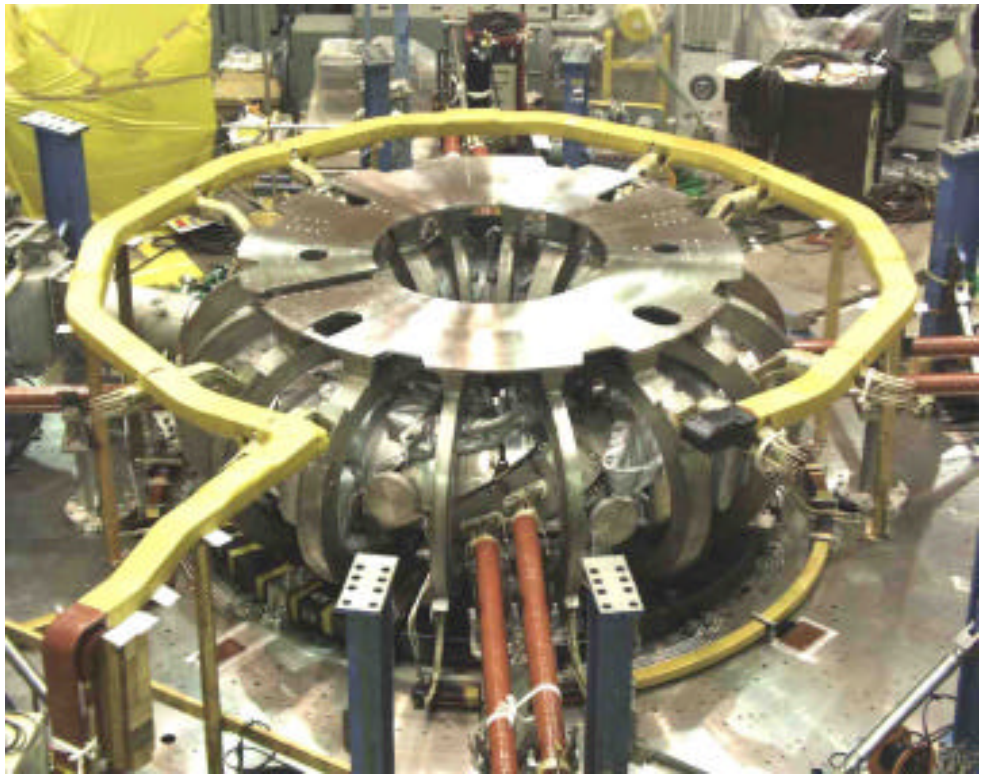
Design and Construction of Heliotron J

An optimization study of a helical-axis heliotron



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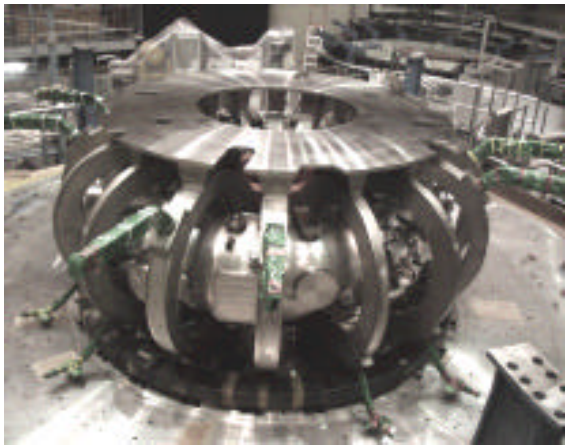


Outline

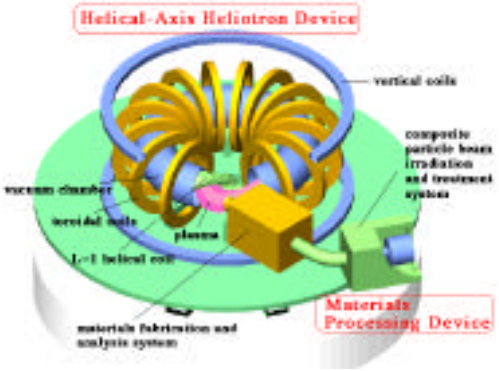
The Heliotron J Project

1. Introduction
2. Objectives
3. Physics design
4. Construction of Heliotron J
5. Summary

Conceptual design of Heliotron J

Basic physics studies of plasma confined in a helical-axis heliotron device for the joint experiment of plasma and materials

Heliotron J



Motivation:

to explore the problem confronted in Heliotron E, i.e.

