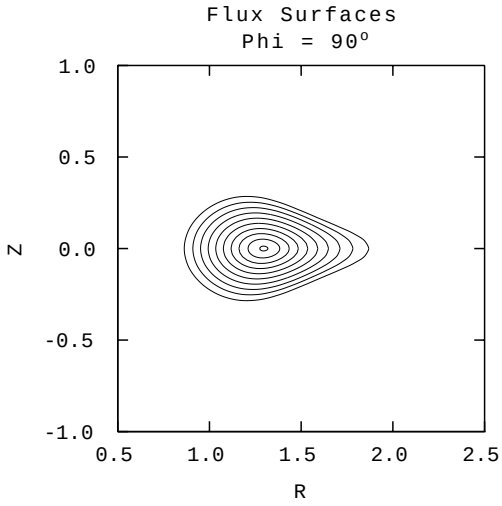


CHS-qa

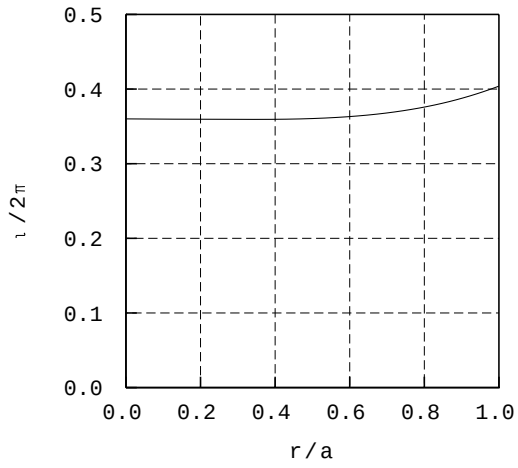


Aspect ratio 3.9 with smaller indentation

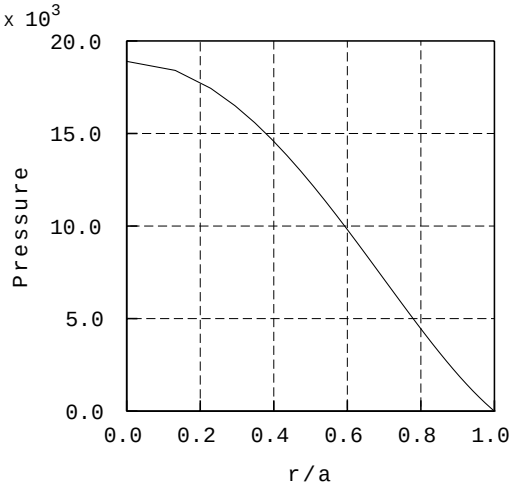




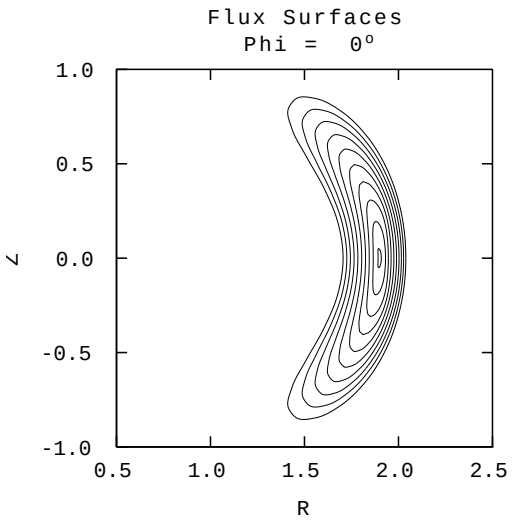
Vacuum rotational transform

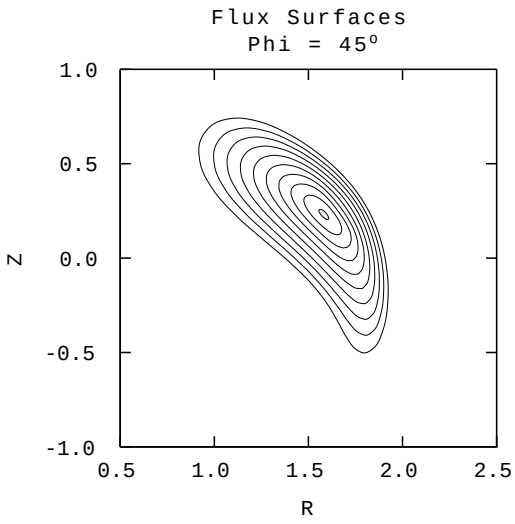


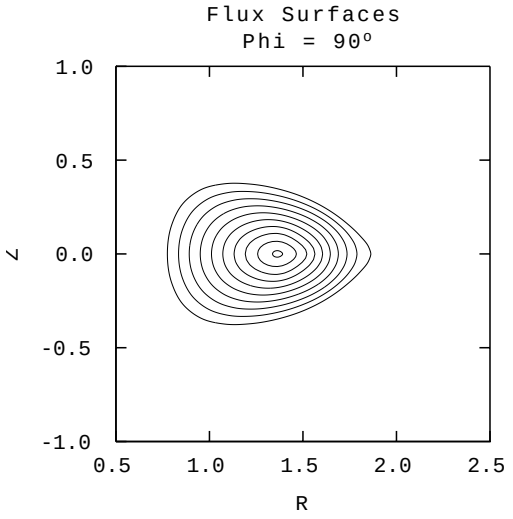
Pressure profile



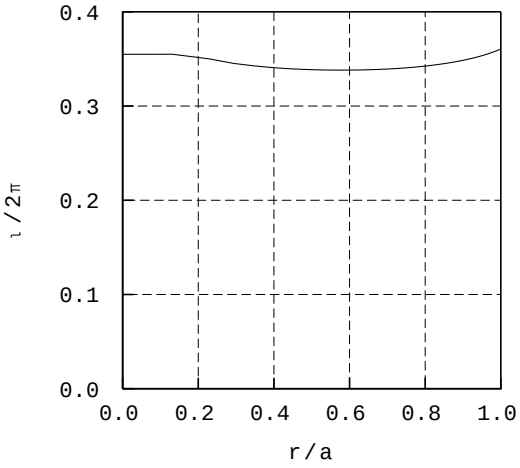
Aspect Ratio 3.2 Configuration with Ballooning Stability Optimization (Average beta 3 %)



