February 14 ~15, 2005
GA, California, U.S.A.

IEA/LT Workshop (W59) combined with
DOE/JAERI Technical Planning of Tokamak Experiments (FP1-2)

Shape and Aspect Ratio Optimization for High Beta, Steady-State Tokamak

Stability Calculations on NCT

(NCT : National Centralized Tokamak)

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J. Bialek and G.A. Navratil : Colombia University

OUTLINE

1) Analyses of Aspect Ratio and Plasma Shape (δ : triangularity) Effects on Critical β_N

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2) Resistive Wall Mode Analyses of NCT Plasma with Real Geometry of Stabilizing Plate and Vacuum Vessel

----- These calculations were performed using VALEN code in collaboration with Colombia University -----

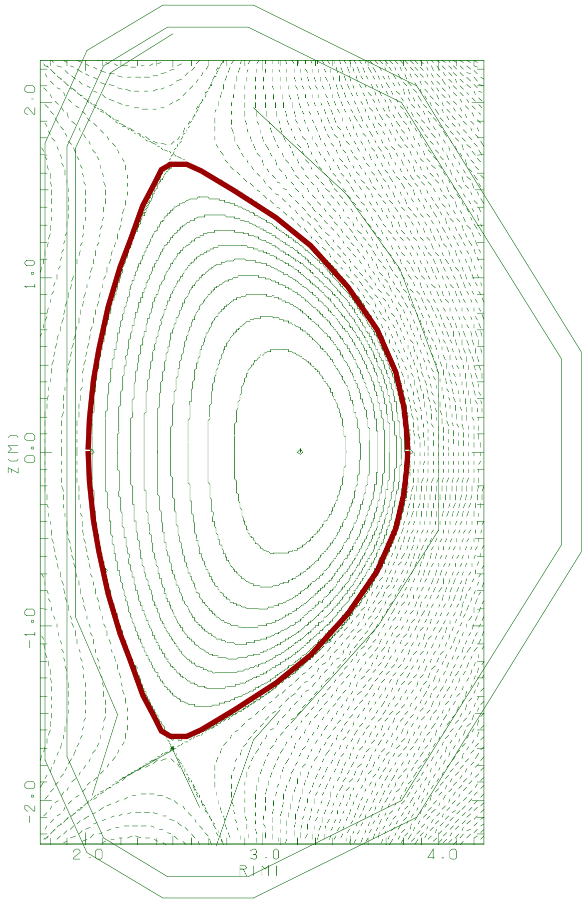
Effect of Shaping Factor on Critical β_N

- Shaping factor has been considered to have increasing effect on critical β_N.

- Here, we investigate the effects of aspect ratio and triangularity deformation on critical β_N.

Effect of Aspect Ratio on Critical β_N

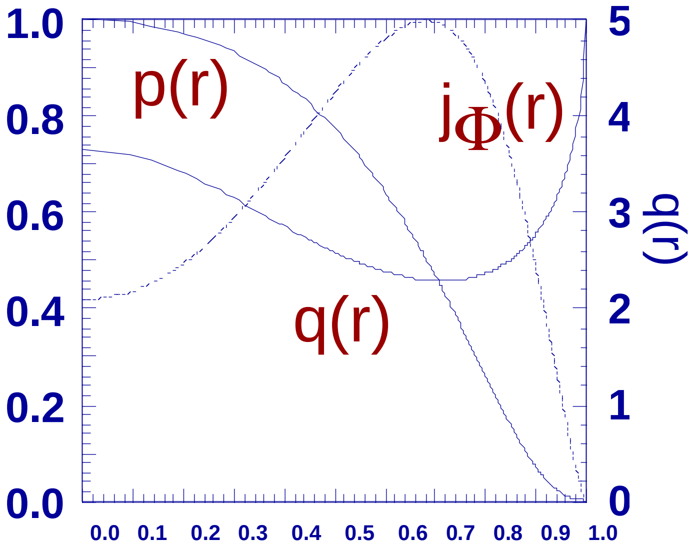
- **Typical Up-Down Symmetric Equilibrium (β_N=5.5)**