" full compatibility between good particle confinement and MHD"

in the heliotron line

planar axis

Heliotron E

Inward magnetic axis shift experiments

- good particle confinement

but

- magnetic hill

Objectives

a new concept exploration experiment

(1) to explore the concept of the nonsymmetric quasi-isodynamic optimization approach to the helical-axis heliotron line

(2) to establish the design principles for the POP facility based on this concept

(3) physics understanding specific to the helical-axis heliotron

Key issues

- **bumpiness control (transport)**
- **edge magnetic well (MHD)**
- **island divertor**

(particle and heat exhaust)

Physics Design

Goal: - An optimized helical-axis heliotron

- to clarify the possibilities and limitations for the quasi- isodynamic (quasi-omnigenous) design of a helical-axis heliotron

A key constraint in physics design :

Helical coil winding law $\theta = \theta_0 + M/L\,\varphi - \alpha \sin(M/L\ \varphi)$

As a first-step device at minimum cost :

$L = 1$ $M = 4$ $\alpha = -0.4$

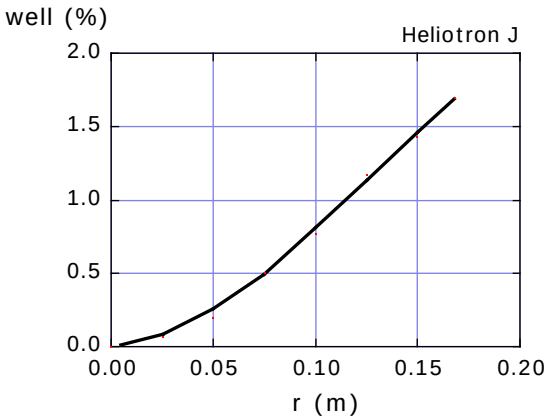
$R = 1.2$ m $\langle a \rangle = 0.1 - 0.2$ m $R/\langle a \rangle = 7 - 11$

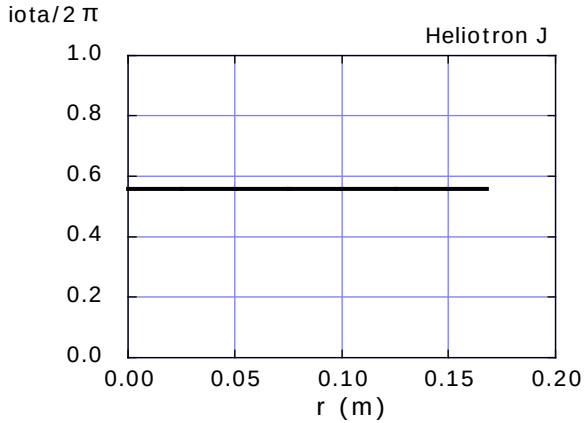
$B = 1 - 1.5$ T $\iota / 2\pi = 0.3 - 0.8\ (0.55)$

Heliotron J parameters achieve :

i) in vacuum
- magnetic well in the whole volume
- medium rotational transform with low shear
- local quasi-isodynamic in the straight section

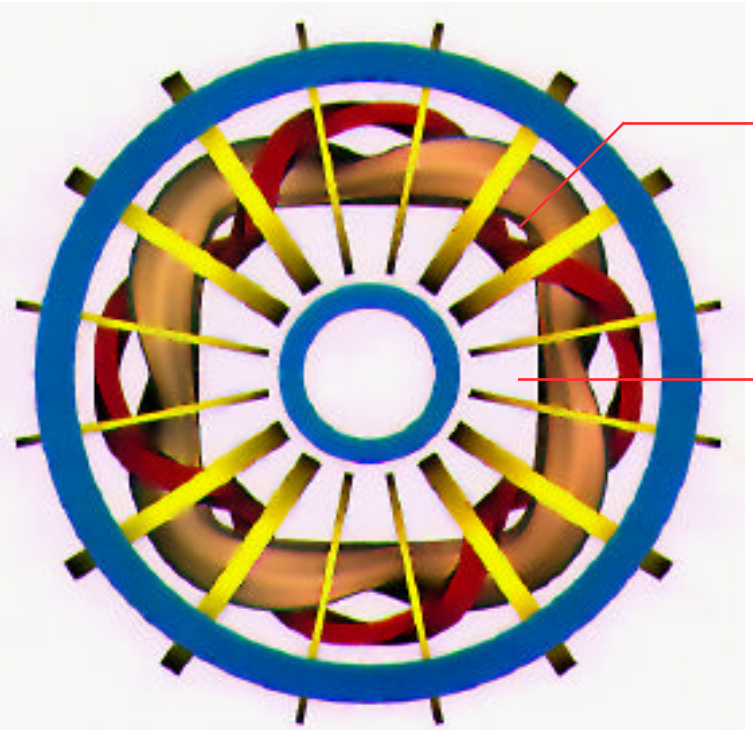
ii) in plasma
- beta induced improvement of collisionless orbits
- electric field induced improvement of collisionless orbits
- beta self-stabilization for interchange modes
- small bootstrap current

