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# MHD Stabilization Analysis in Tokamak with Helical Field

Kozo Yamazaki

Nagoya University

# INTRODUCTION

Our aim is to search for
a Compact & Disruption-Free Configuration.

(1) COMPACT

=> Low Aspect Ratio ?
Advanced Shaping?

(2) DISRUPTION-FREE

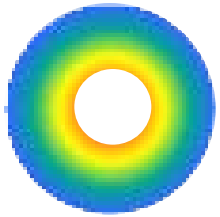
=> Helical system ?
Tokamak Stellarator Hybrid ?

# (1) COMPACT ? Advanced Plasma Shaping

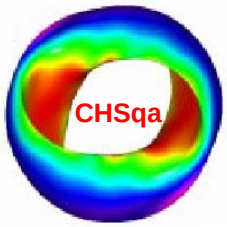
Smaller N

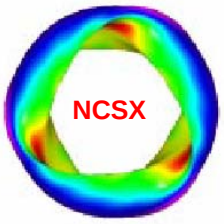
N=0 N=1 N=2 N=3 N=4 N=5

**QA**
Quasi Axi Symmetry



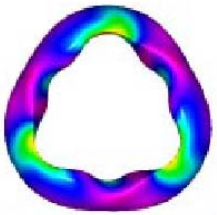
Tokamak



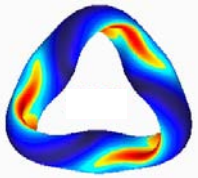



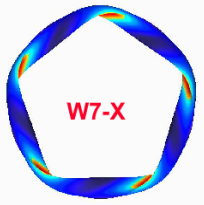

**QP**
Quasi Poloidal Symmetry

N=1 proposal

**QO**
Quasi Omunigenity






**QH**
Quasi Helical Symmetry

Core Symmetry

Modular Coil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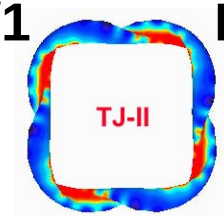
Surface Symmetry

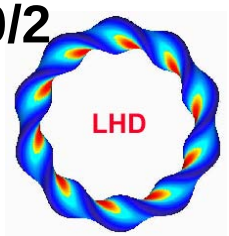
Continuous Coil

N=1,2 proposal

N/L=4/1



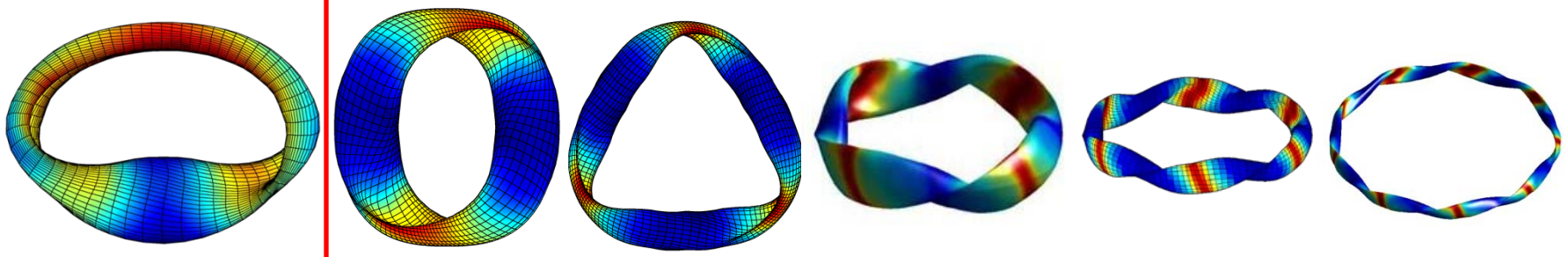

N/L=10/2




Helical Divertor

# Ballooning Beta Limit of QI Configurations

**NEW Proposal**



| N=1 | N=2 | N=3 | N=4 | N=6 | N=9 |
|---|---|---|---|---|---|
| A~4, <β>=1.5% | A~3.9, <β>=2.4% | A~6.8, <β>=3.9% | A~9 <β>=5% | A~12 <β>=5~8.8% | A~22 <β>=10~15% |

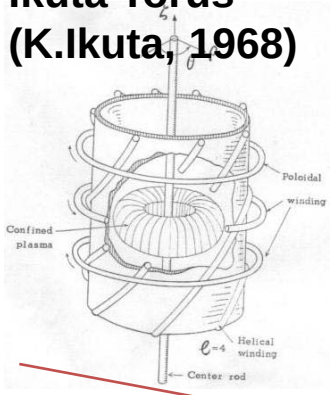
By adding plasma current, we may get higher beta.

It is not easy to find out a compact good-confinement and high beta configuration.