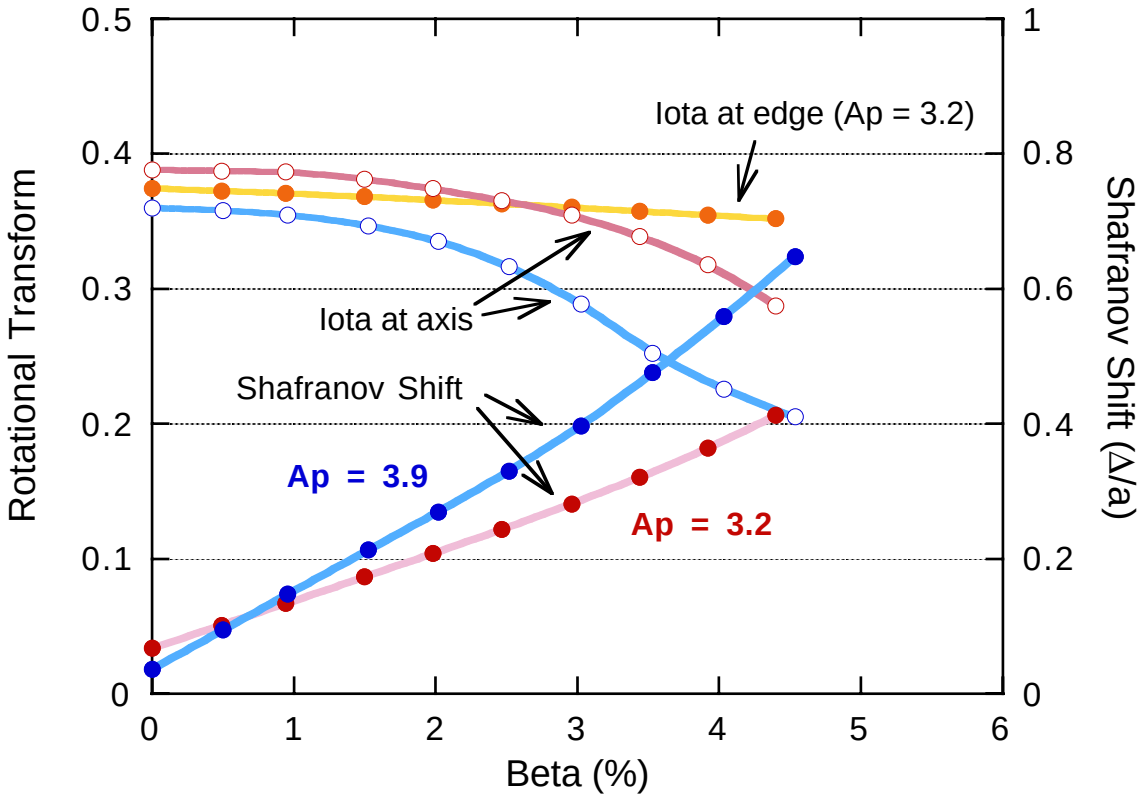




Rotational transform



Shafranov Shift is Reduced for Lower Aspect Ratio Solution



- **The reason why the Shafranov Shift is reduced by the ballooning optimization is not completely understood.**
- **Decreasing rotational transform toward edge appears for low beta Ap = 3.2 configuration.**

Engineering Design Study for CHS-qa

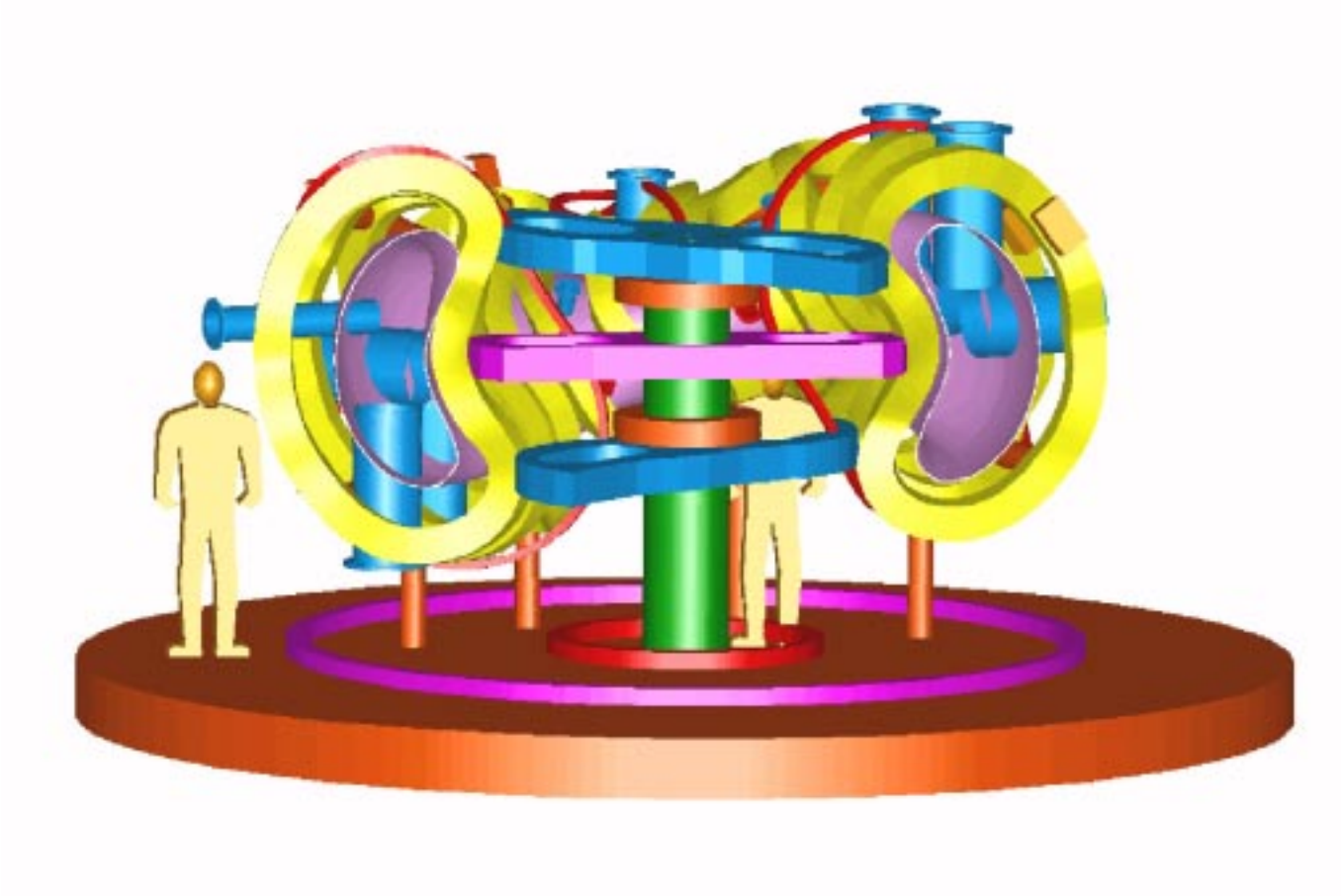
1. Fix the target configuration for a sufficiently long period of design work. Ap = 3.9 configuration was used with N = 2, R = 1.5 m, Bt = 1.5 T.