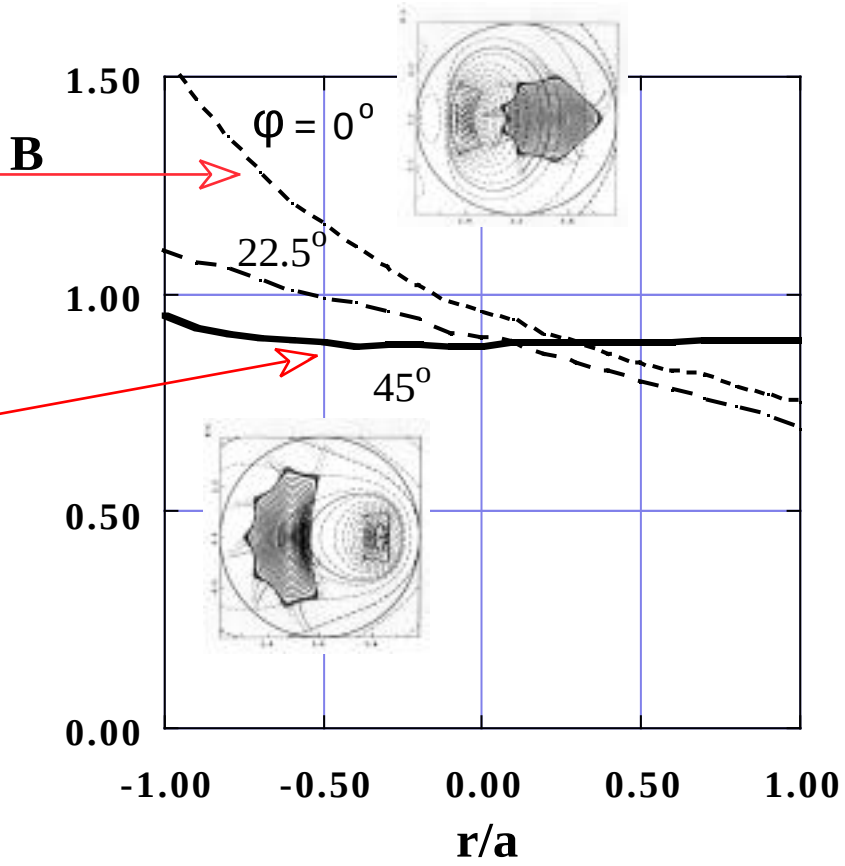




Local quasi-isodynamic in the straigt section

A potential of this concept for the quasi-isodynamic optimization



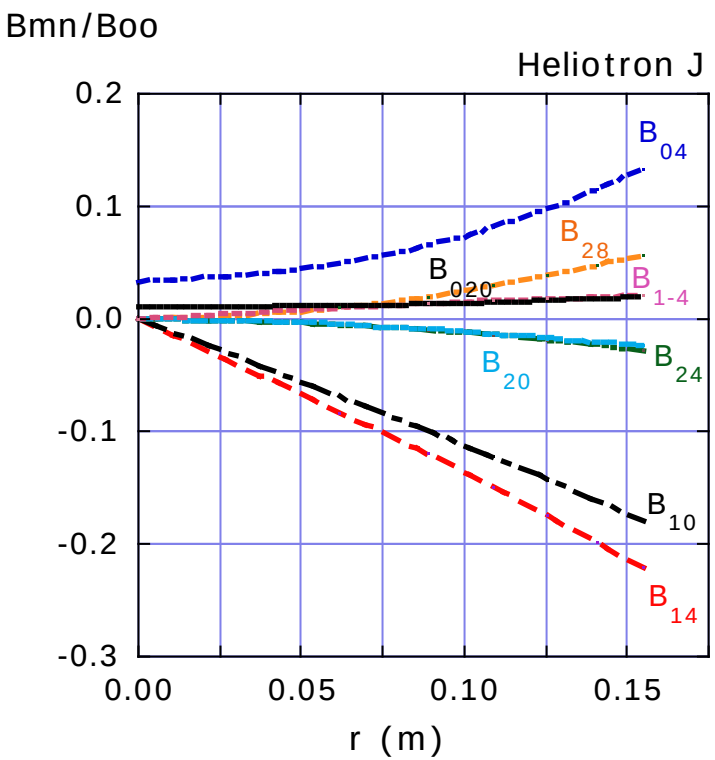