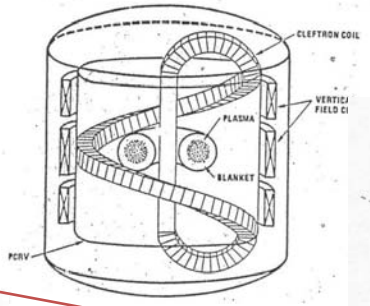
M.Mikhailov & K.Yamazaki

# Exotic Tokamak-Stellarator Hybrids

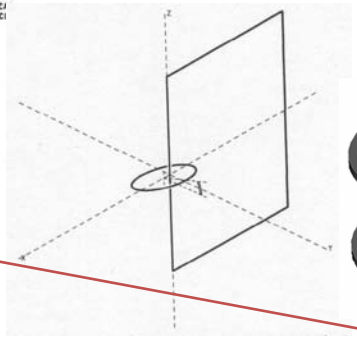
**Ikuta Torus**
**(K.Ikuta, 1968)**



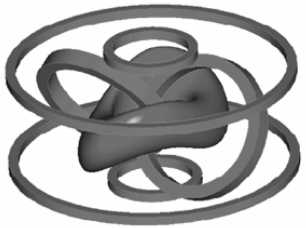

**Cleftron**
**(T.Ohkawa, 1981)**




**Ultra Simple Stellarator**
**(T.Todd,1990)**

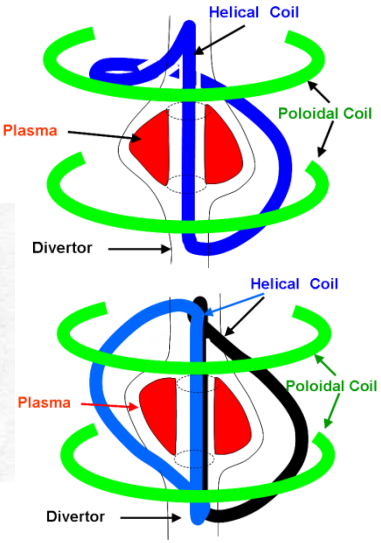


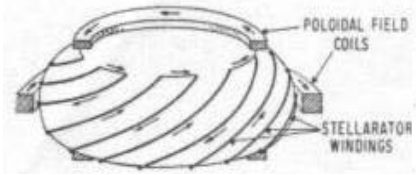
**CNT**
**(T.S.Pedersen & A.H.Boozer, 2002)**



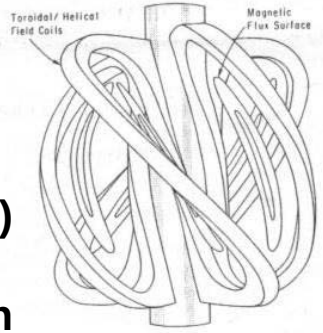
**Non-Axisymmetric Shaping Proposals**

**C-Tokastar**
**(K.Yamazaki,2004)**

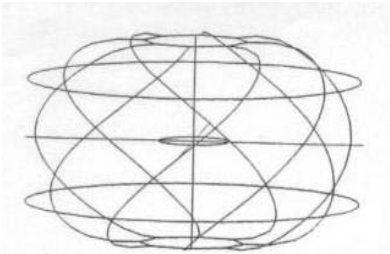


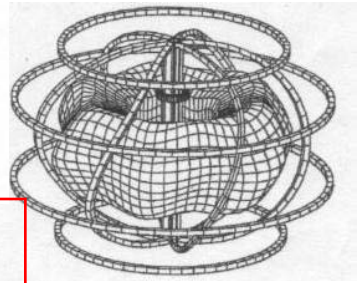

**Strong Negative V"**
**(H.P.Furth et al., 1968)**




**Tokatron**
**(H.P.Furth et al., 1981)**



**Tokastar**
**(K.Yamazaki, 1985)**



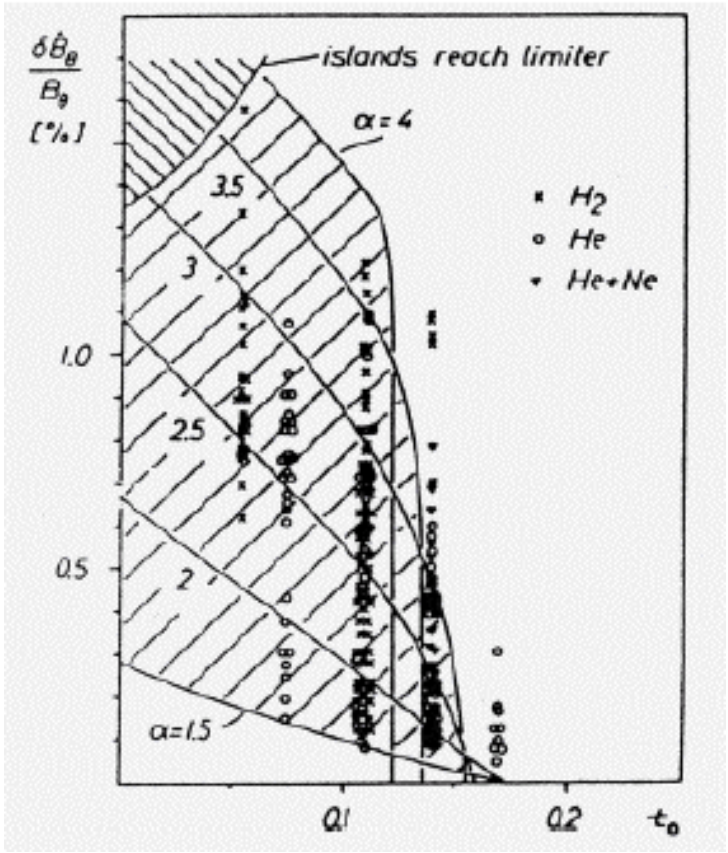
**Spherical Stellarator**
**(P.E.Moroz, 1996)**