2. Complete total device design as a whole with all important components included.

3. Incorporate additional coil components (poloidal and toroidal coils) to increase flexibility of the experiment operation.

4. Evaluate the effect of machining error and find out the necessary accuracy of manufacturing.

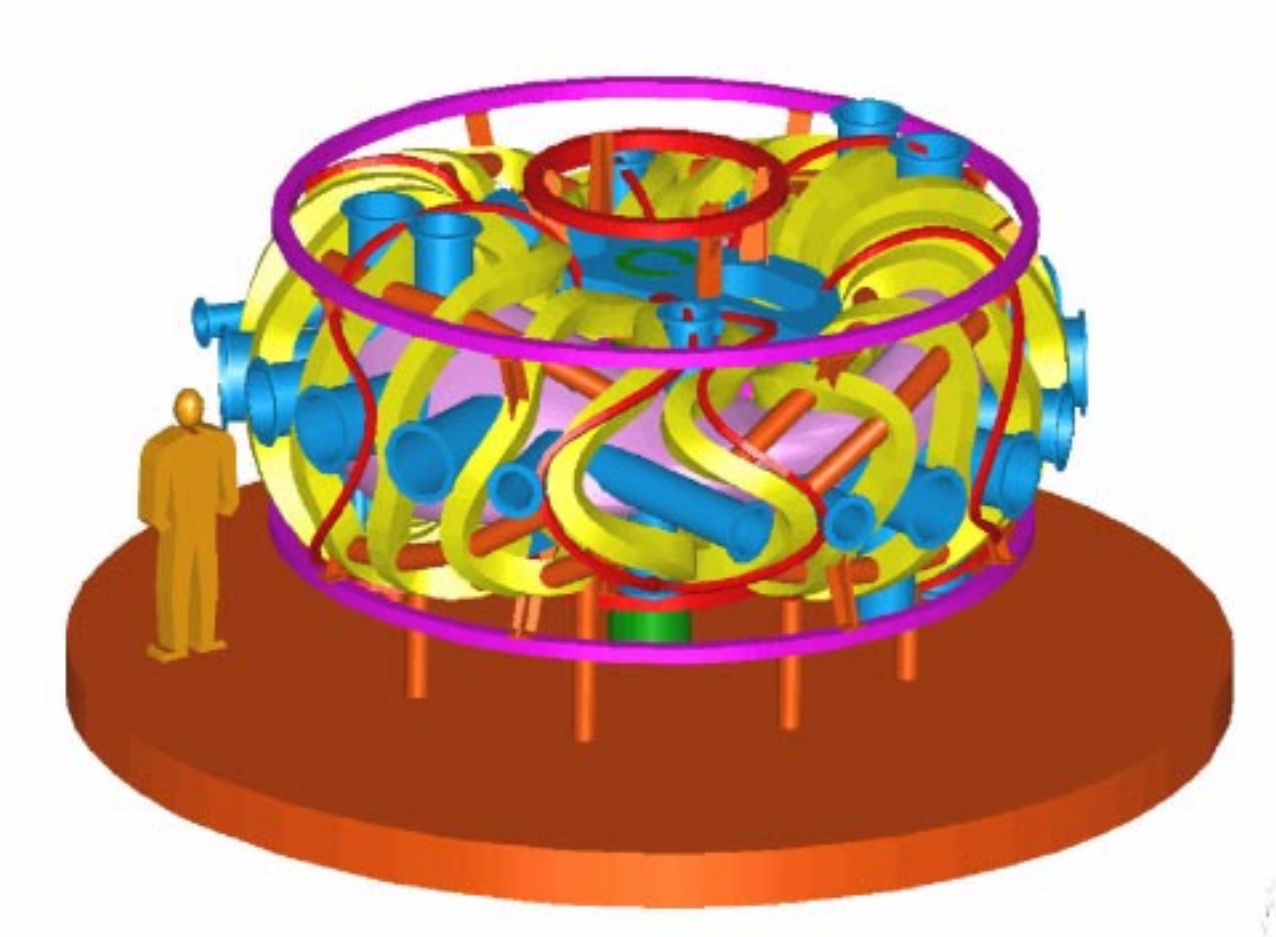
Central Mechanical Support Structure for Modular Coils



- **Compressional forces of modular coils are supported by three plates located at the central pole.**

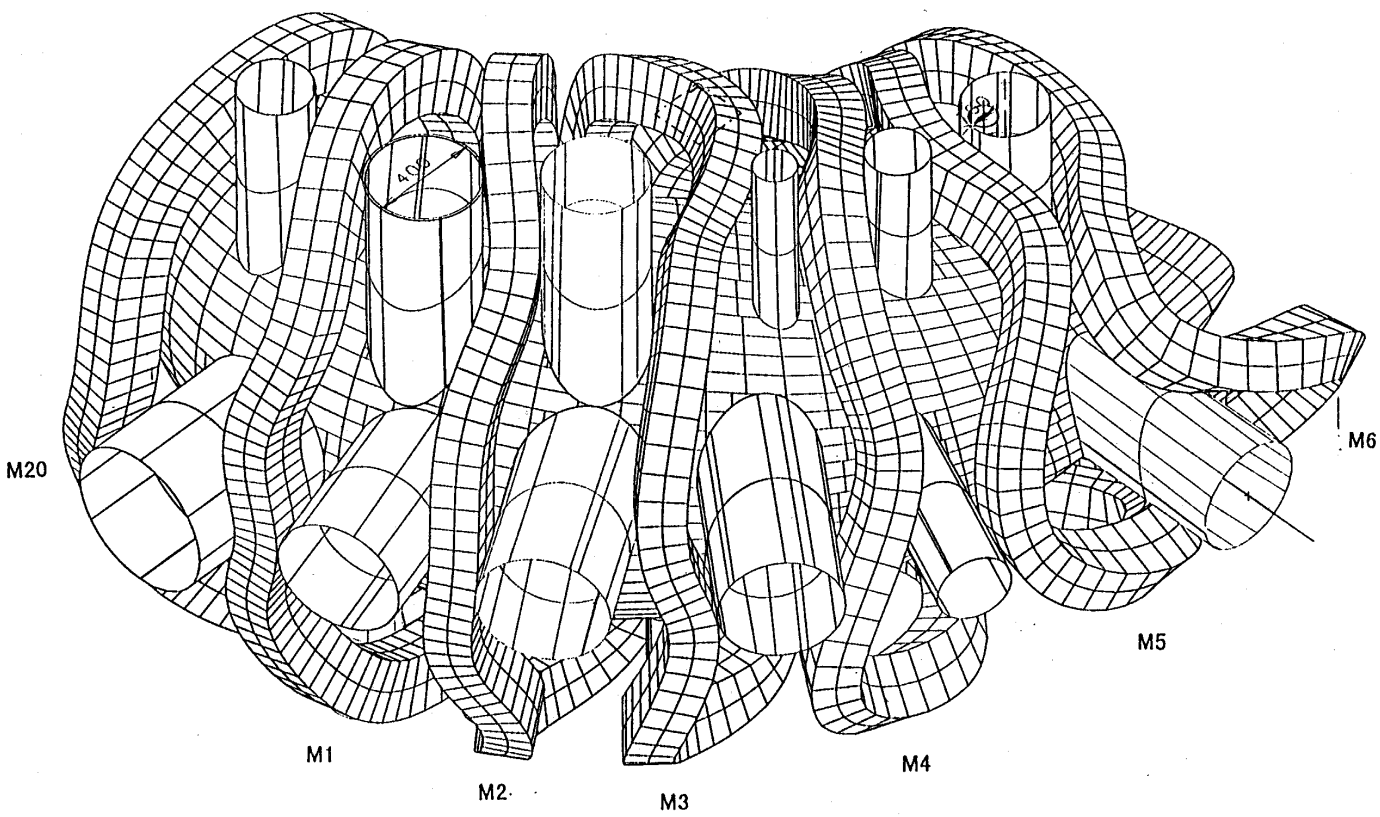
- **There is no big support structure outside modular coils allowing free access to all ports for diagnostics and heatings.**