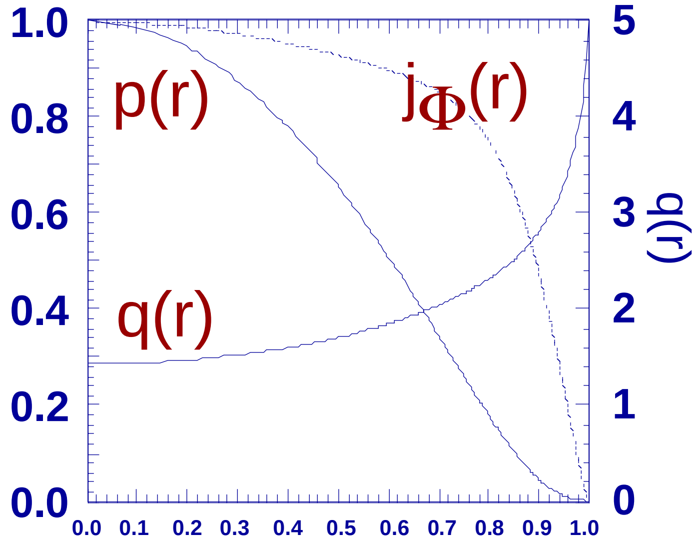


I_p=4[MA], B_t=3.7[T], κ=1.85 : κ_{95}=1.76, δ=0.44 : δ_{95}=0.35

- **Negative Shear**
  $q_0/q_{95}/q_{min.}$=3.63/3.59/2.28,
  li(3)=0.48, p_0/<p>=2.2

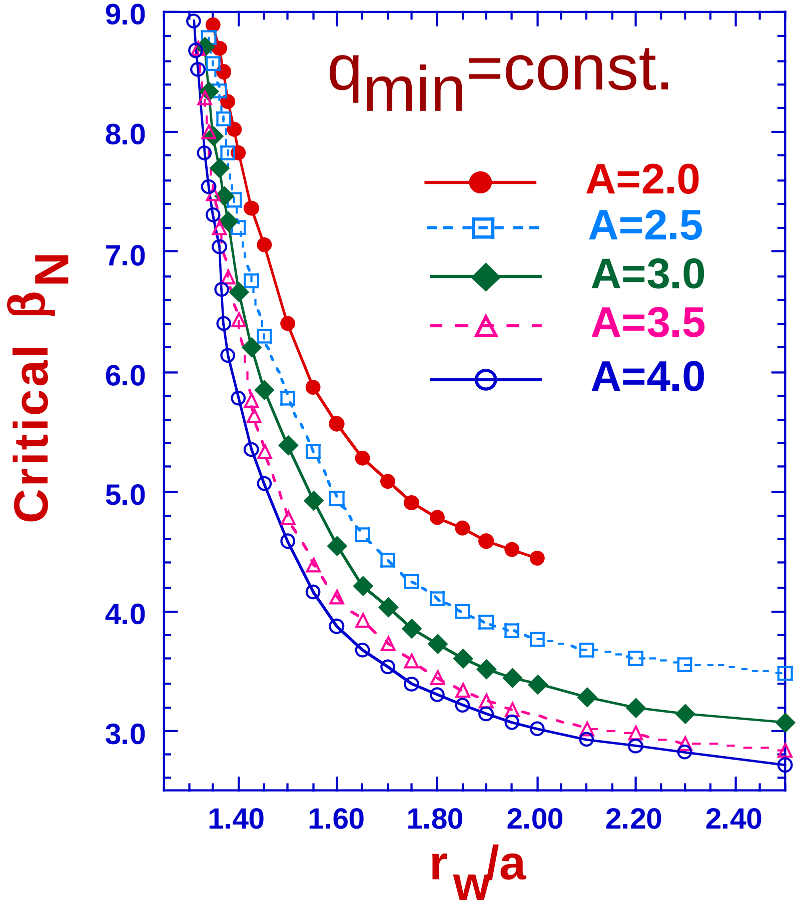
- **Positive Shear**
  q_0/q_{95} =1.42/3.48,
  li(3)=0.56, p_0/<p>=2.6