## (2) DISRUPTION-FREE ?

### Disruption-Free in Helical System

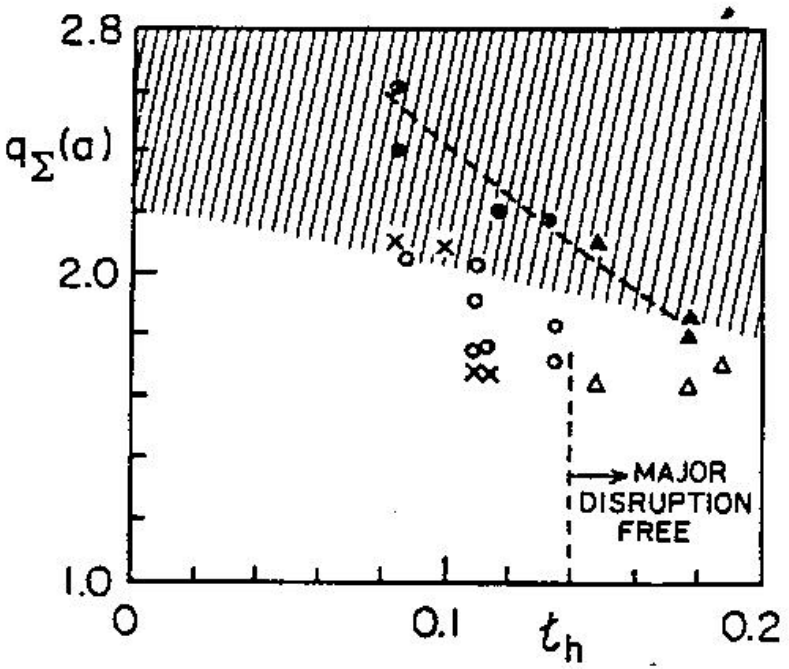
**no disruption with q(external)<7 even at q~2**

**W7-A**




WVII- A Team,
Nucl. Fusion 20 (1980) 1093.

**JIPP T-II**




Fujita et al.,
IEEE Transaction on
Plasma Science
PS-9 (1981) 180.

(Current Carrying Stellarator
without BS current)

(1) COMPACT
(2) DISRUPTION-FREE

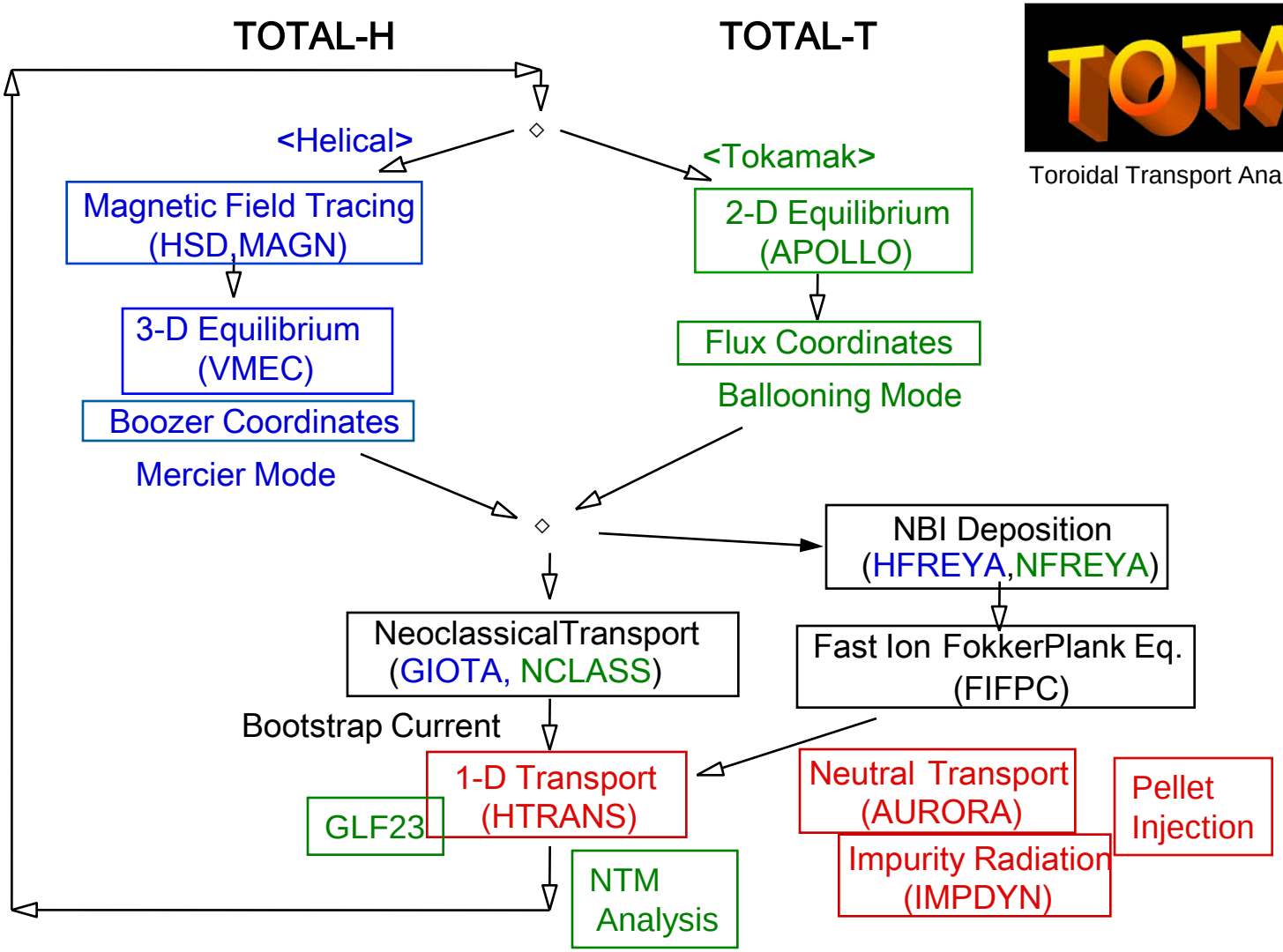
Can external helical filed play a role in tokamak?
(TM,NTM,RWM, Ballooning mode etc.)