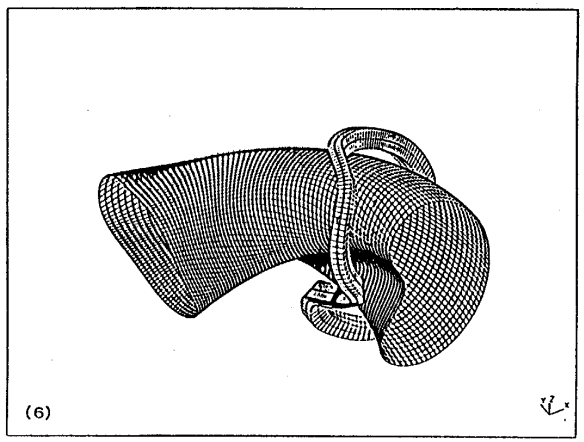
Whole Coil Arrangement with Supporting Rods Between Coils



- **Three pairs of poloidal coils are installed for plasma shaping control and inductive current control**

- **Additional toroidal coils (shown by red) gives a control of rotational transform**


M20
M1
M2
M3
M4
M5
M6
Z
X
Y



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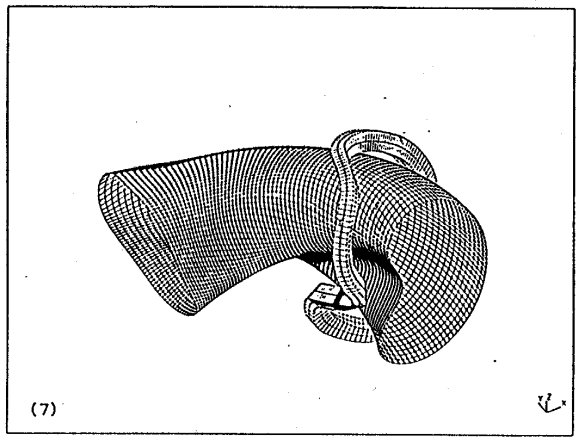

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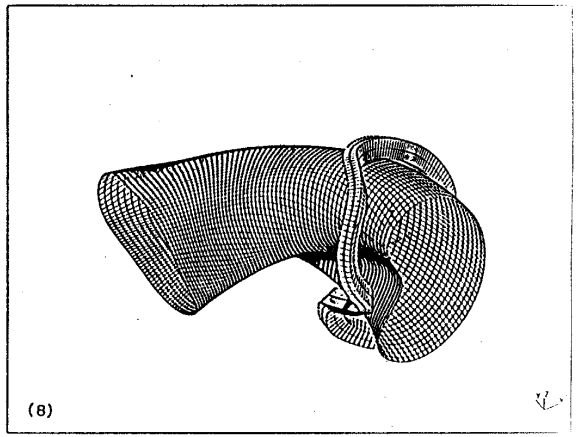

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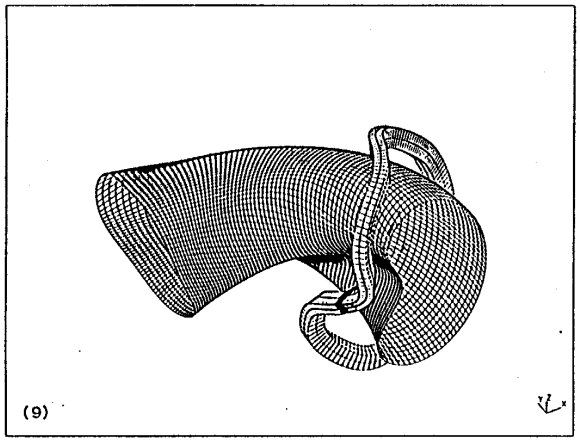

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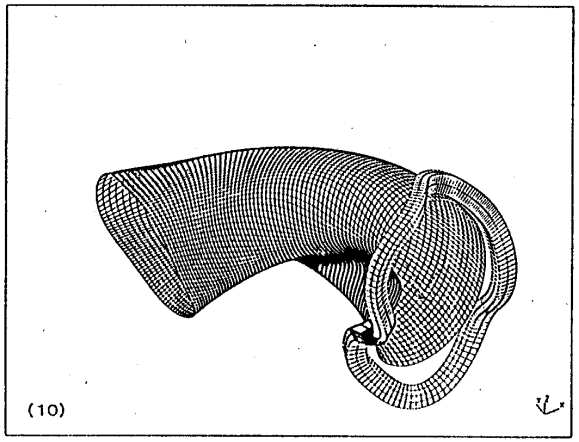

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CHS Experiments in Toki site towards CHS-qa

1. **Two NBIs with both co-injection. Measure toroidal rotation with doubled momentum input.**