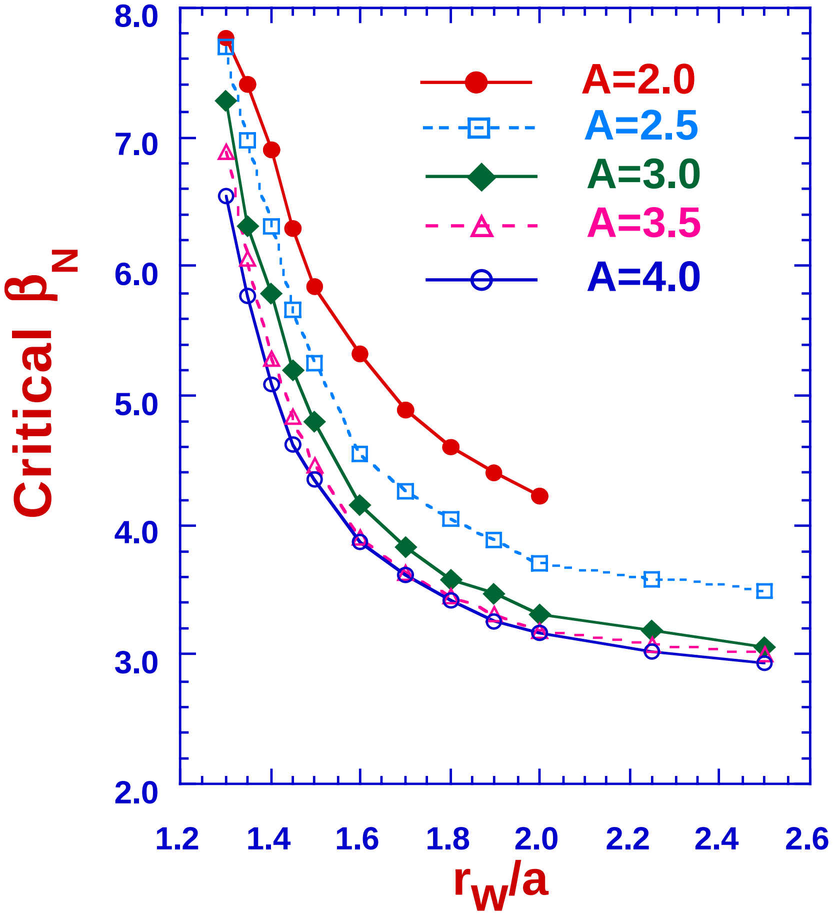




- **Profiles of safety factor, plasma current and plasma pressure**

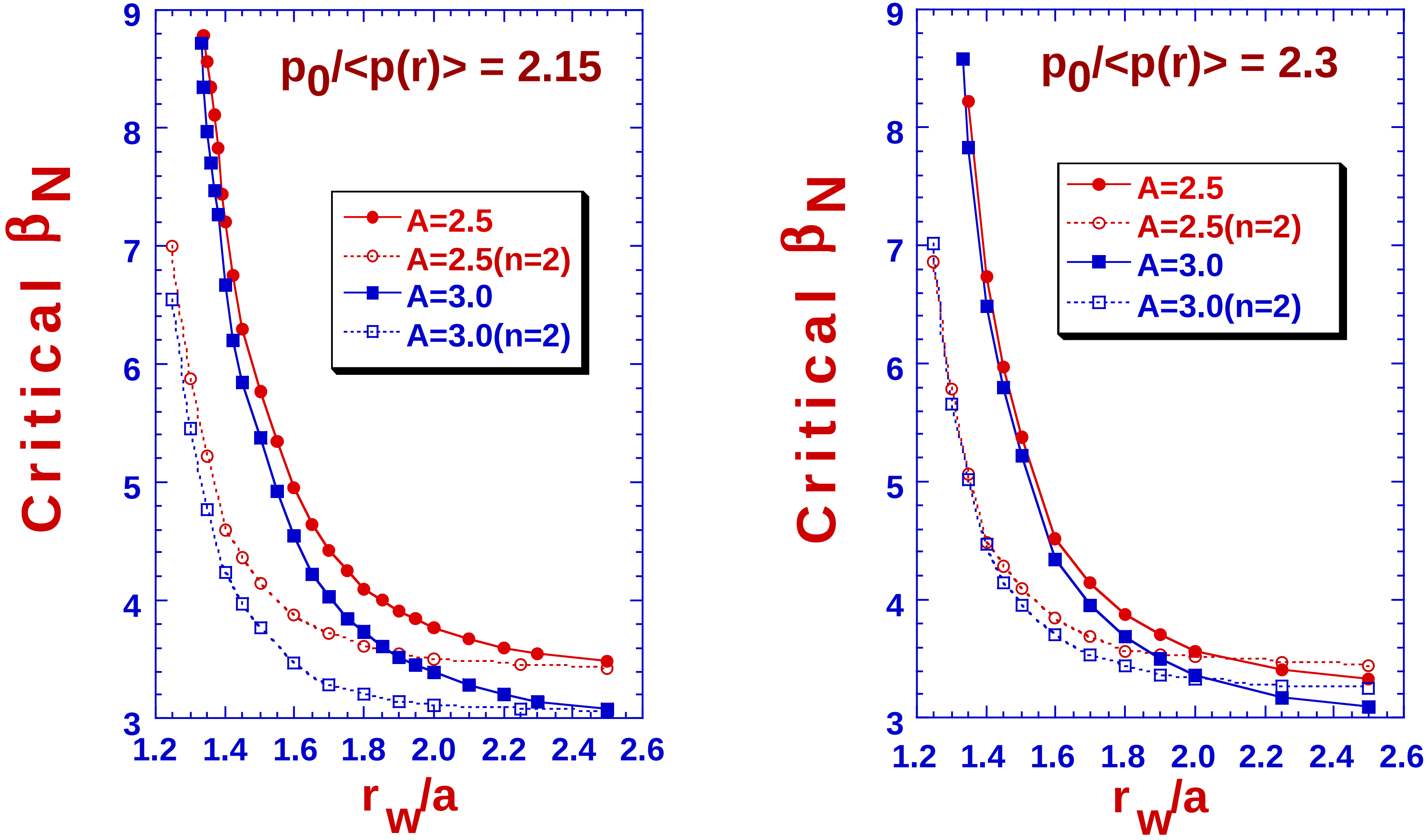
Critical β_N vs. Radius of Conducting Wall





