History and Scientific Strategy from CHS experiment to CHS-qa program

National Institute for Fusion Science

Research Enhancement Strategy Office

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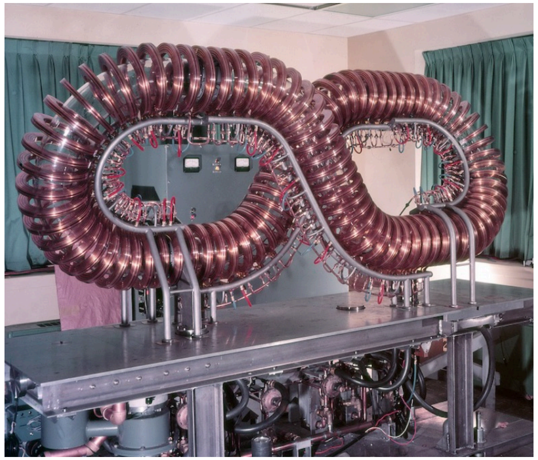
Development of early stellarators

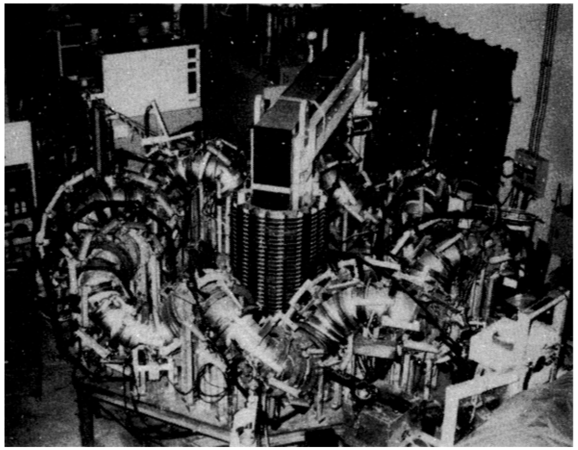
Princeton stellarators in 1950s to 1960s

C-stellarator → ST tokamak in 1970



B-3 stellarator

Helical axis torus at Tohoku univ. Japan in 1970s

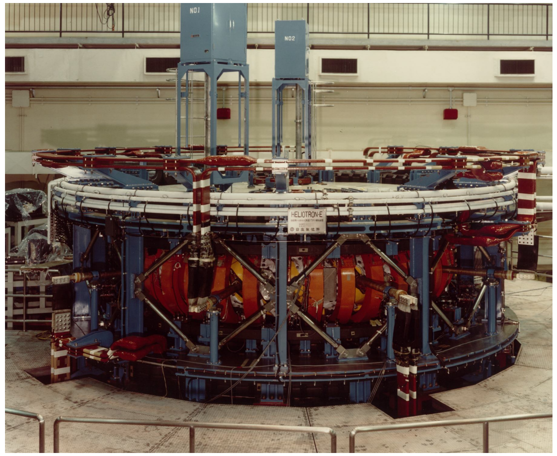


Asperator NP-4

Interchangeable module stellarator (IMS) in Wisconsin univ. USA 1980s

Heliotron series and Wendelstein series

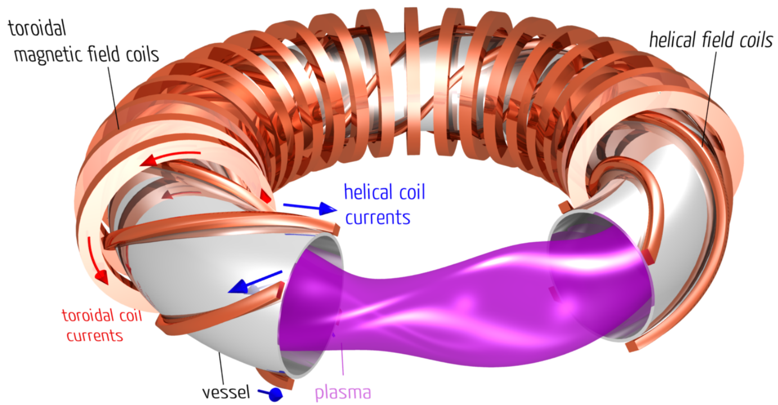
Heliotron-E 1980



Heliotron A → B → C → D →

in Kyoto univ. Japan
from 1960s

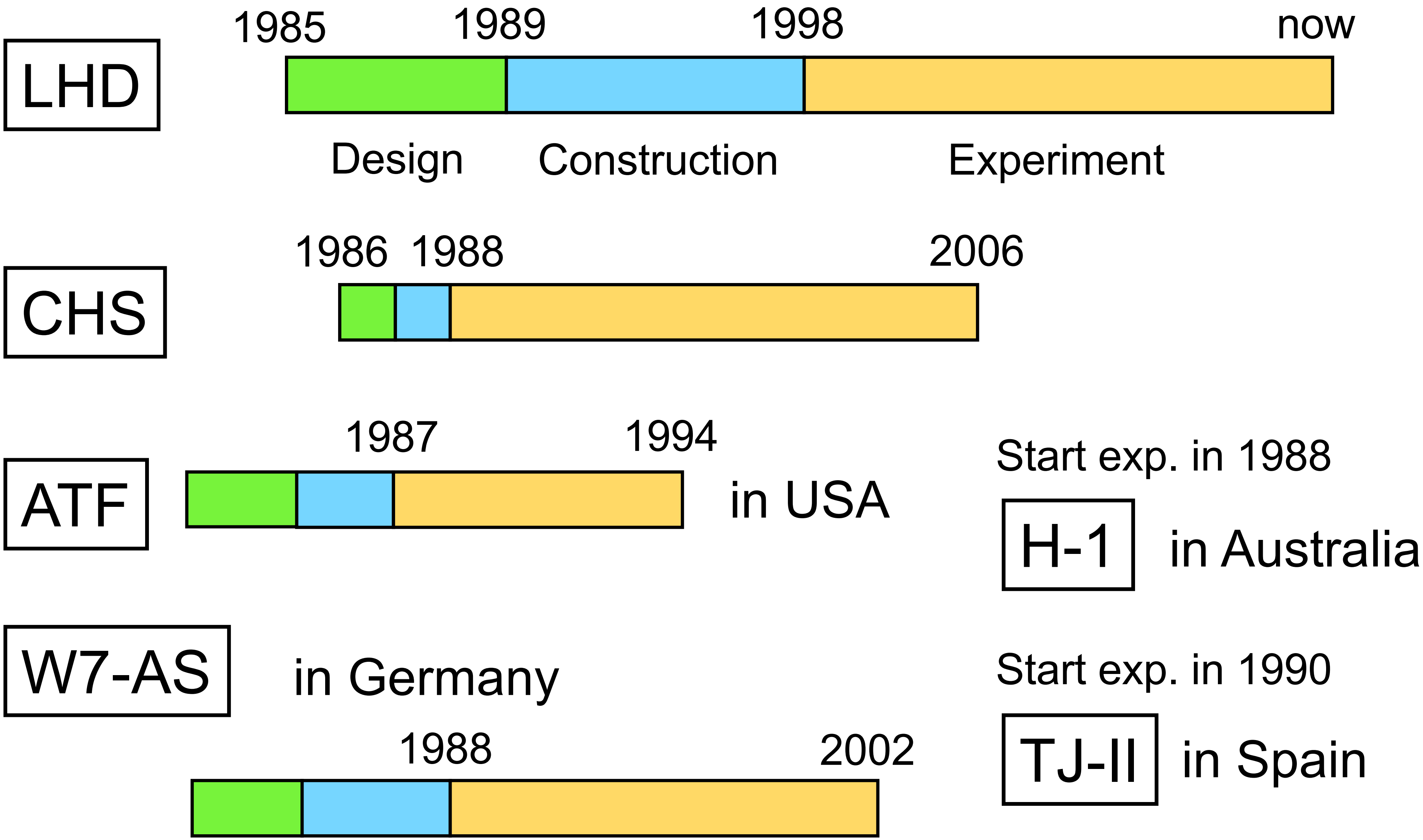
Wendelstein 7-a 1975



Wendelstein 1 → 2 → 3
→ 4 → 5 → 6 →

in Garching Germany
from 1960s

New stellarator experiments in 1990s



Aspect ratio and toroidal period number

Wendelstein 7-a stellarator 1975 — Aspect ratio $A_p = 20$

Heliotron-E 1980 — $A_p = 11$ — Toroidal period number $N = 19$

ATF 1987 — $A_p = 7$ — $N = 12$

LHD 1998 — $A_p = 6.5$ — $N = 14$, $N = 10$

CHS 1988 — $A_p = 5$ — $N = 8$

Role and objetives of CHS experiment

- Confirm good confinement characteristics of low aspect ratio stellarator. Put top priority on realizing low aspect-ratio ($A_p = 5$).
- Take great care of accuracy of magnetic field and device. We thought it is especially important for low aspect-ratio device.
- Do not take so much care about neo-classical transport (confinement of high energy ions).
- Second priority is to develop high-level diagnostics for innovative physics studies in stellarator.
- In device design, take special care on port arrange-ments for diagnostics.