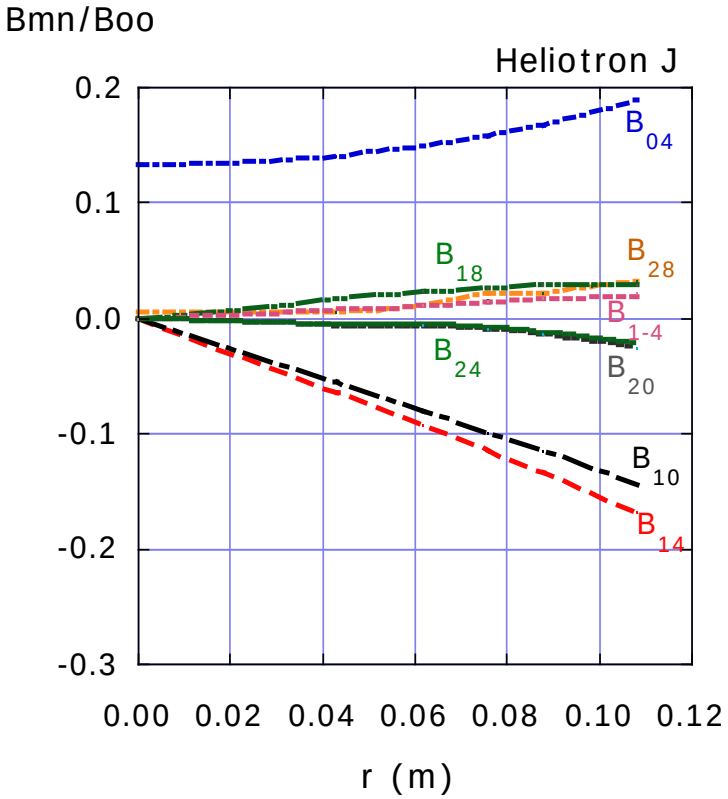
A key issue:

to extend the region of quasi-isodynamic → *bumpiness control*

Heliotron J has enough flexibility toward the bumpiness control for confinement.