Integrated Simulation Studies (TOTAL code)
Small Plasma Experiment (Tokastar)
Reactor Assessment (COE,$CO_2$, EPR etc.)

K.Yamazaki et al. IAEA 2008

# TOTAL Code Development

For Predictive Simulation and Experimental Data Analysis




TOTAL

Toroidal Transport Analysis Linkage

# NTM with Helical Field

Model: Modified Rutherford Equation

$$\frac{dW}{dt} = \Gamma_{\Delta'} + \Gamma_{BS} + \Gamma_{GGJ} + \Gamma_{pol} + \Gamma_{EC} + \Gamma_{HF}$$

$$\Gamma_{\Delta'} = k_1 \frac{\eta}{\mu_0} \Delta'(W) \left\langle |\nabla\rho|^2 \right\rangle$$

$$\Gamma_{BS} = k_2 \eta L_q j_{BS} \left\langle \frac{|\nabla\rho|}{B_p} \right\rangle \frac{W}{W^2 + W_d^2}$$

$$\Gamma_{GGJ} = -k_3 \frac{\eta}{\mu_0} \varepsilon_s^2 \beta_{ps} \frac{L_q^2}{\rho_s L_p} \left(1 - \frac{1}{q_s^2}\right) \left\langle |\nabla\rho|^2 \right\rangle \frac{1}{\sqrt{W^2 + 0.2W_d^2}}$$

$$\Gamma_{pol} = -k_4 \frac{\eta}{\mu_0} g(\varepsilon_s, \nu_i) \beta_{ps} \left(\frac{\rho_{pi} L_q}{L_p}\right)^2 \left\langle |\nabla\rho|^2 \right\rangle \frac{1}{W^3}$$

$$\Gamma_{EC} = -k_5 \eta \frac{L_q}{\rho_s} \left\langle \frac{|\nabla\rho|}{B_p} \right\rangle f\eta_{EC} \frac{I_{EC}}{a^2} \frac{1}{W^2}$$

**Resonant HF**

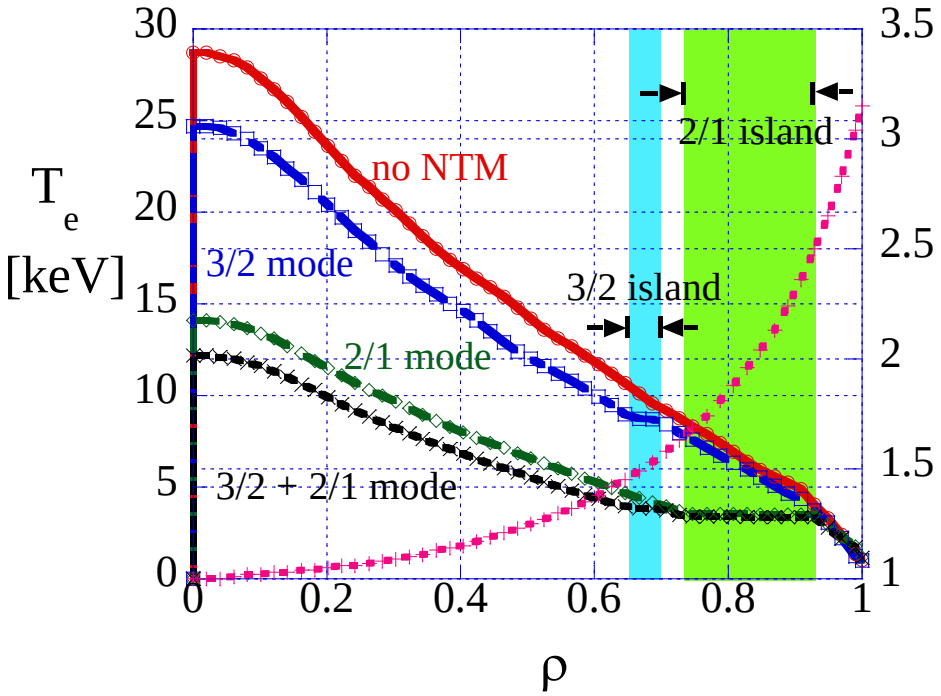
$$\Gamma_{HF} = \frac{2m}{r_s} \left(\frac{W_{HF}}{W}\right)^2 \cos\phi$$