Magnetic coils for CHS

Toroidal period number

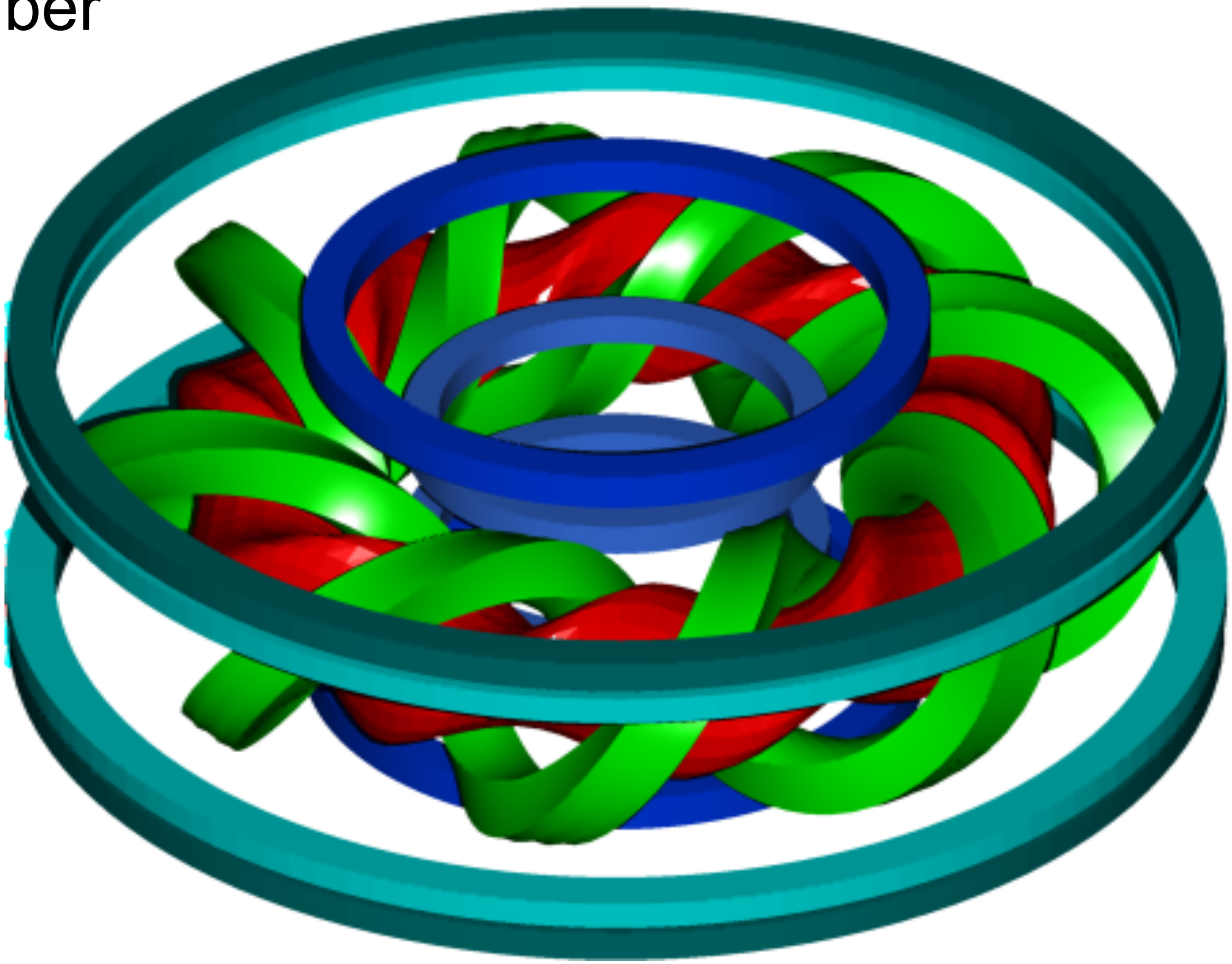
$N = 8$

Magnetic field

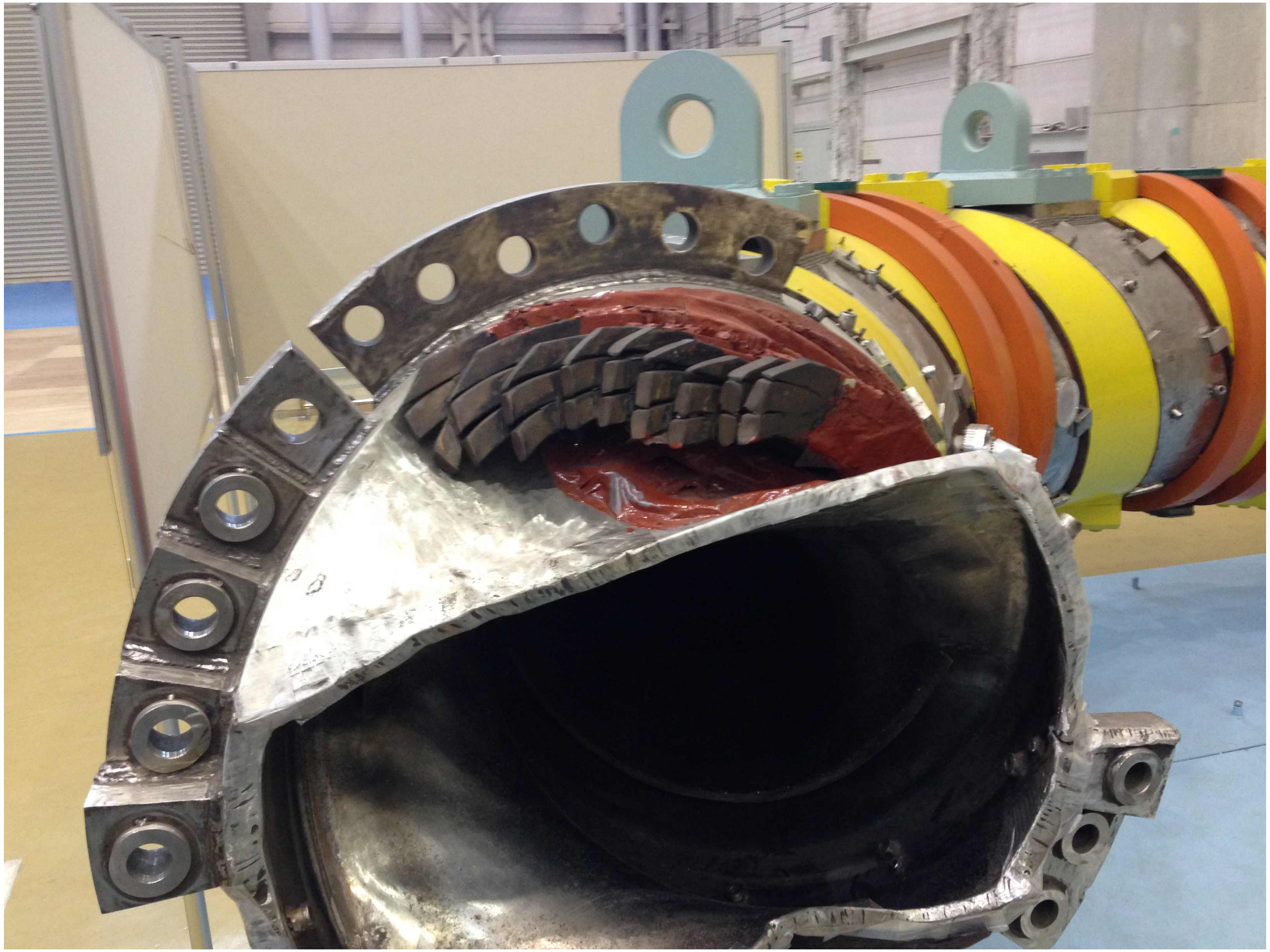
$B_t = 2$ T (max)

Poloidal coils

3 pairs for plasma control in positioning and shaping



Helical coils and vacuum chamber of Heliotron-E



Vacuum chamber and coil support of CHS

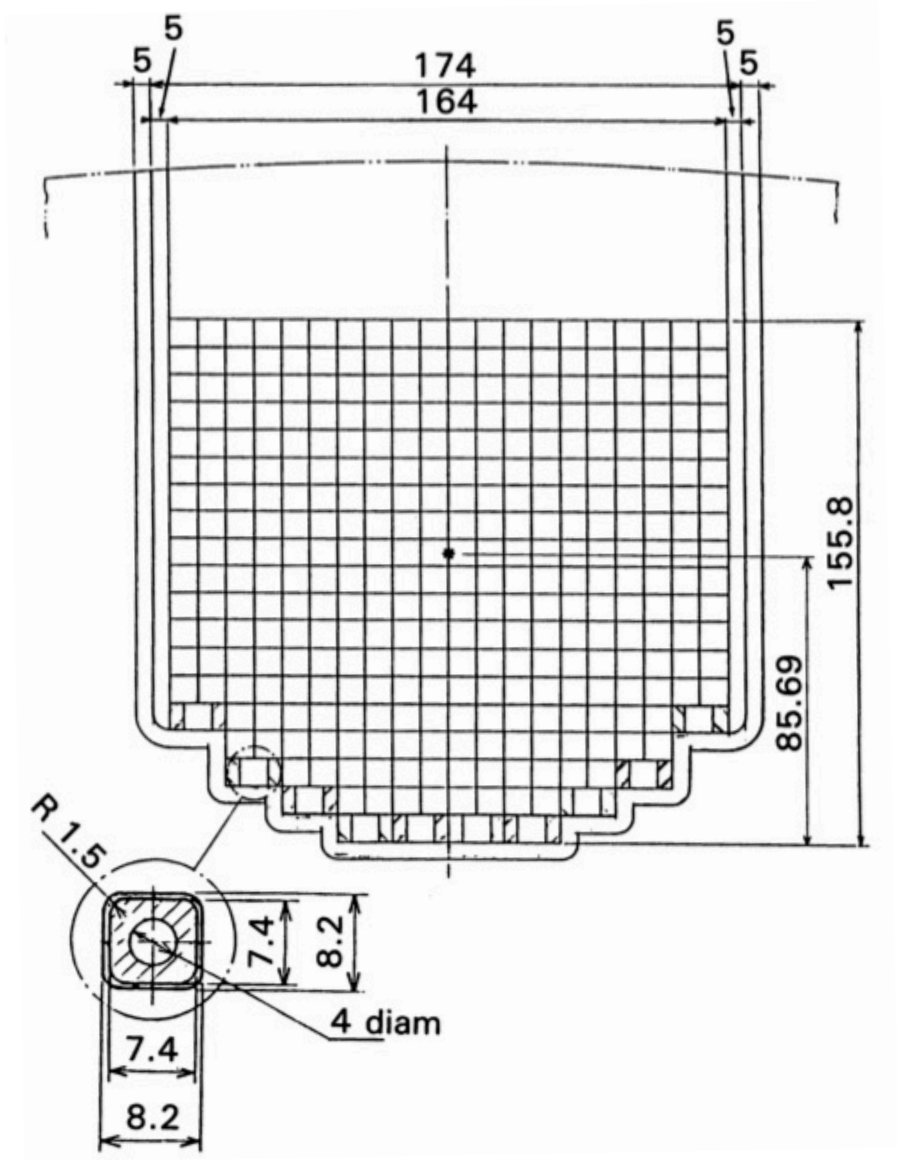
Special care was taken for the accuracy of device and magnetic field