a new parameter space in the heliotron line

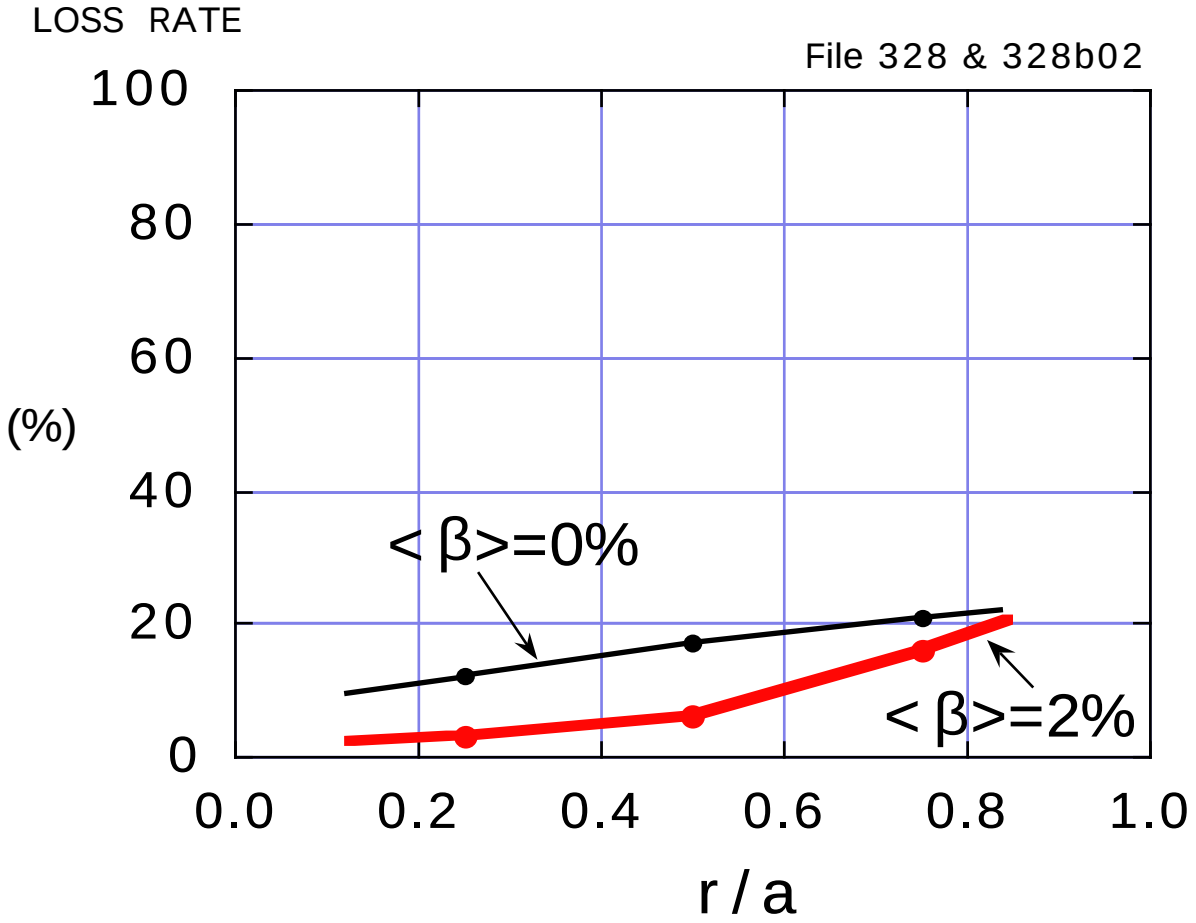


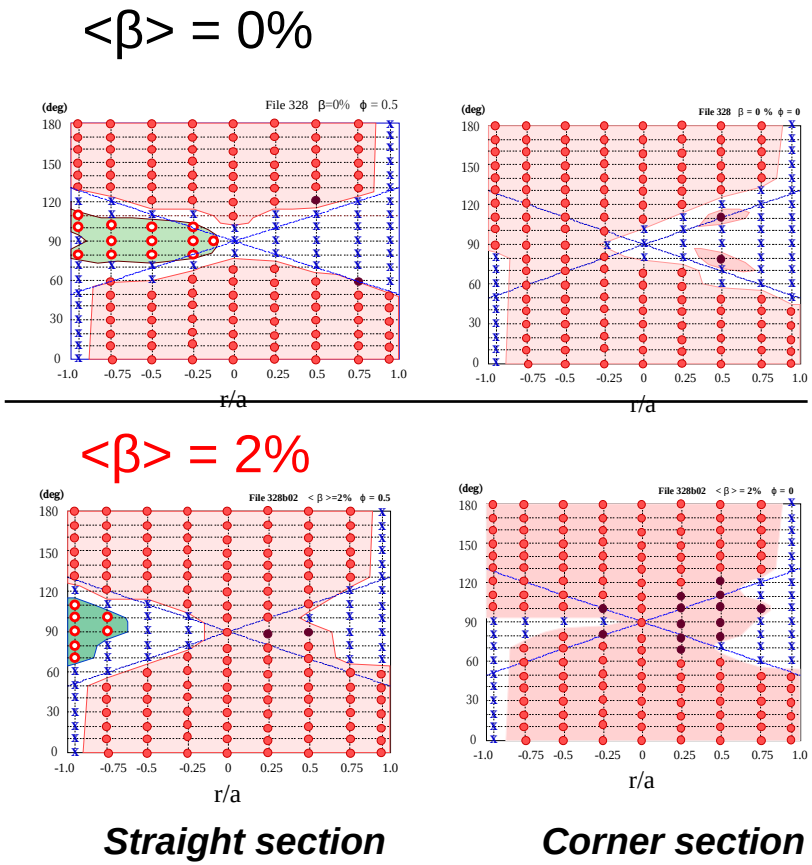


- $\varepsilon_b/\varepsilon_h$ *: wide operation space*
- $\varepsilon_t/\varepsilon_h$ *: narrow operation space, a limitation of Heliotron J*

Collisionless orbit calculations showed that an increase in beta reduces the orbit loss rate (1 keV protons) down to a few % level in the core region.