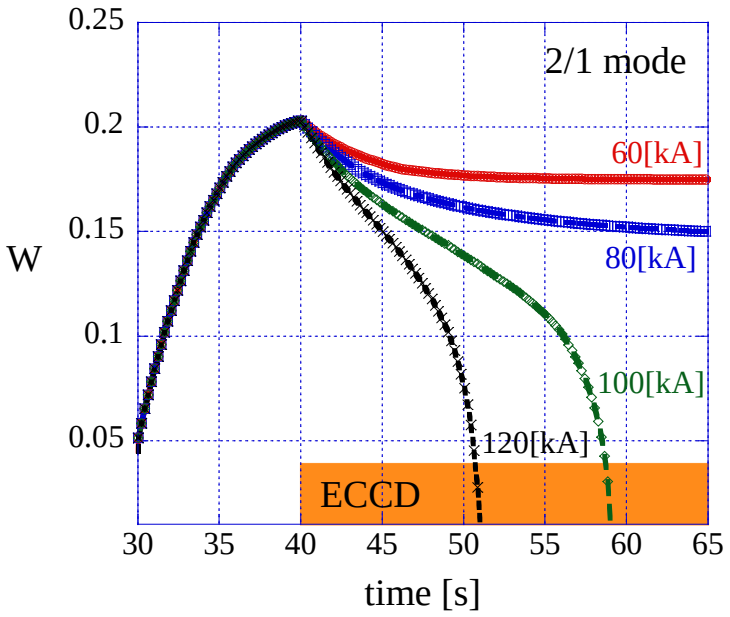
**Non-resonant HF**

$$W_d \propto \left(\frac{\chi_\perp}{\chi_\parallel}\right)^4 \rightarrow \left(\frac{\chi_\perp}{\chi_\parallel} + \frac{b_r^2}{4}\right)^4$$