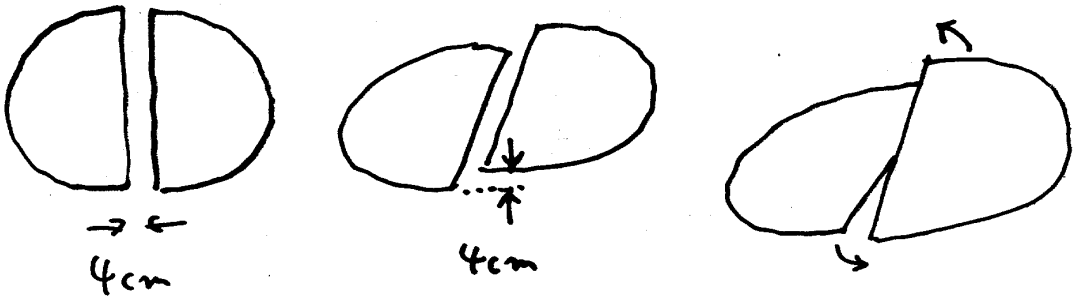
2. **Precise study of helical ripple trapped energetic ions using diagnostic beam with variable injection angle and movable neutral particle energy analyzer.**

3. **High beta experiments with the Mercier unstable configuration to study experimentally real beta limit mechanism in stellarators.**

EFFECT OF POSITIONING ERROR OF MODULAR COILS

- Examine various patterns of positioning error with a scale length of 4 cm/R = 1.5 m.

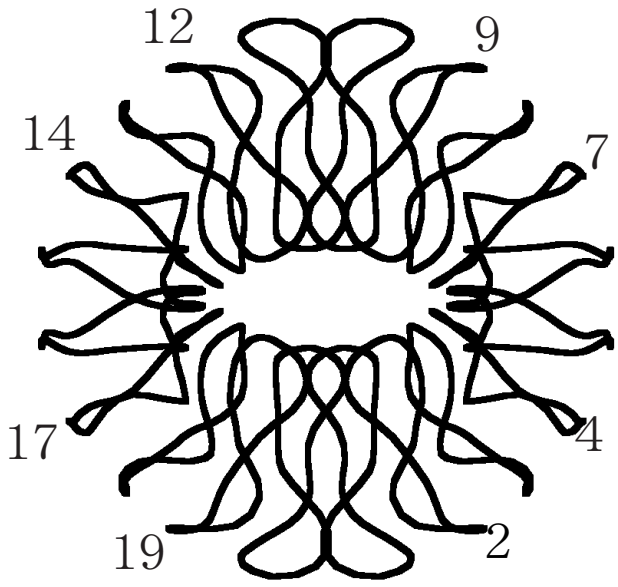
Split half torus Shift half torus Tilt half torus



- Resultant field error is much smaller than we expected from the experience of CHS & LHD

- More drastic case is to take off part of modular coils

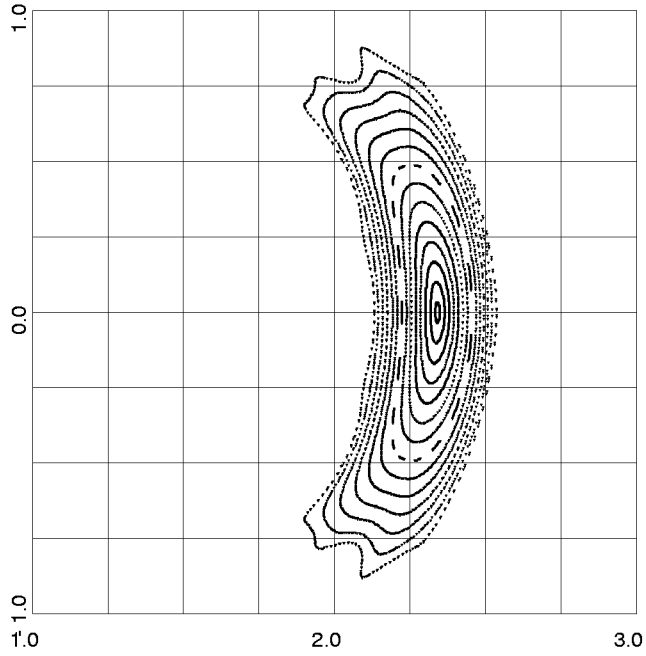
Magnetic Surfaces with missing eight coils

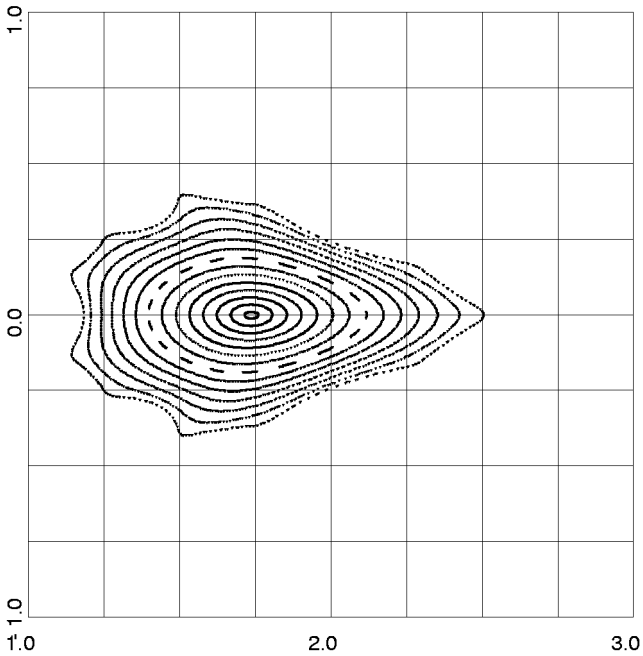


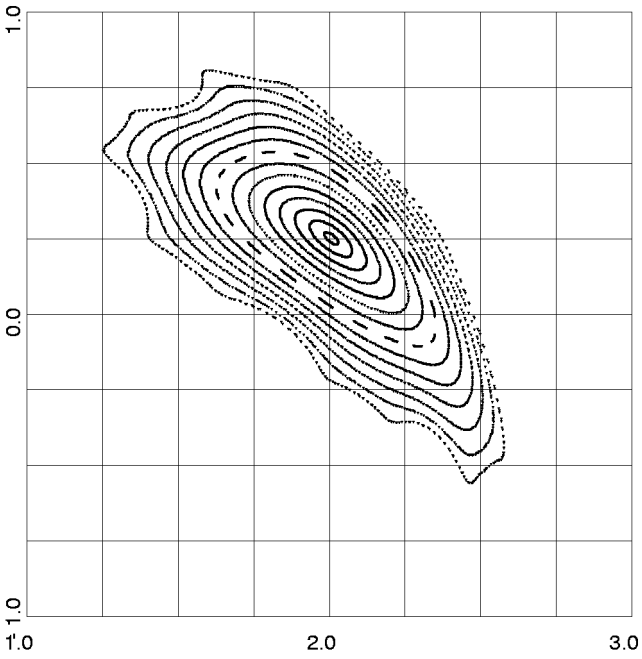
Study magnetic surfaces produced by 14 coils out of 20