The diamagnetic effect due to β reduces the value of $\varepsilon_t / \varepsilon_h$.

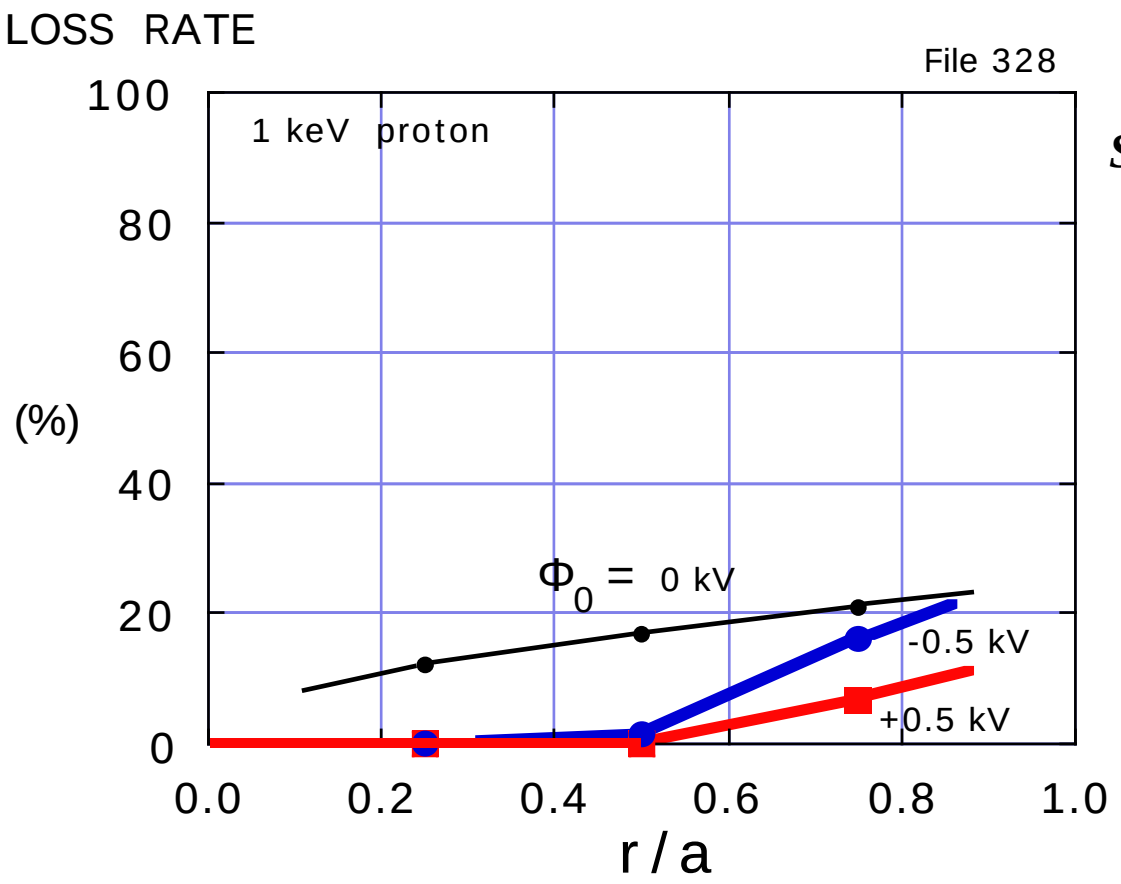




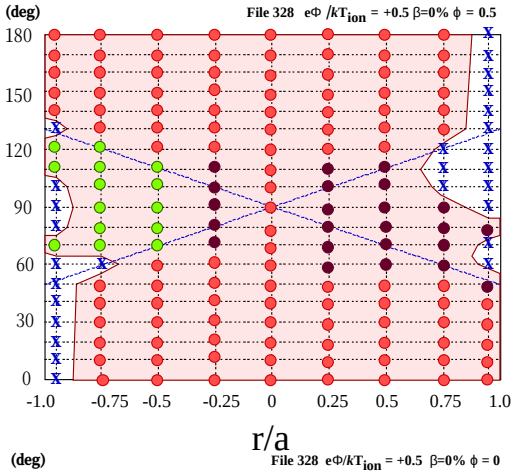
However, we should be careful of the growth of higher harmonics.