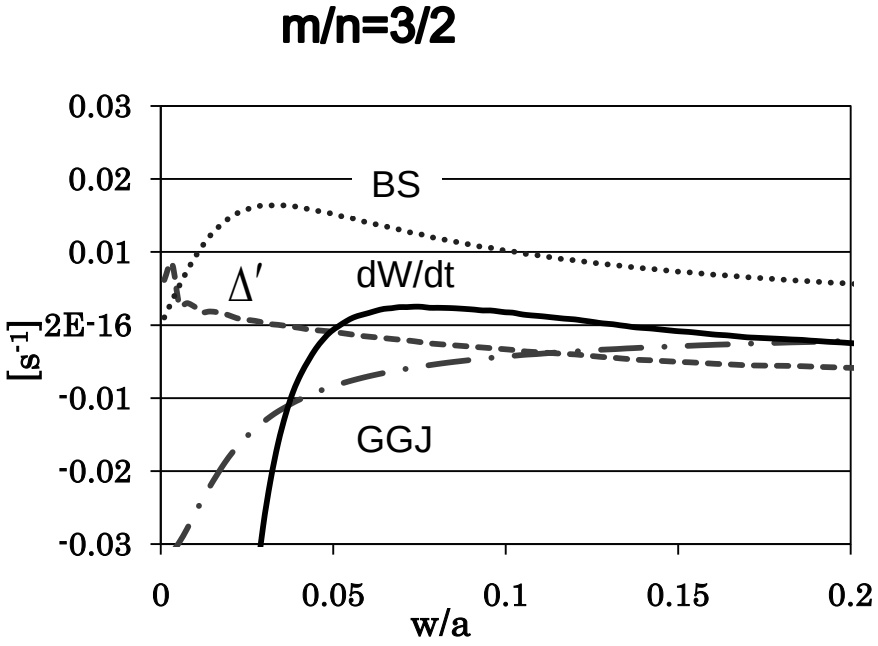
Q.Yu et al., PRL 85(2000)2949

# Example of NTM analysis of an ITER Plasma without external helical field

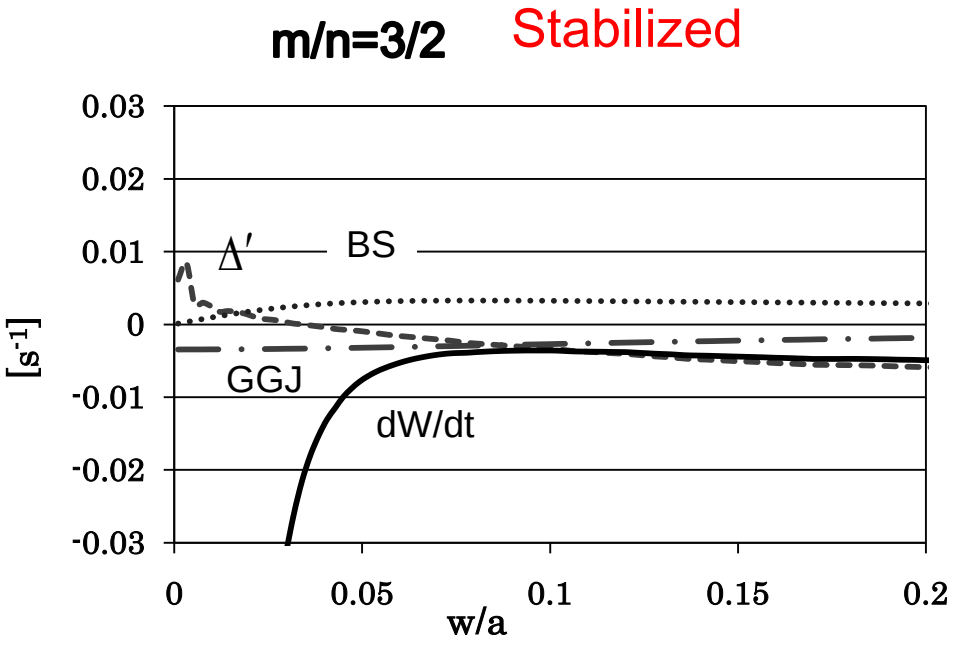


# Non-Resonant Helical Field Application




Without Helical Field

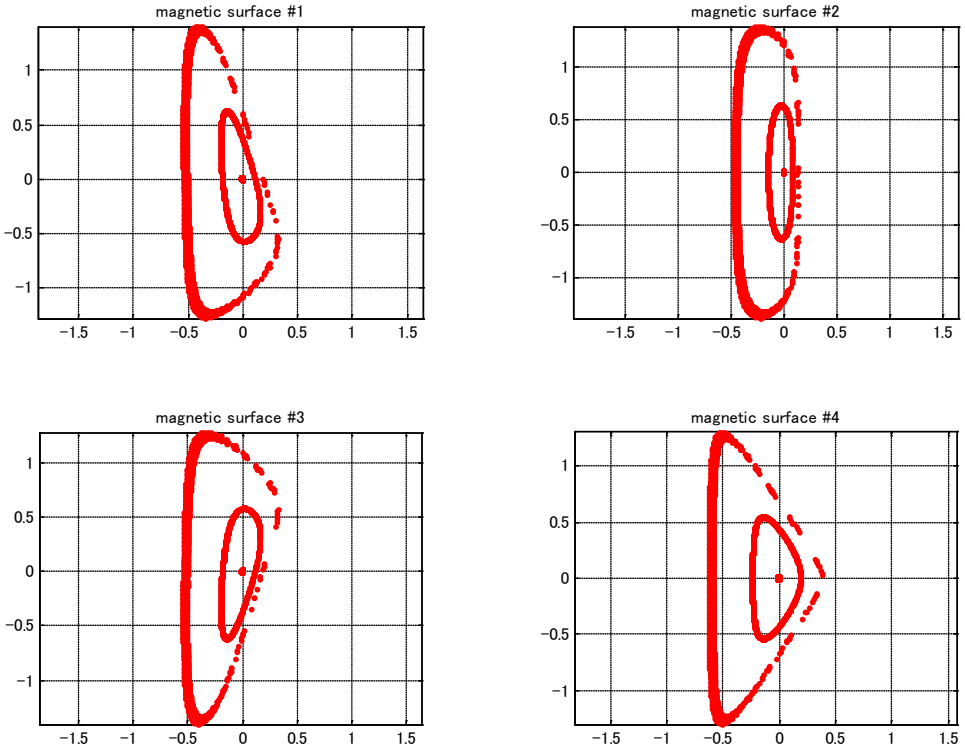