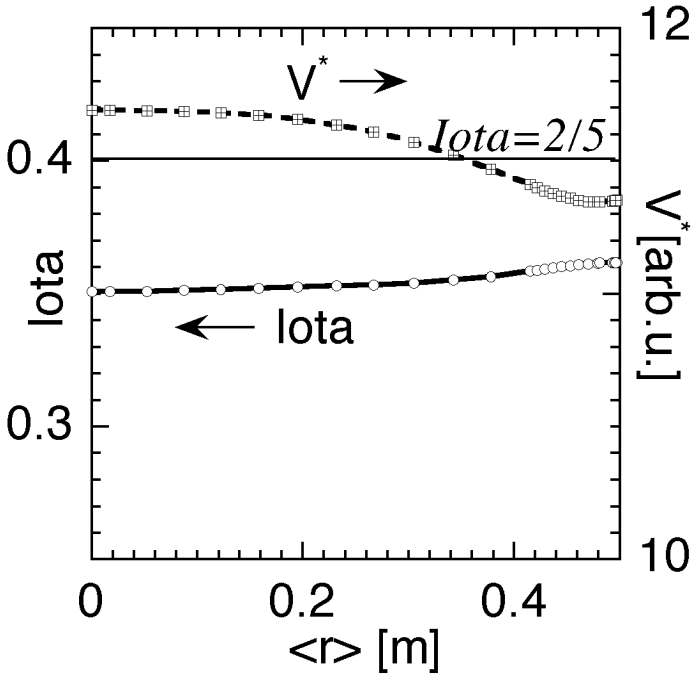
No current in coils : 2, 4, 7, 9, 12, 14, 17, 19