Use NC lethe for making vacuum chamber wall and magnetic coil winding frame

Cross section of helical coil of CHS

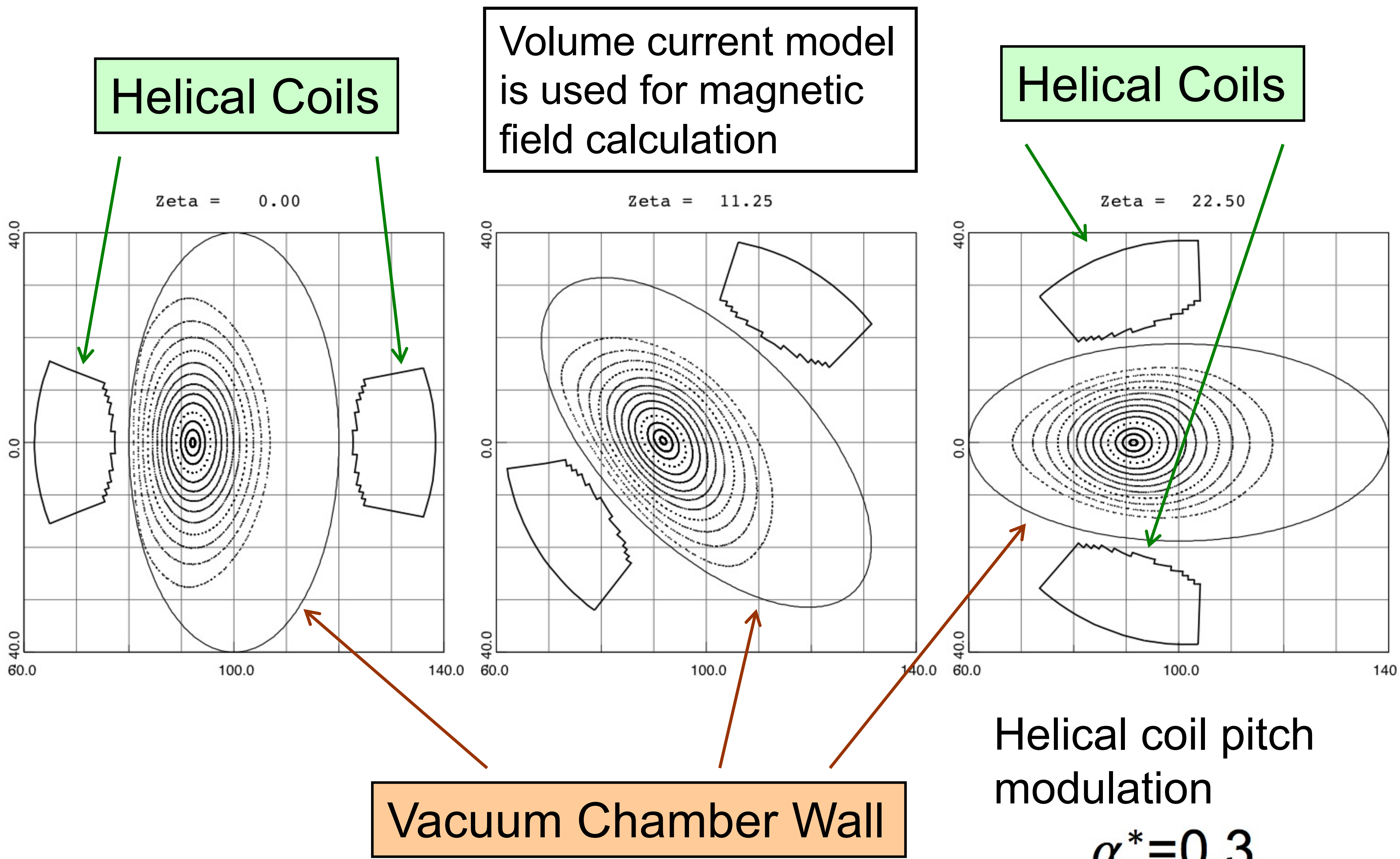
342 turns of conductors with 3.655 kA current