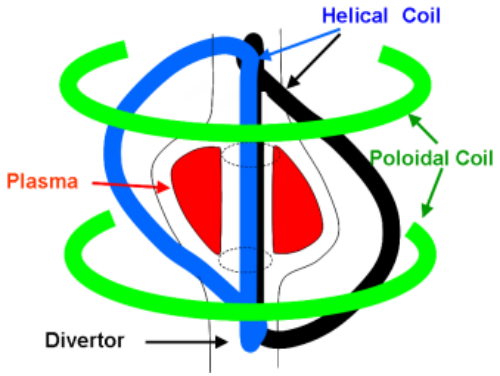

With Helical Field

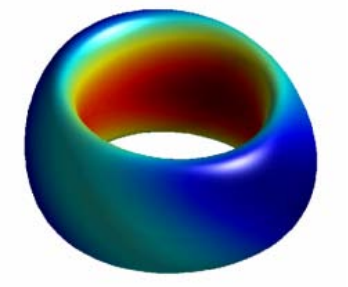
$B_r/B_0 \sim 10^{-3}$

# Experimental Preparation

## (1) C-Tokastar



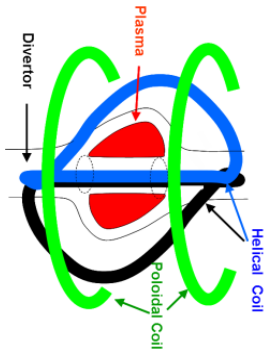



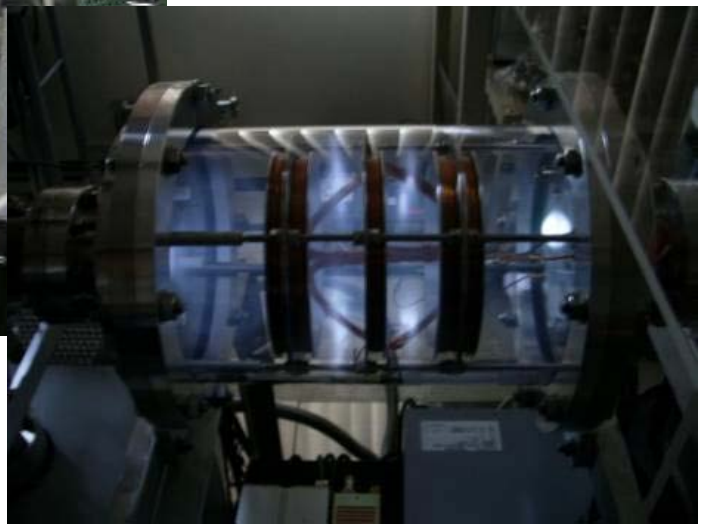



Vacuum magnetic field in N=2
C-Tokastar with double helical coil.