Magnetic Surfaces and Rotational Transform



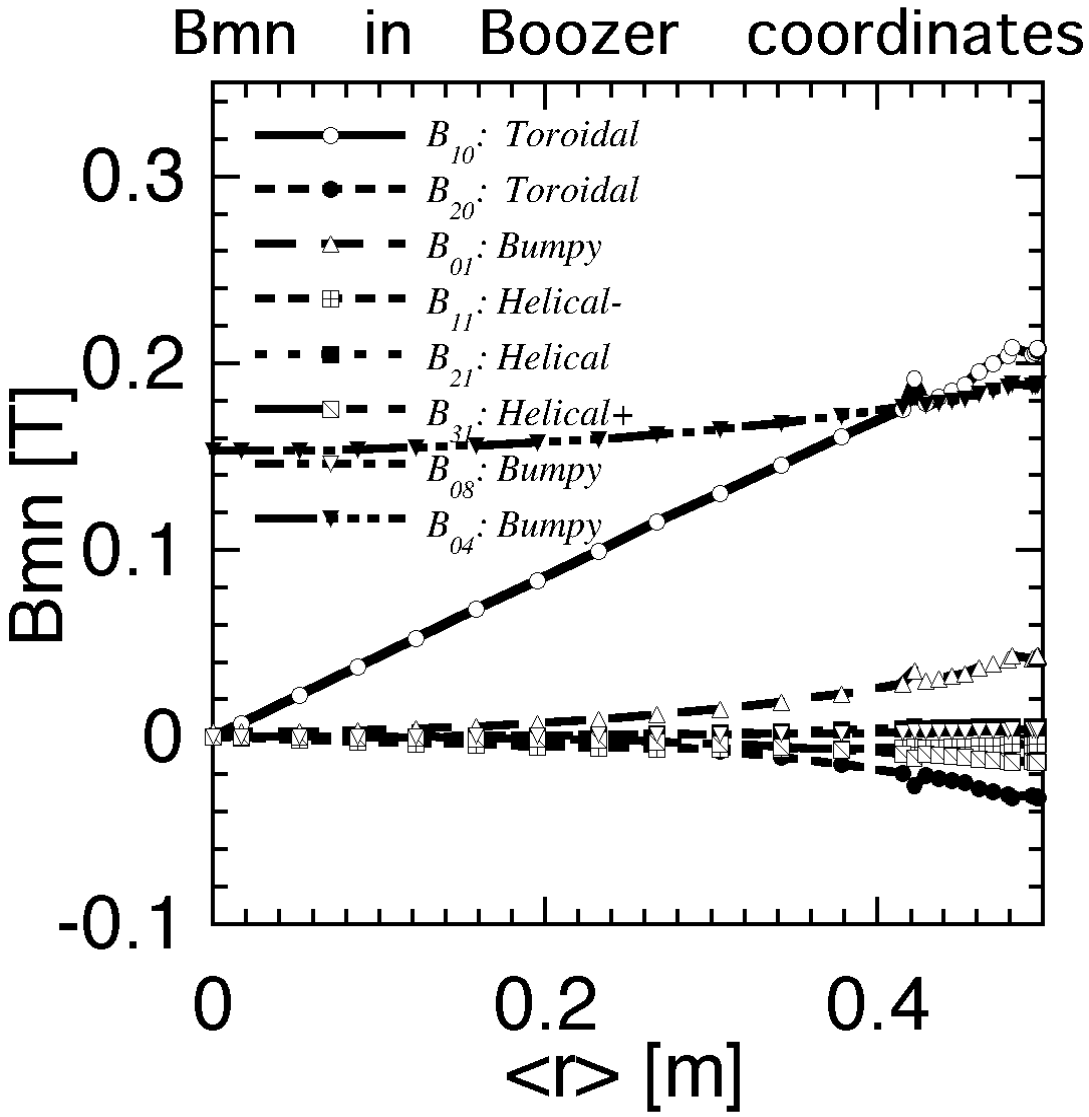






Magnetic surfaces remain but the rotational transform decreases

Boozer Spectrum



Big mirror component appears but other ripple components remain unchanged

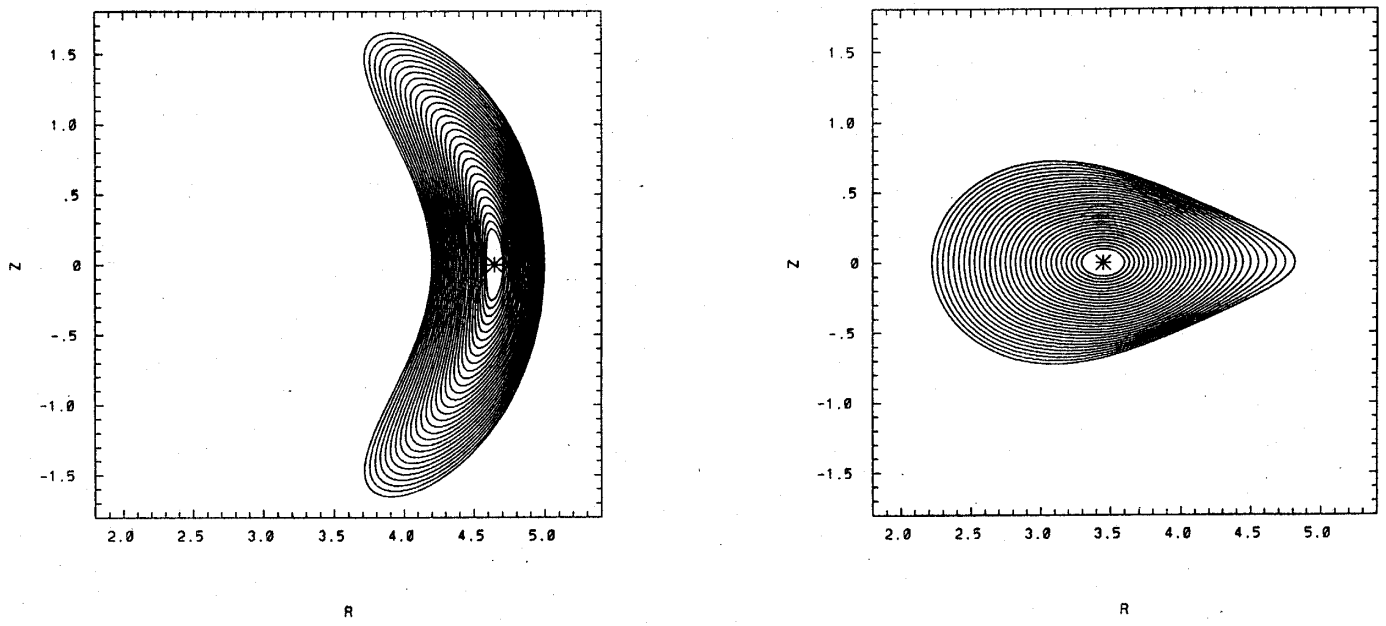
SELECTION OF BETA FOR MODULAR COIL DESIGN

- Optimization of the boundary shape is made for the target beta. Coil design is usually made for the vacuum field with the target plasma shape.

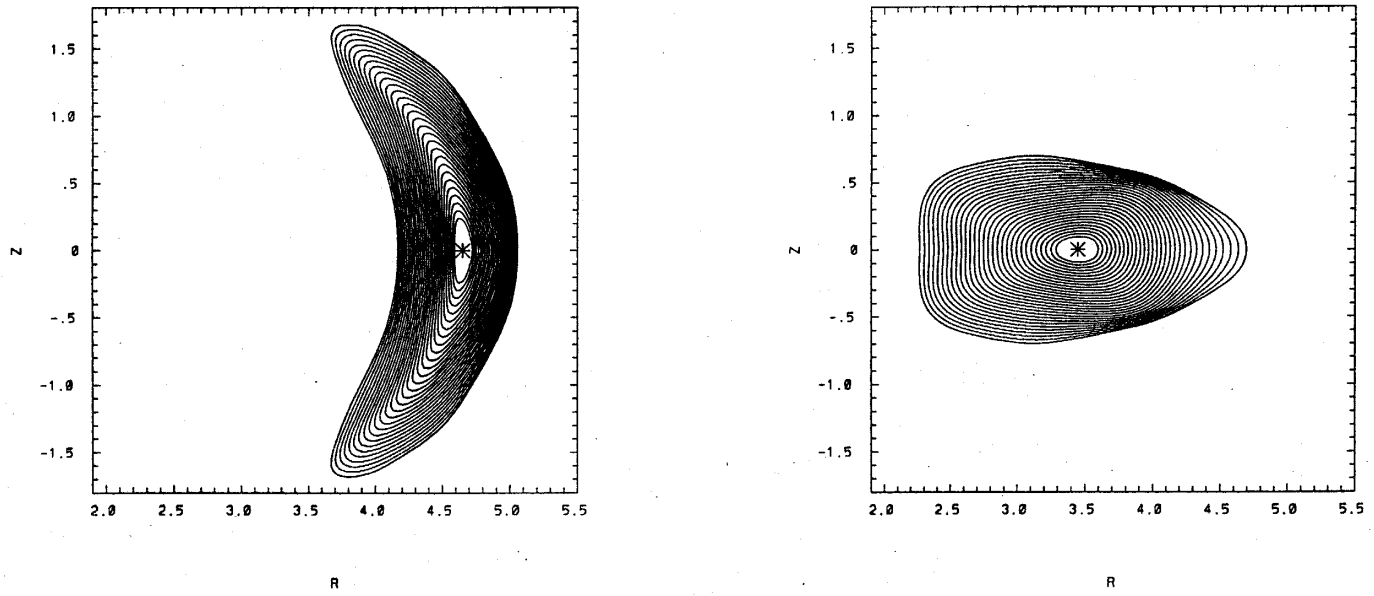
- P. Merkel developed new version of NESCOIL to design coils for the finite beta configuration.

- How much beta will we have for the most of discharges in experiments ?