Total current of each helical coil is 1.25 MA for 2 T magnetic field



Helical coil winding work

Magnetic surfaces of CHS



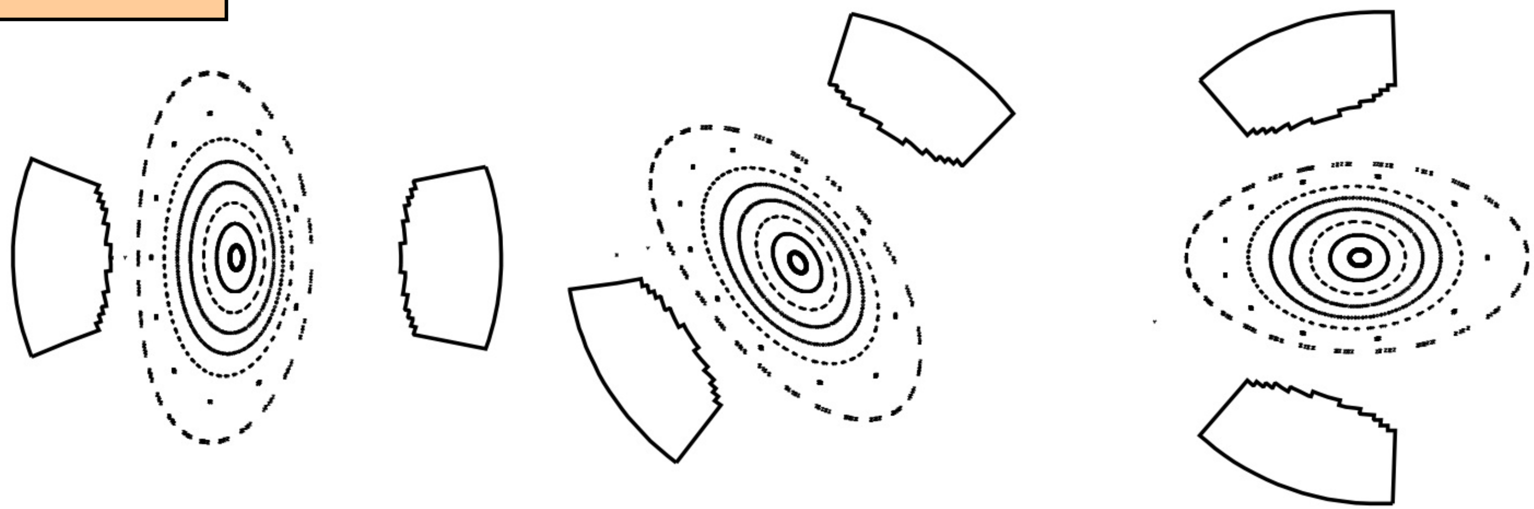
Helical coil pitch modulation

$\alpha^*=0.3$

Pitch modulation gives larger magnetic surfaces

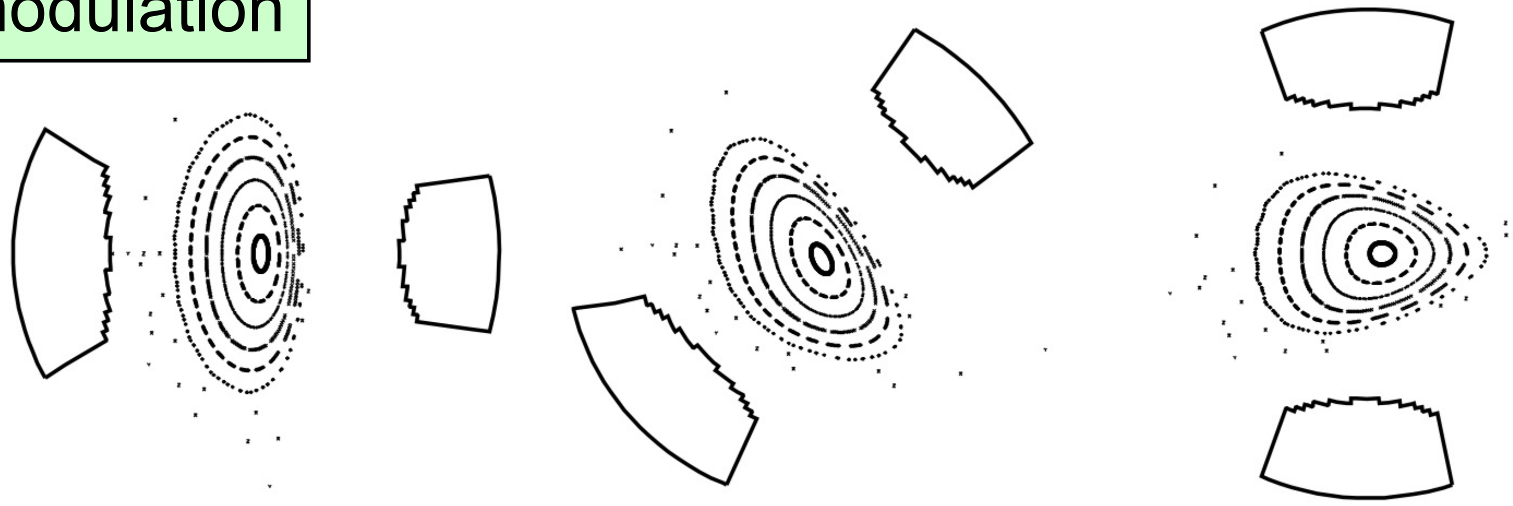
CHS helical coils

$\alpha^*=0.3$



No pitch modulation

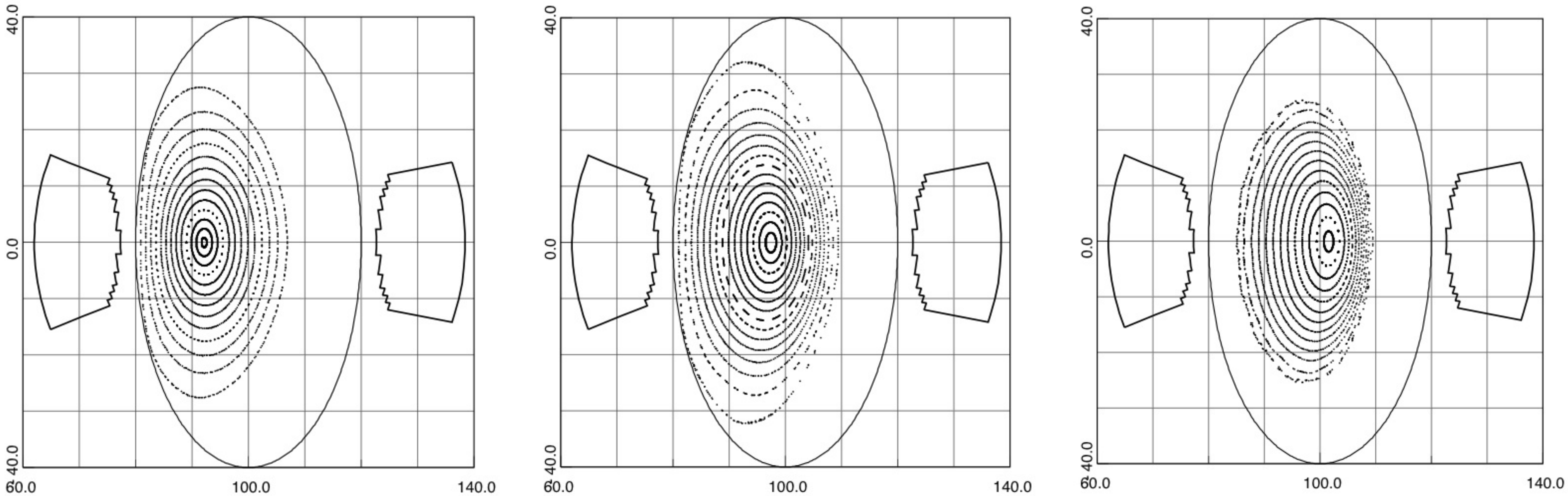
$\alpha^*=0.0$



CHS magnetic surfaces with poloidal field control

Strong B_{vert} | Maximum size | Week B_{vert}

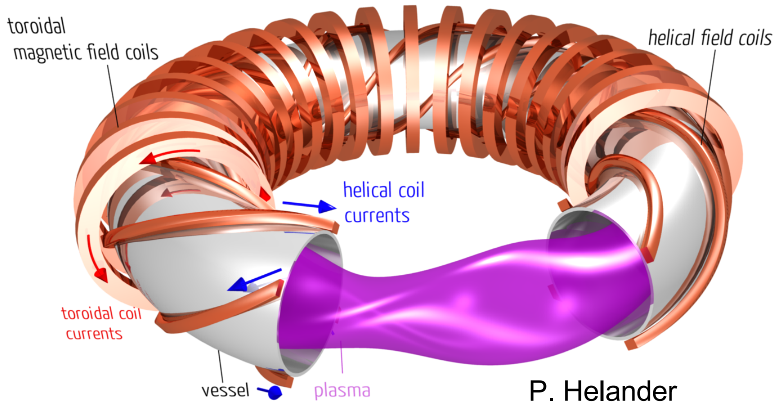
Rax = 92.1 cm | Rax = 97.4 cm | Rax = 101.6 cm



a = 21.1 cm Ap ≤ 5

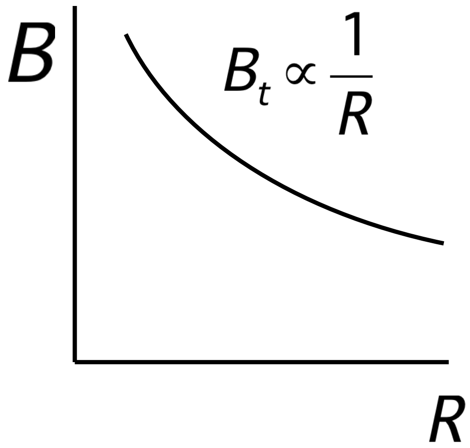
Ap ≤ 5 is obtained only if helical coil pitch modulation is $\alpha^{*}=0.3$

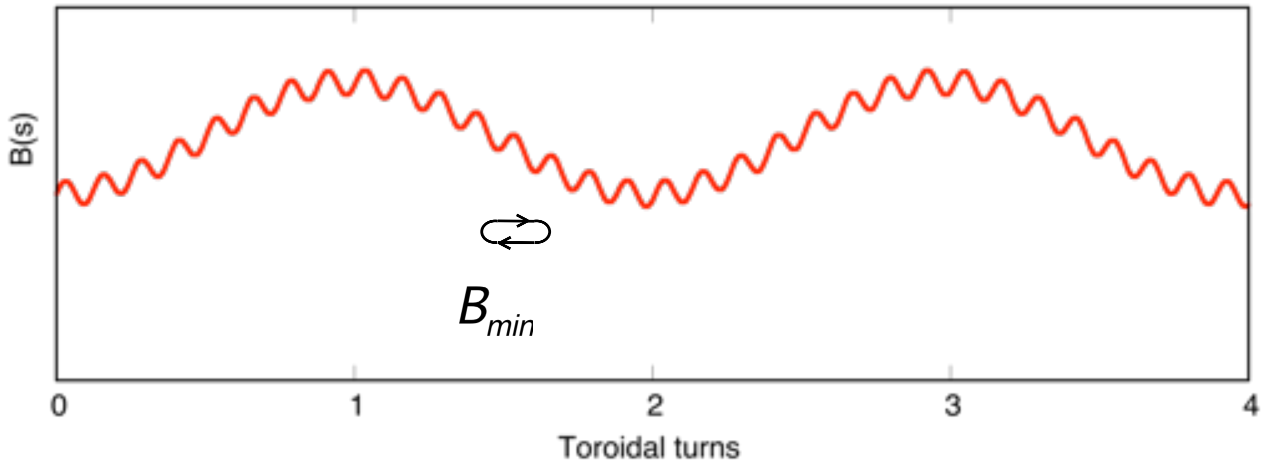
Ripple structure of classical stellarator