Even a weak plasma electric field can reduce the loss rate down to nearly zero % in the core region.

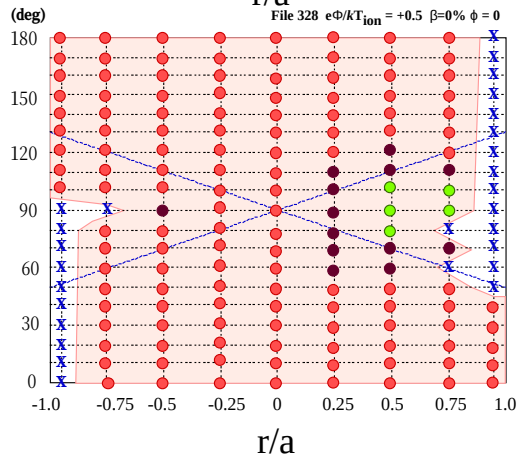
A remarkable feature of the quasi-isodynamic approach which can provide a sufficient poloidal rotation



Straight section

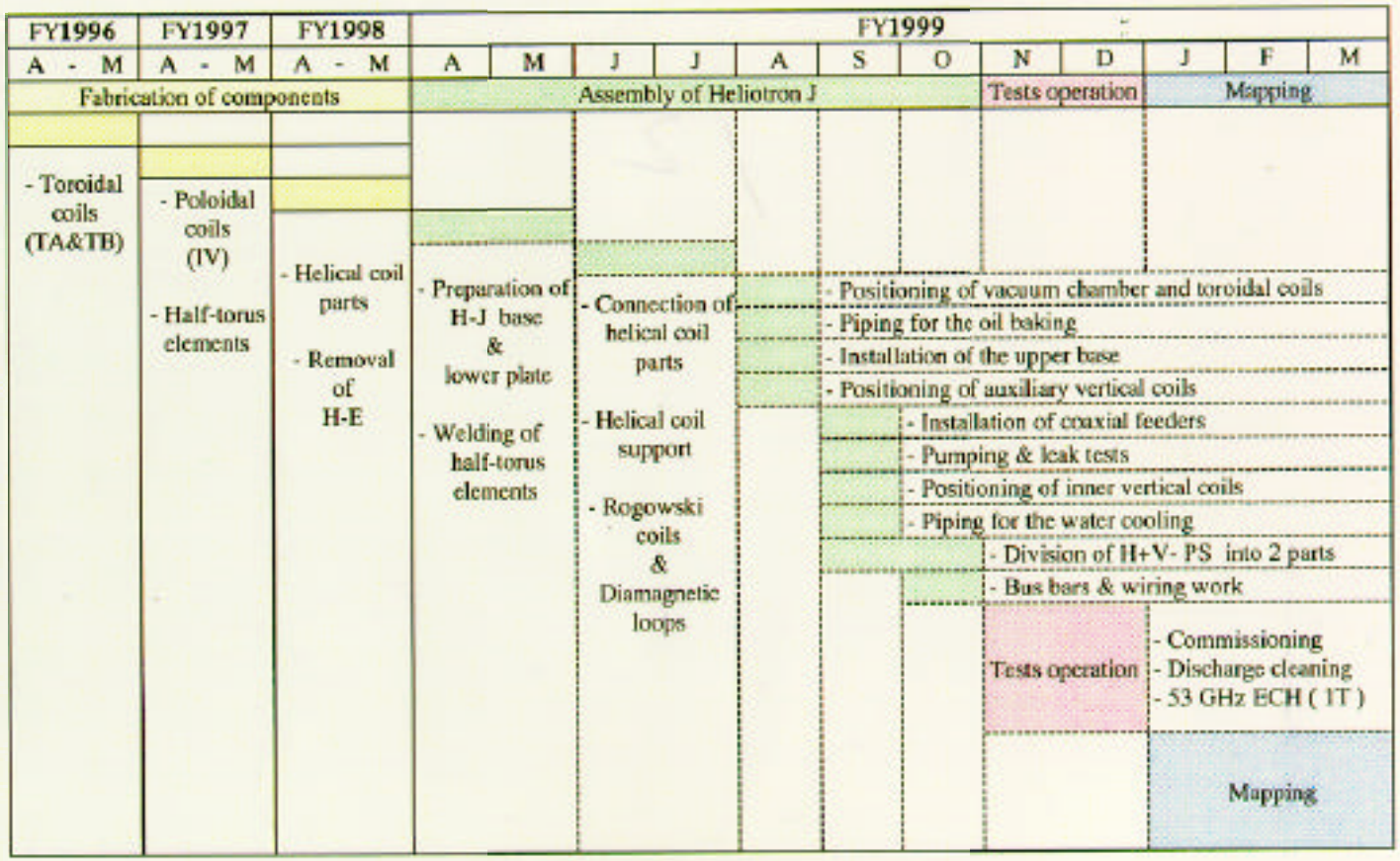


Corner section

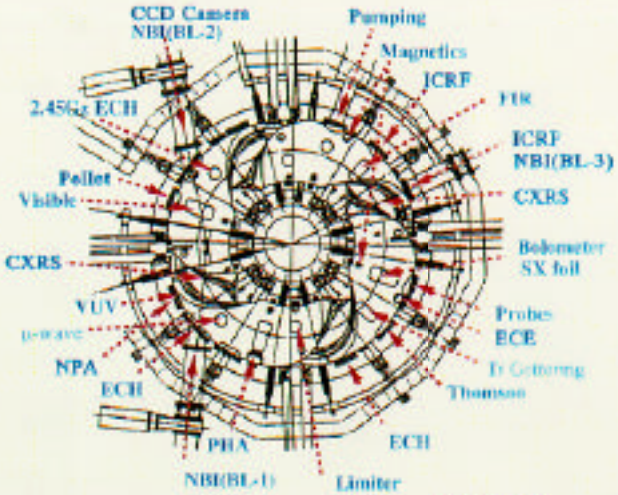


Construction of Heliotron J

a new concept exploration experiment
by utilizing the existing resources from Heliotron E



Experimental Program



Preparations of diagnostics are under way.

Long-term Research Schedule

(FY1999) ***to complete the installation and to start the tests and commissioning of the coil system.***

(FY1999-2002) ***Operation Phase I : to review the data of confinement and stability for further development of the helical-axis heliotron.***

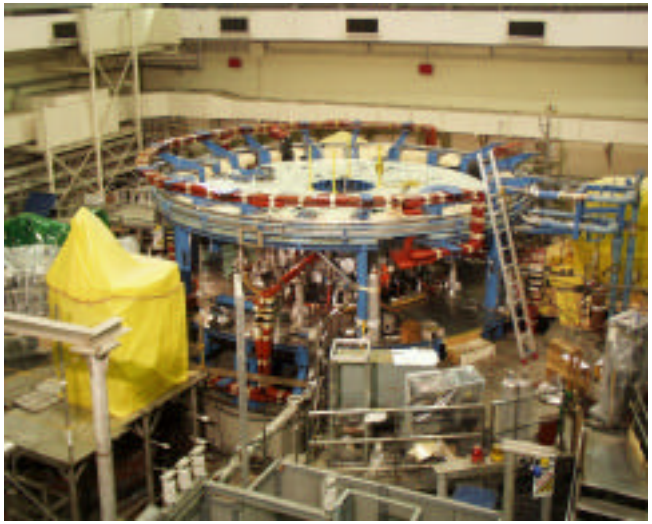
(FY2003-2005) ***Operation Phase II :***

- ***installation of the full additional heating***
- ***achievement of the ultimate performance***
- ***installation of a divertor***
- ***plasma operation with the material synthesis***

(FY2005) ***to issue a final design proposal of the POP facility***

Experimental Schedule of Heliotron J

1	2	3	4	5	6	7	8	9	10
FY1996	FY1997	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005
Design & Construction				Operation (Phase I)			Operation (Phase II)		
Commissioning									
Test operations & Mapping									
ECH (0.5MW-53GHz)									
ECH (0.5MW-84GHz)									
NBI (0.6MW-BL2)									
NBI (0.6MW-BL1)									
NBI (0.3MW-BL3)									
ICRF (2.5MW)									
Check & Review (machine upgrade)									
Divertor Development									
Fusion Material Development									
Design of POP Facility (Heliotron K)									



Summary

Commissioning &

Plasma production

- **Heliotron J was designed to be a first step on the way to an optimized helical-axis heliotron.**
- **The construction of Heliotron J has entered its final stage.**
- **The test plasma operation will be started in November 1999 by using 53 GHz ECH.**