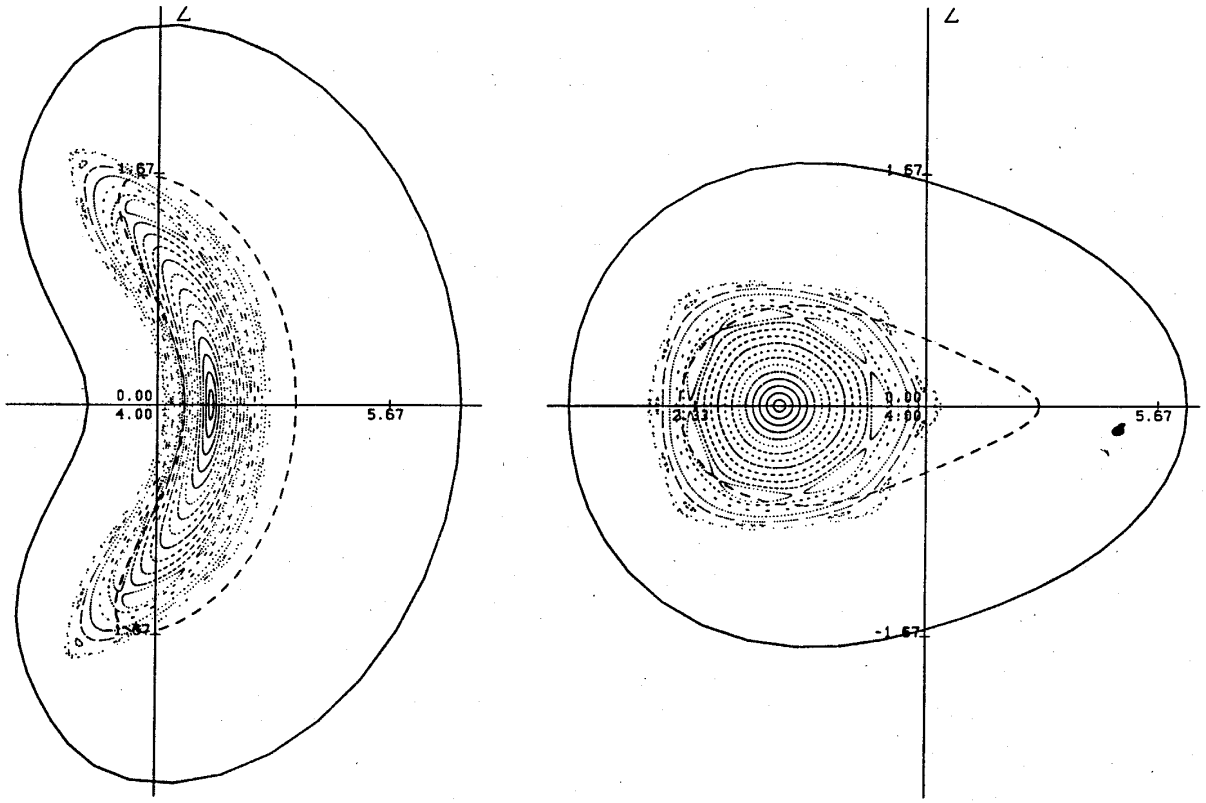
- Auxiliary coil design is possible for the second selection of beta. Which auxiliary coil do we choose for the iota control or finite beta adjustment ?



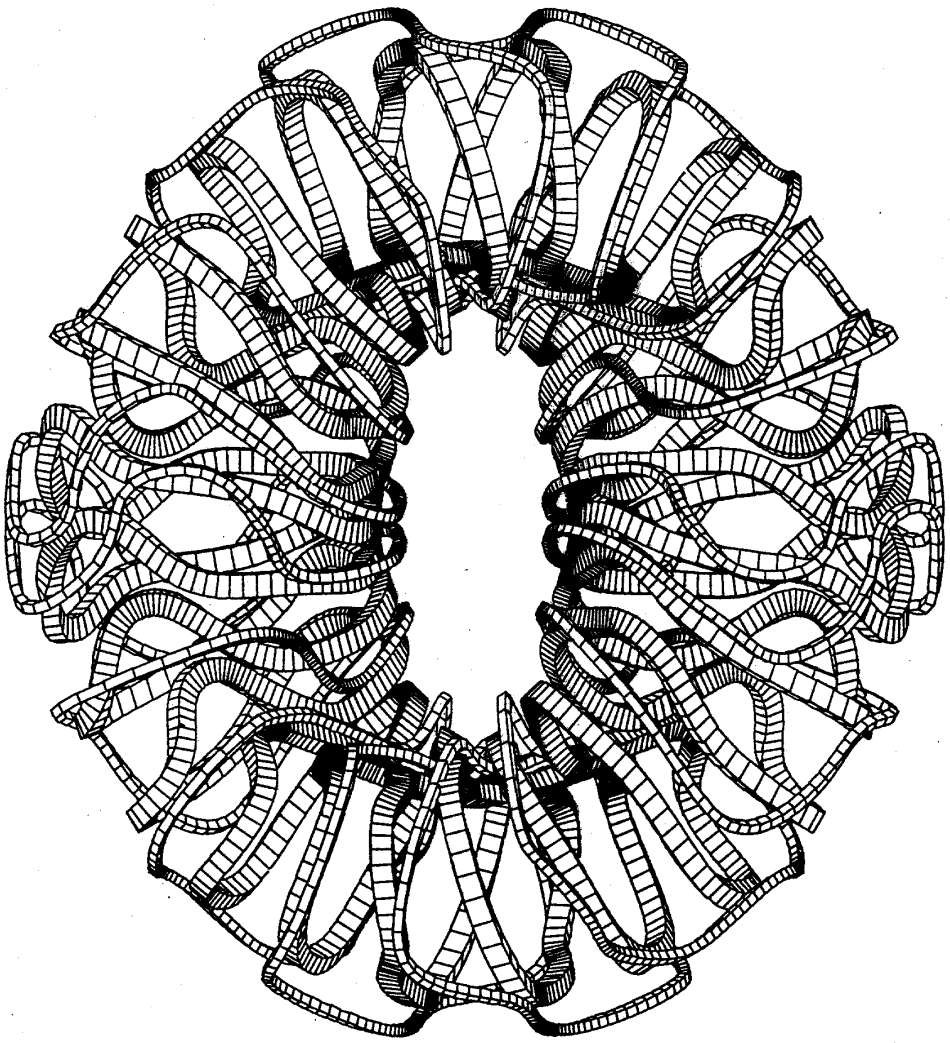
Fixed-boundary equilibrium of a quasi-axisymetric tokamak configuration: Aspect ratio $A \approx 4$, $< \beta > \approx .03$, rotational transform $\iota \approx 0.51$(axis), 0.56(edge), toroidal plasma current $I_{\text{tor}} = -0.015 \cdot I_{\text{pol}}$, $I_{\text{pol}} =$ coil current



Free-boundary equilibrium of the above case obtained in the external field of the main coil set. The coils are determined such that the fix-boundary plasma configuration is reproduced.



Poincaré plots of the vacuum field produced by the main coil system Boundary (red) of the quasi-axisymmetric tokamak, filament carrying surface (blue)



Coil system for a quasi-axisymmetric tokamak, Main coil set $N_c = 12$ coils per period. Auxiliary coil set $N_c = 8$ coils per period.

SUMMARY

- New optimization procedure including ballooning stability gave higher beta limit with a reduced Shafranov shift.

- Total machine design was made for a selected configuration (N = 2, R = 1.5 m, Bt = 1.5 T). Additional toroidal coils and three sets of poloidal coils are included.

- The effect of coil positioning error was examined. It was much smaller than expected if the profile of the rotational transform does not cross low order rationals.

- Modular coil design for the finite beta equilibrium is possible but it does not fit continuous range of beta. Additional coil gives the configuration fit only for the second selection of beta.