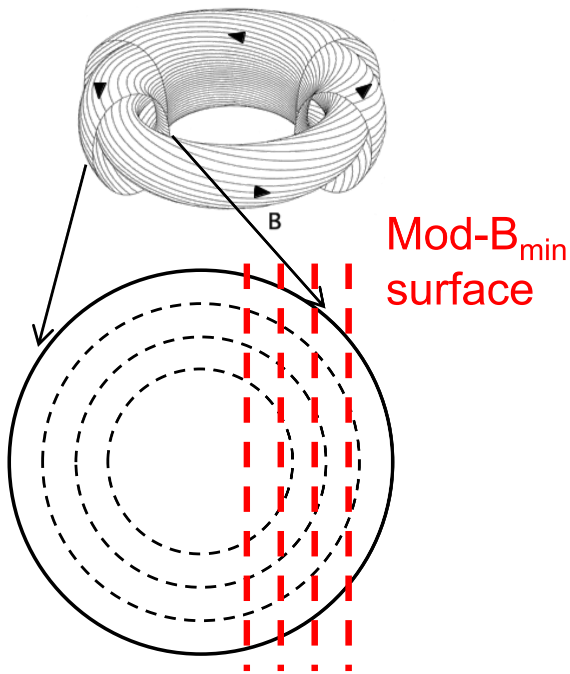


$I_t >> I_h$

Strong toroidal field
Week helical field

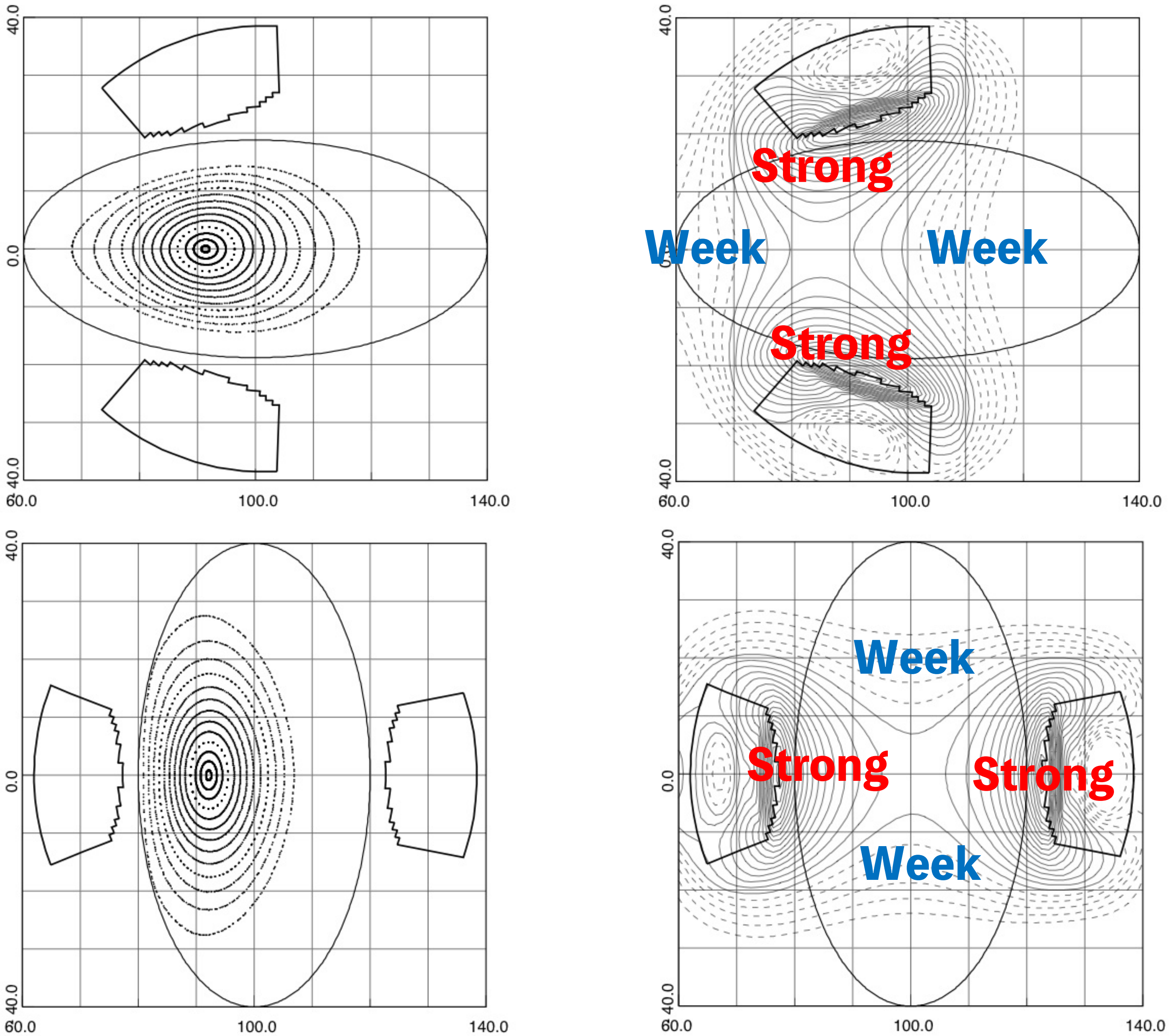






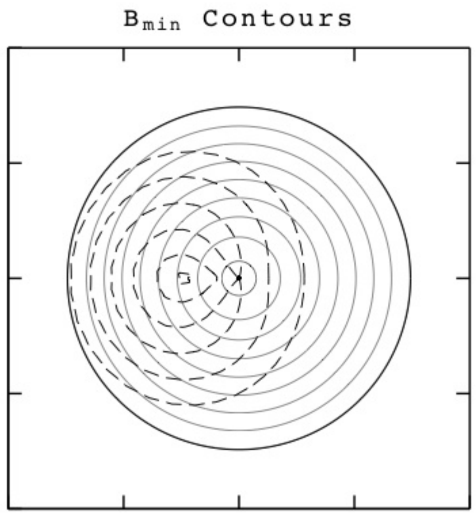
Trapped particles in helical ripples escape along Mod-B_{min} surface