Finite beta equilibrium

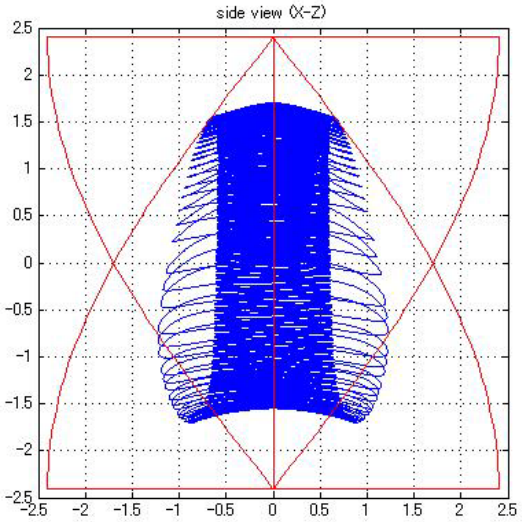
R coil= 6cm
B < 0.1 kG

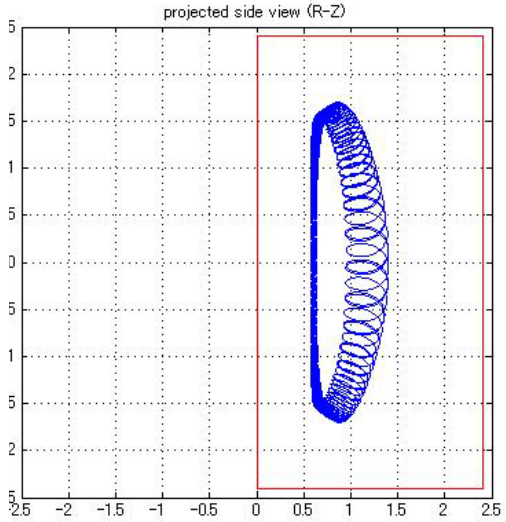


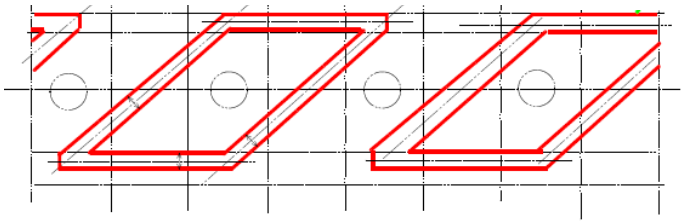



Now checking magnetic surfaces using impedance method

# (2) Tokastar-2 under construction

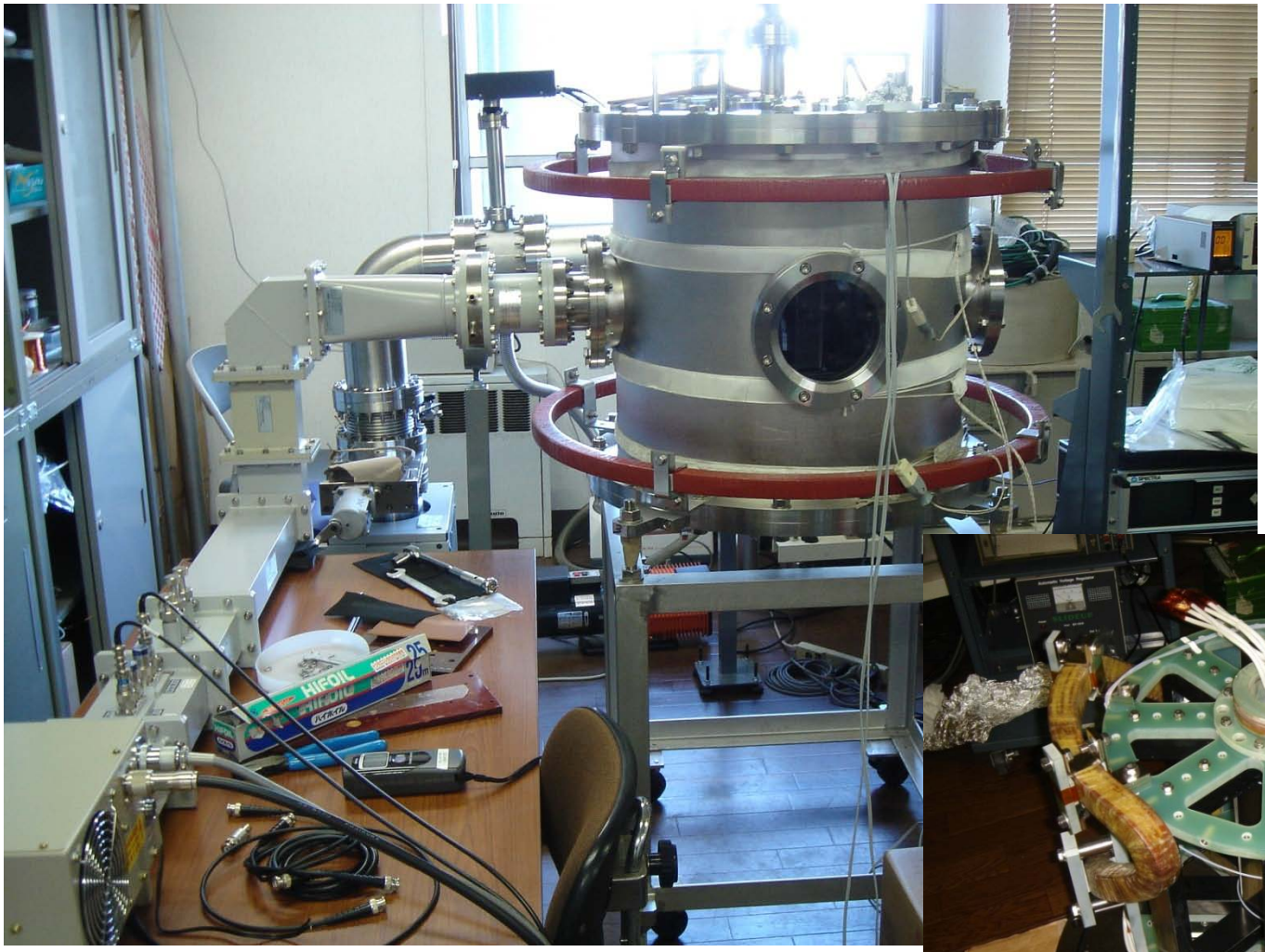


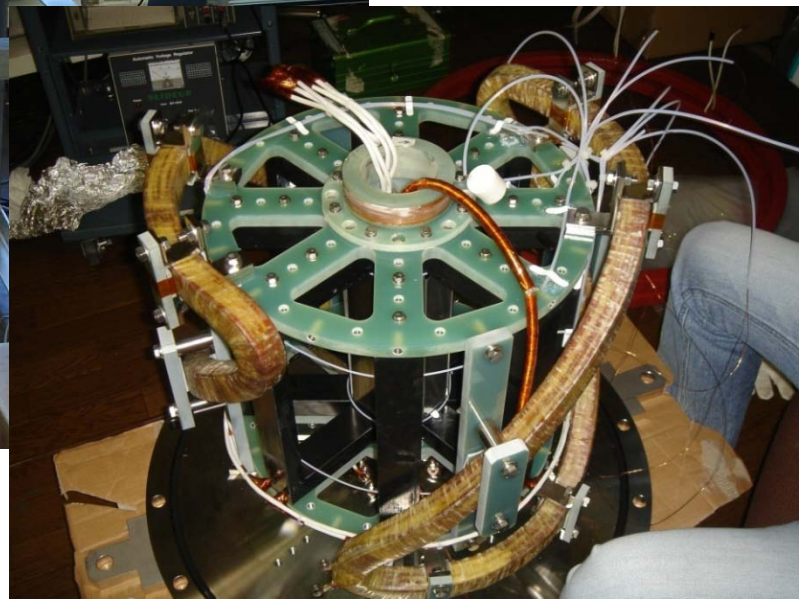



N=2 outer helical field coils are installed outside toroidal field coil.

Vacuum magnetic surfaces exist as a pure stellarator operation.




R ~10 cm
a~ 5 cm
B ~ 1 kG
Ip < 10 kA
$P_{ECH}$ ~2 kW



All were installed in the vacuum chamber,
and now in baking process

# Summary

**(1) 1.5-D(dimensional) tokamak code and 2.0-D helical code have been developed and, preliminary analysis for TM, NTM in Tokamak with helical field has been started.**

**(2) Small Tokamak-Stellarator Hybrids, C-Tokastar and Tokastar-2 are under construction. The experiments on resonant or non-resonant magnetic field application to tokamak will be started in the near future.**