CHS magnetic surfaces and contour map of B



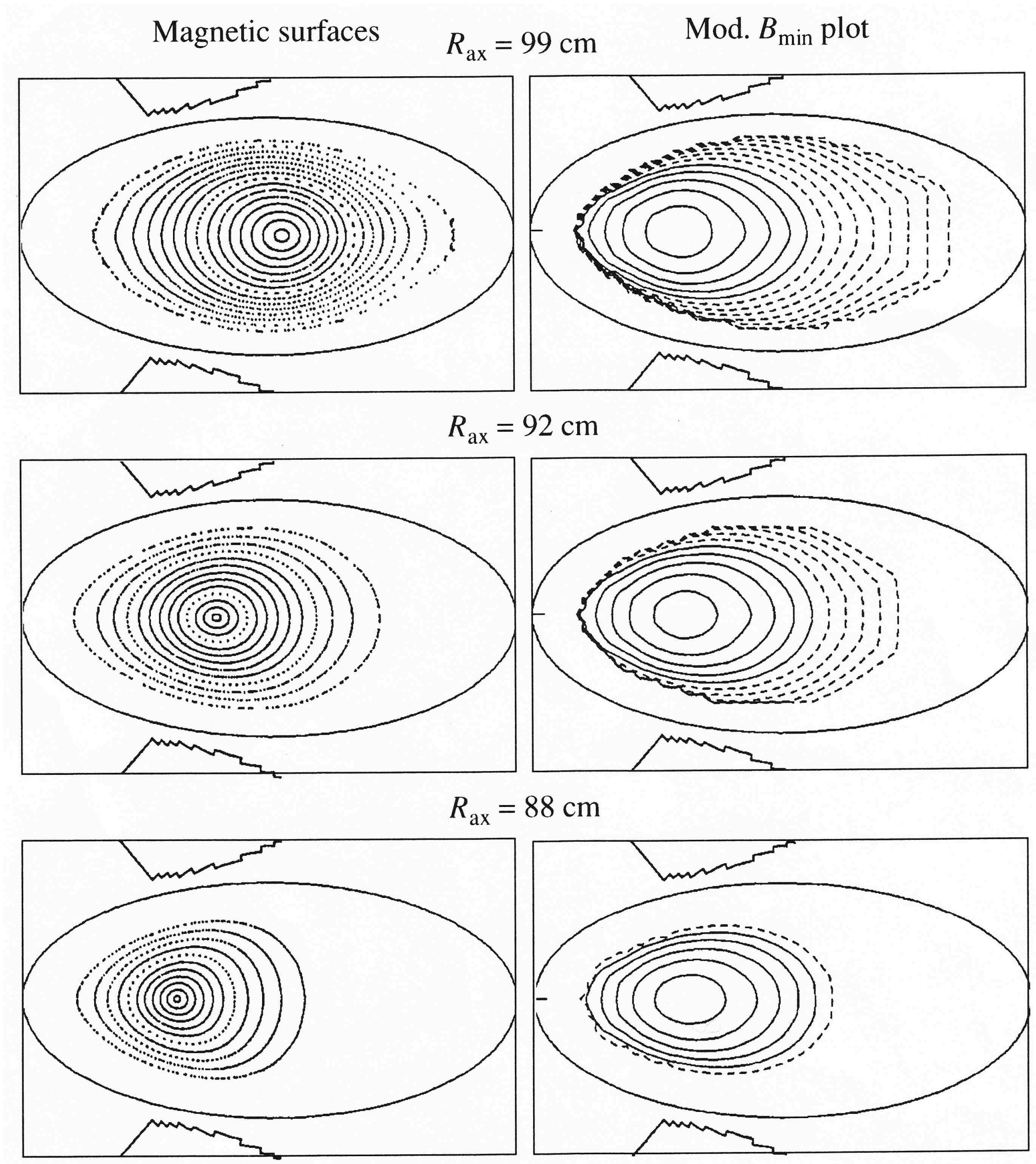
CHS Mod.B min plot

Magnetic coordinate

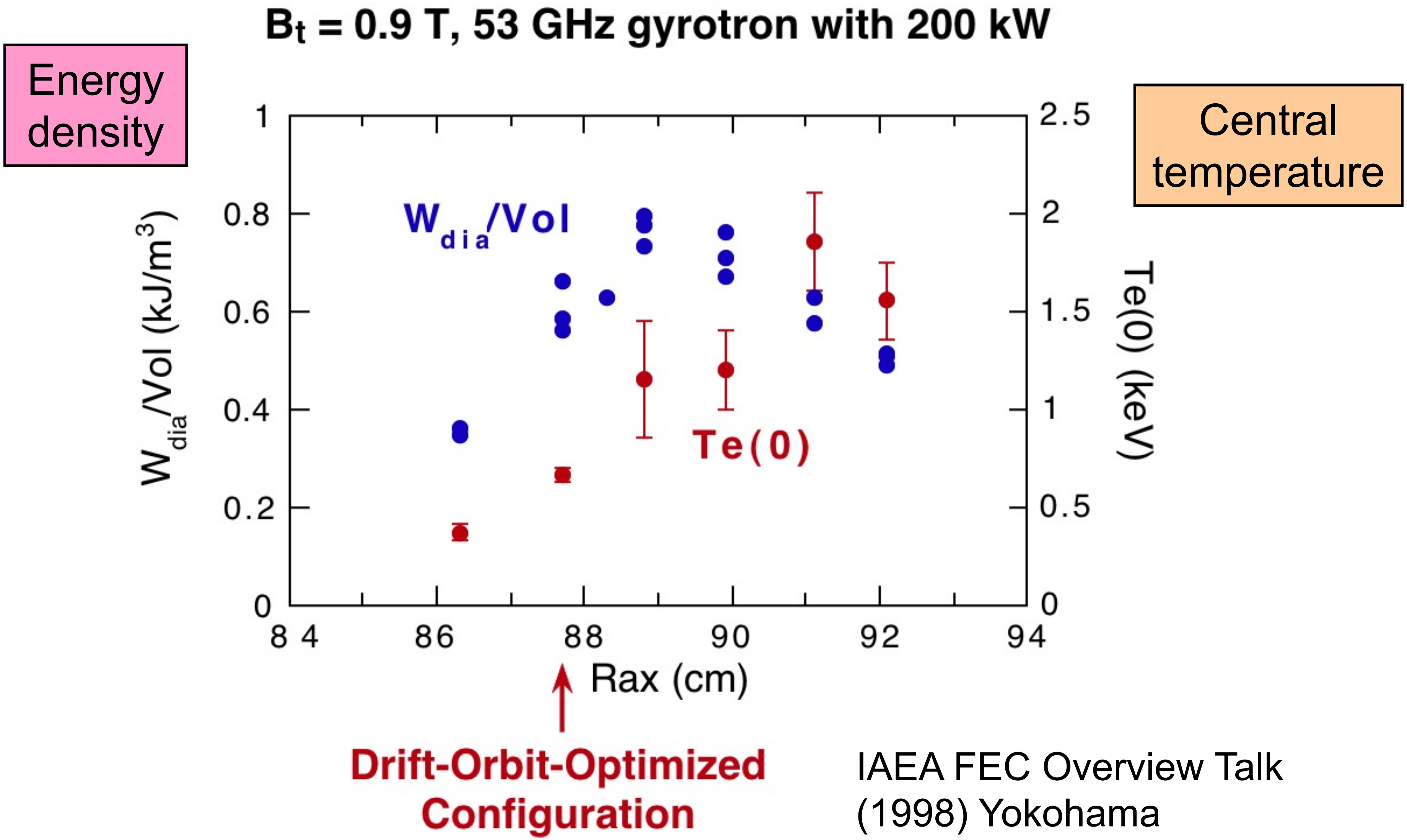


Coaxial circles show magnetic surfaces

Doted lines show trapped particle orbits

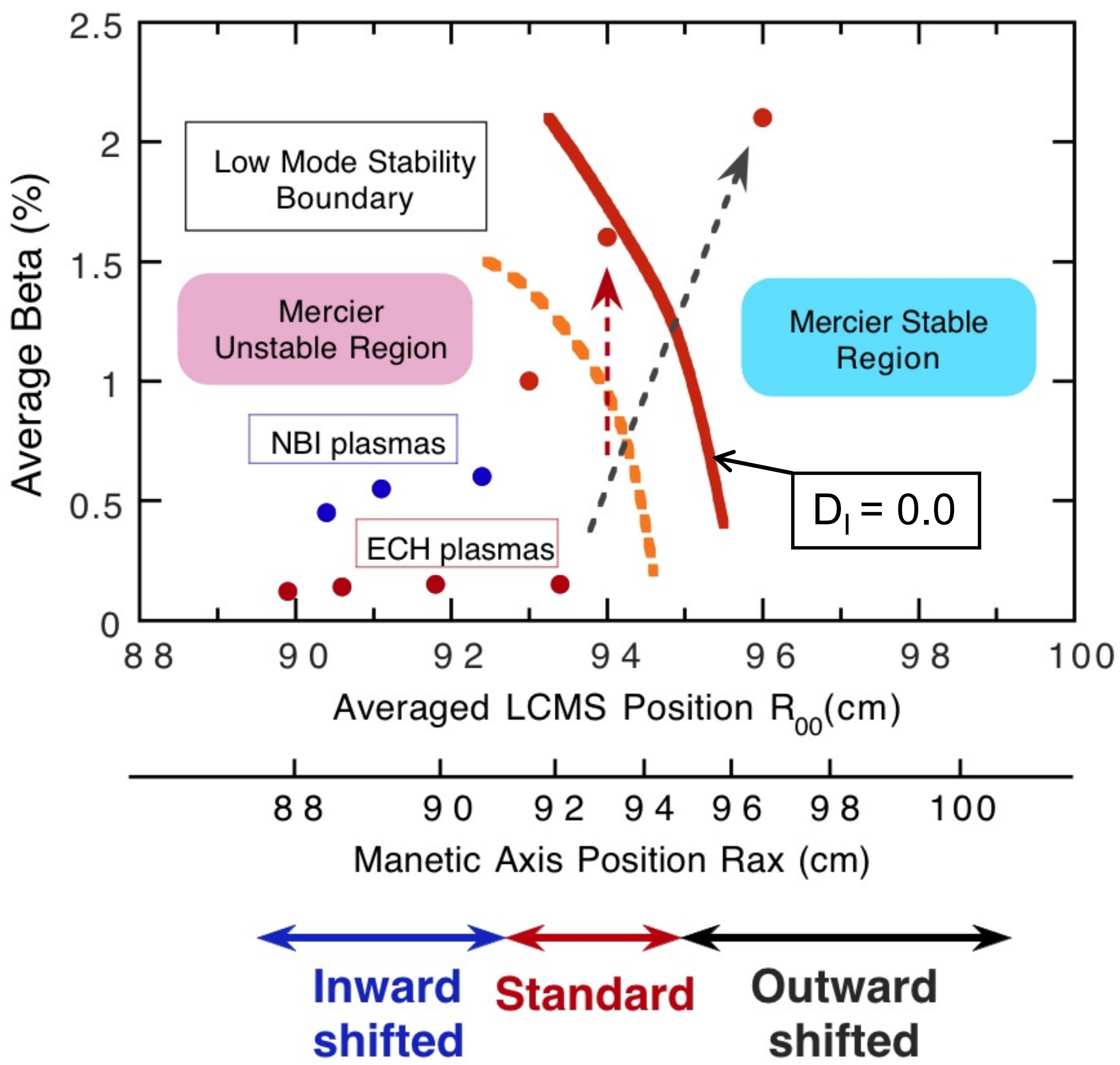


ECH plasmas for drift-orbit optimization



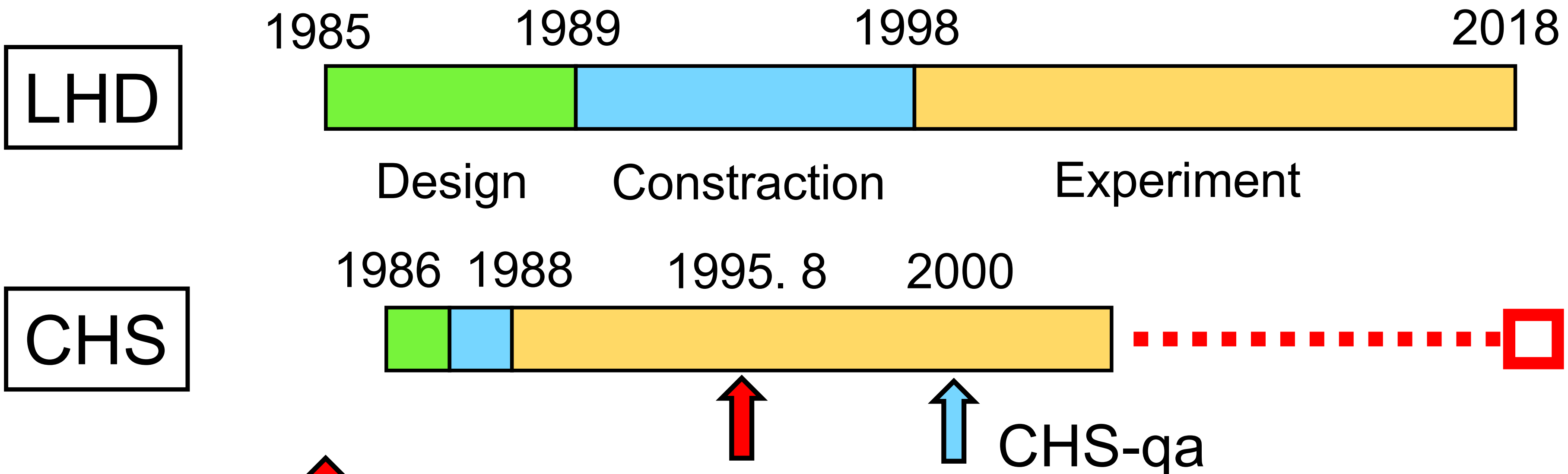
IAEA FEC Overview Talk (1998) Yokohama

MHD stability for CHS high-beta plasmas



Plasma with 2% averaged-beta stays in Mercier stable region while many discharges stay in Mercier unstable region

Next step to CHS experiment



1995. 8

Start discussion for next step program to CHS

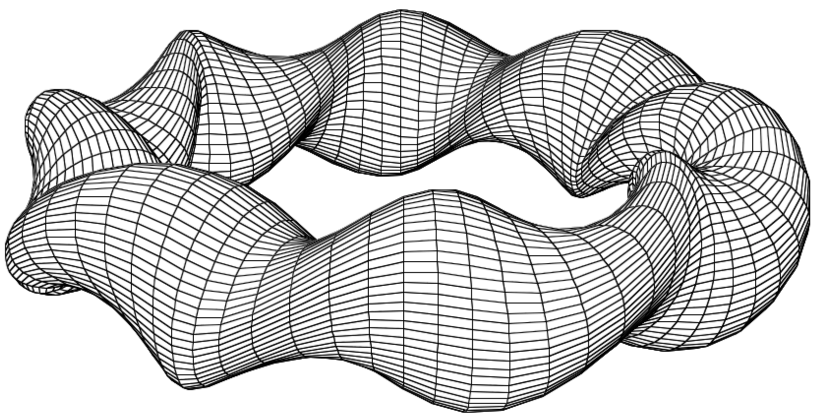
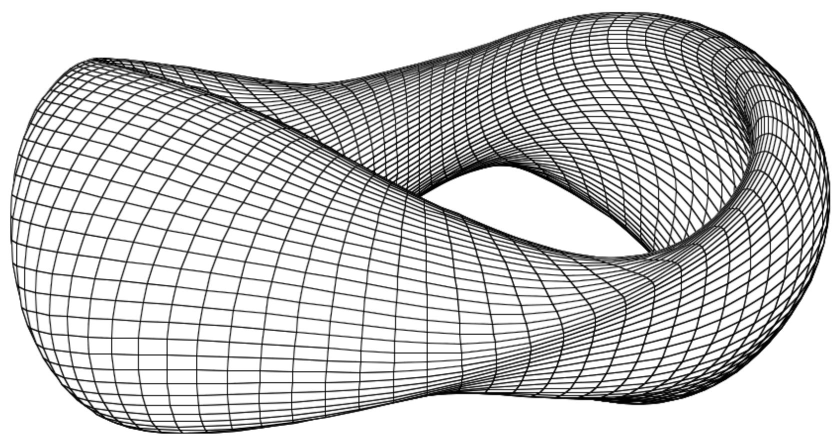
Lower aspect ratio for compact reactor

Obtain good confinement and stability simultaneously

2000

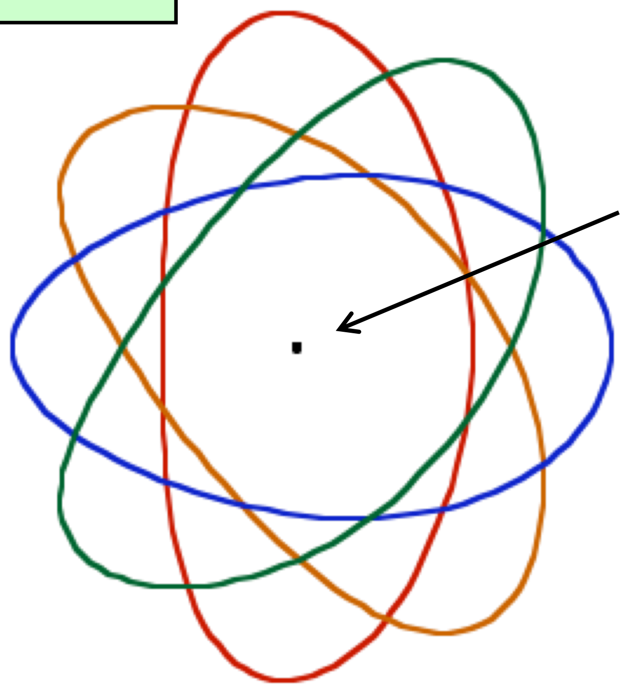
Submit proposal of CHS-qa experiment to NIFS

from CHS to CHS-qa

Conventional Stellarator	Quasi-axisymmetric stellarator
$B(s) = B(\phi,\theta) = \sum_{m,n} B_{mn} \cos(m\theta - n\phi)$	$B(s) = B(\phi,\theta) \cong B(\phi)$
	ϕ : toroidal, θ : poloidal angles
Magnetic surface of CHS	Magnetic surface of CHS-qa
	
Plasma aspect ratio Ap = 5	Ap = 3.2

Cross sections of CHS and CHS-qa

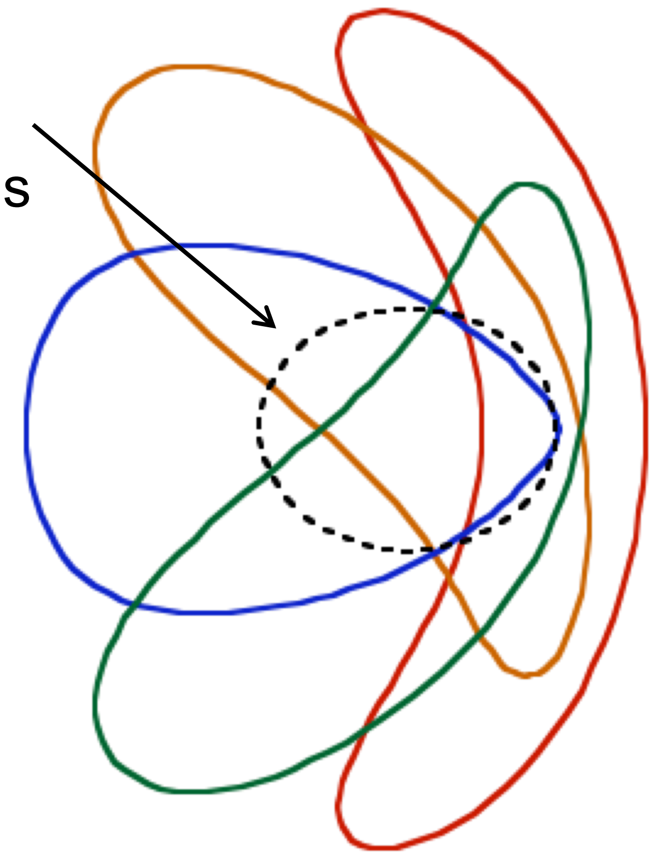
CHS

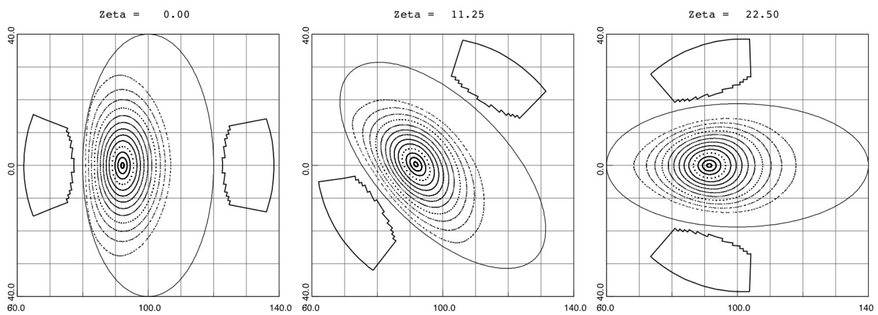


CHS-qa

Helical axis

Excursion of magnetic axis



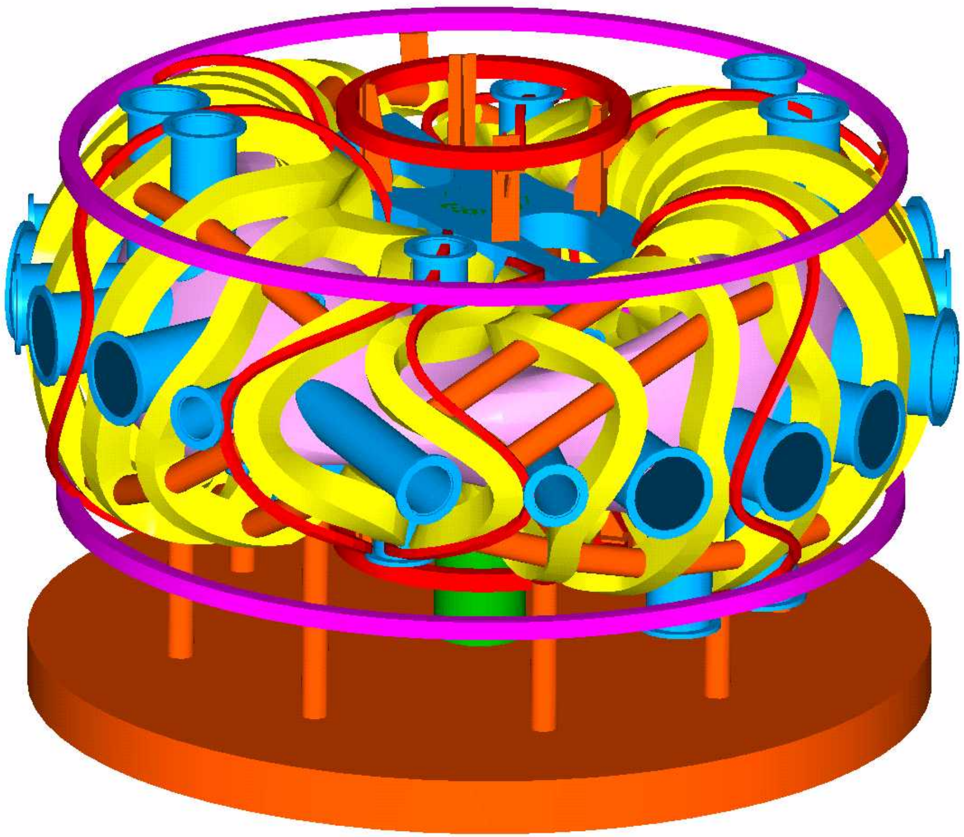


CHS-qa device design

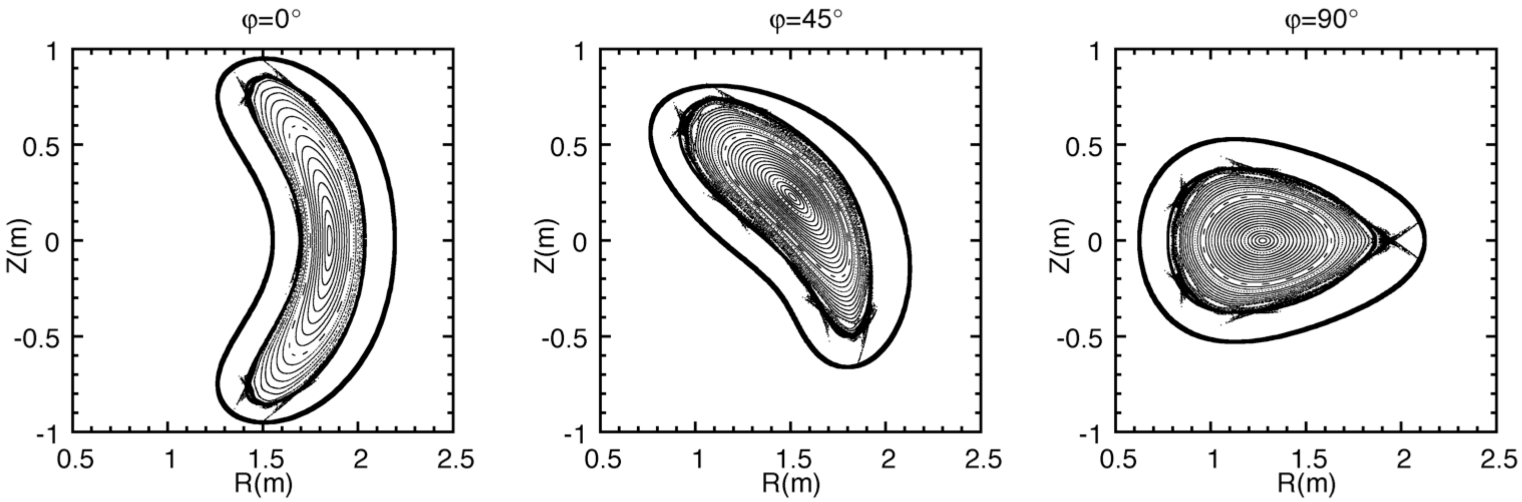
R = 1.5 m
a_p = 0.38 m
B = 1.5 T
N = 2
A_p = 3.9

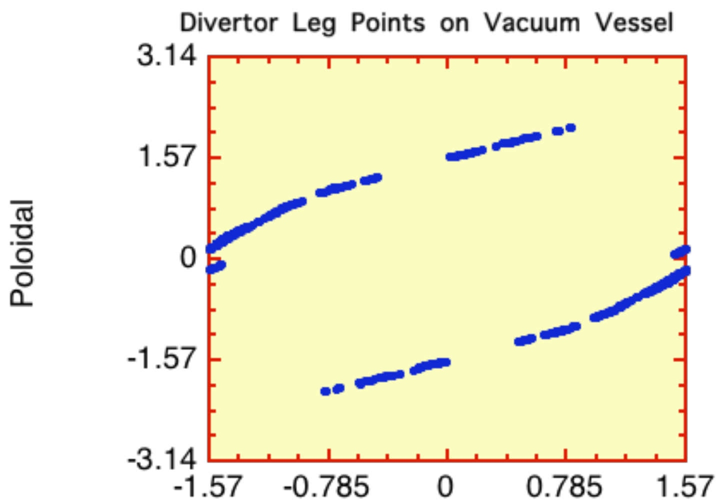
Device design was completed with mechanical supports for coils and diagnostic port arrangement

In addition to main yellow modular coils, configuration control is available with auxiliary red and magenta coils

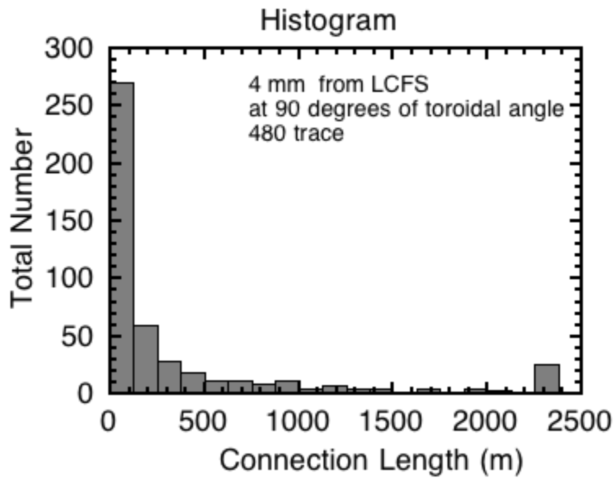


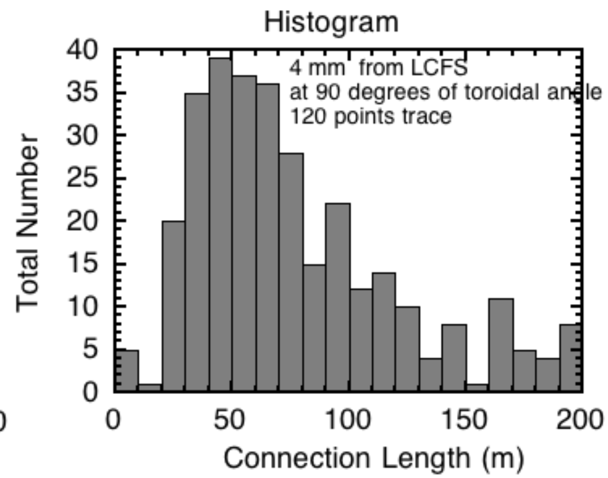
Divertor structure of CHS-qa





Distribution of divertor field line length to first wall





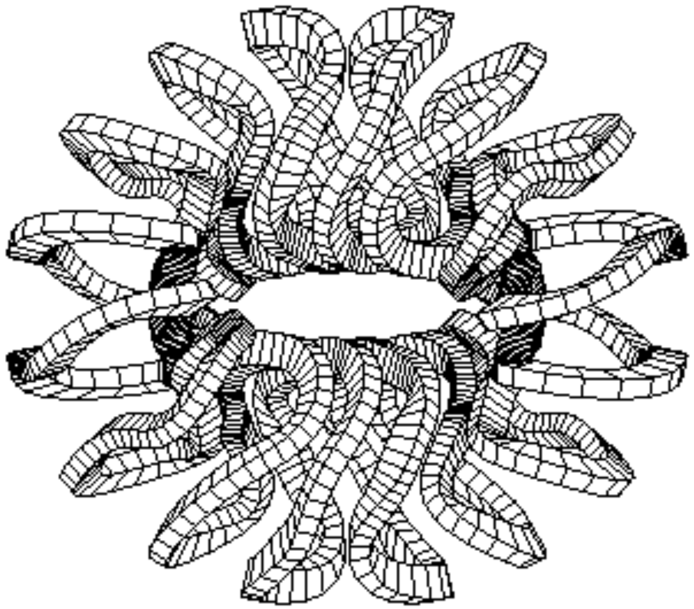
NSJP for Japan and China Cooperation

NSJP NIFS and SWJTU Joint Project

Japan	China

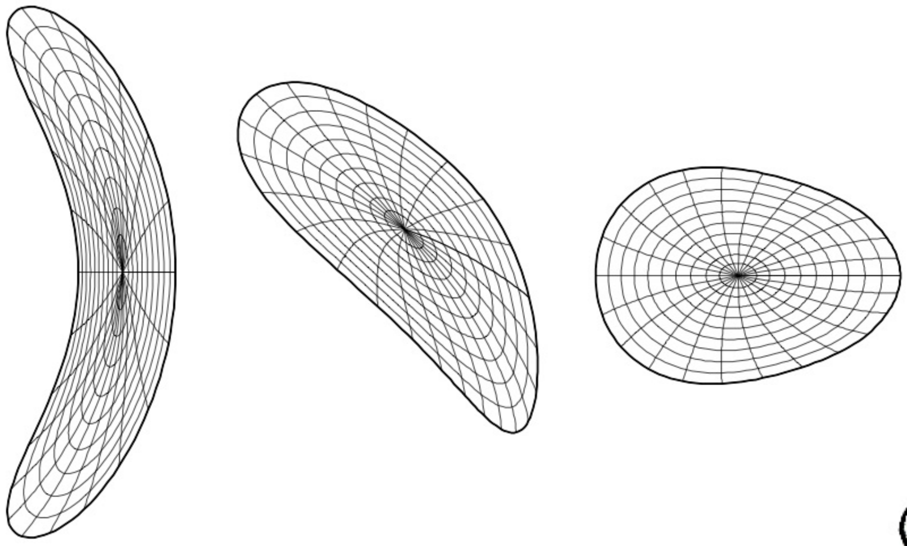
- Collaboration in device design
- Plasma heating facilities from CHS
- Plasma diagnostics from CHS
- International collaboration in experiment

CFQS stellarator

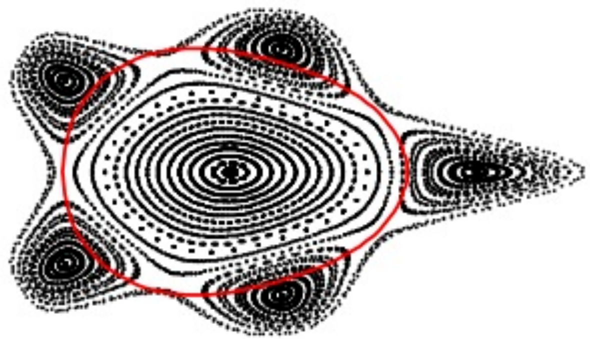


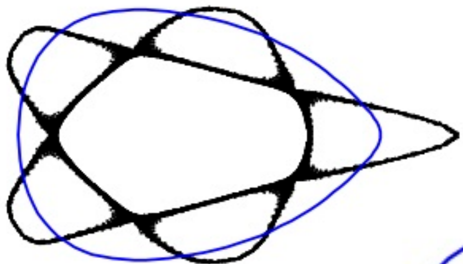
What is new in CFQS

Plasma boundary shape



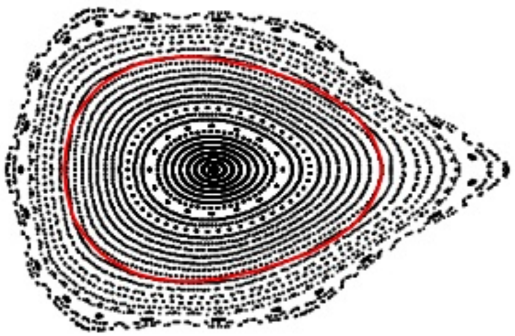
Island Bundle Divertor (IBD)



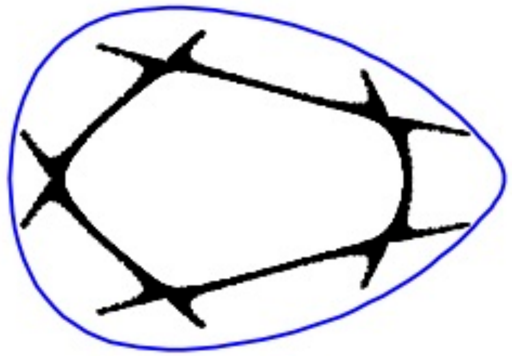


Similar to tokamak divertor

Magnetic surfaces



Advantage :
As many as ten divertor feet



Summary

- CHS experiment was planned to guarantee a good confinement in low aspect-ratio stellarator in preparation to a major program of LHD in NIFS.
- CHS-qa was designed to investigate confinement in a further low aspect-ratio stellarator with good stability and neo-classical transport.
- A new quasi-axisymmetric stellarator CFQS is designed with an innovative divertor concept of "island bundle divertor".