- Smaller aspect ratio always give larger critical β_N for both cases.
- Negative shear plasm has larger stabilizing effect of conducting wall than positive shear plasma.

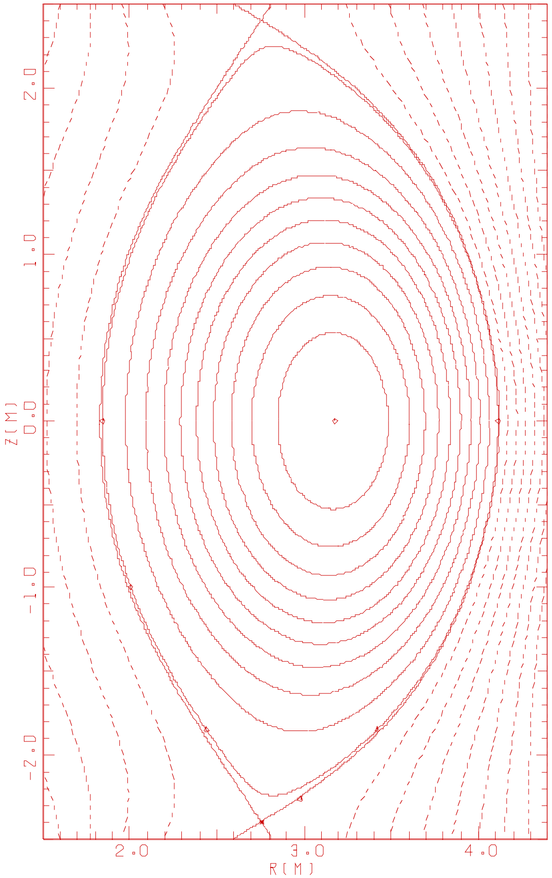
Aspect Ratio Effect on Critical β_N : n=2 mode



- Smaller aspect ratio always give larger critical β_N values for n=2 mode also.
- Effect is reduced for large pressure peaking factor.

Effect of Triangularity on Critical β_N for Positive Shear Plasma

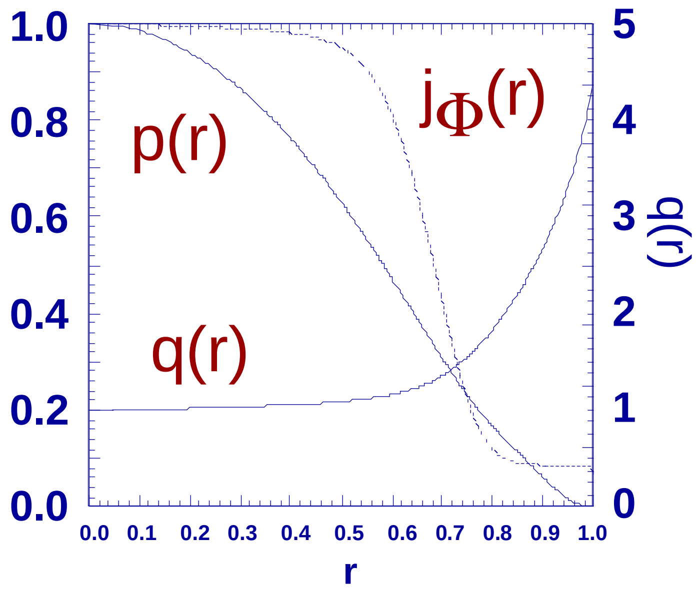
- **Typical Up-Down Symmetric Equilibrium (β_N=2.5)**



κ=1.97 : κ_{95}=1.84, δ=0.14 : δ_{95}=0.05

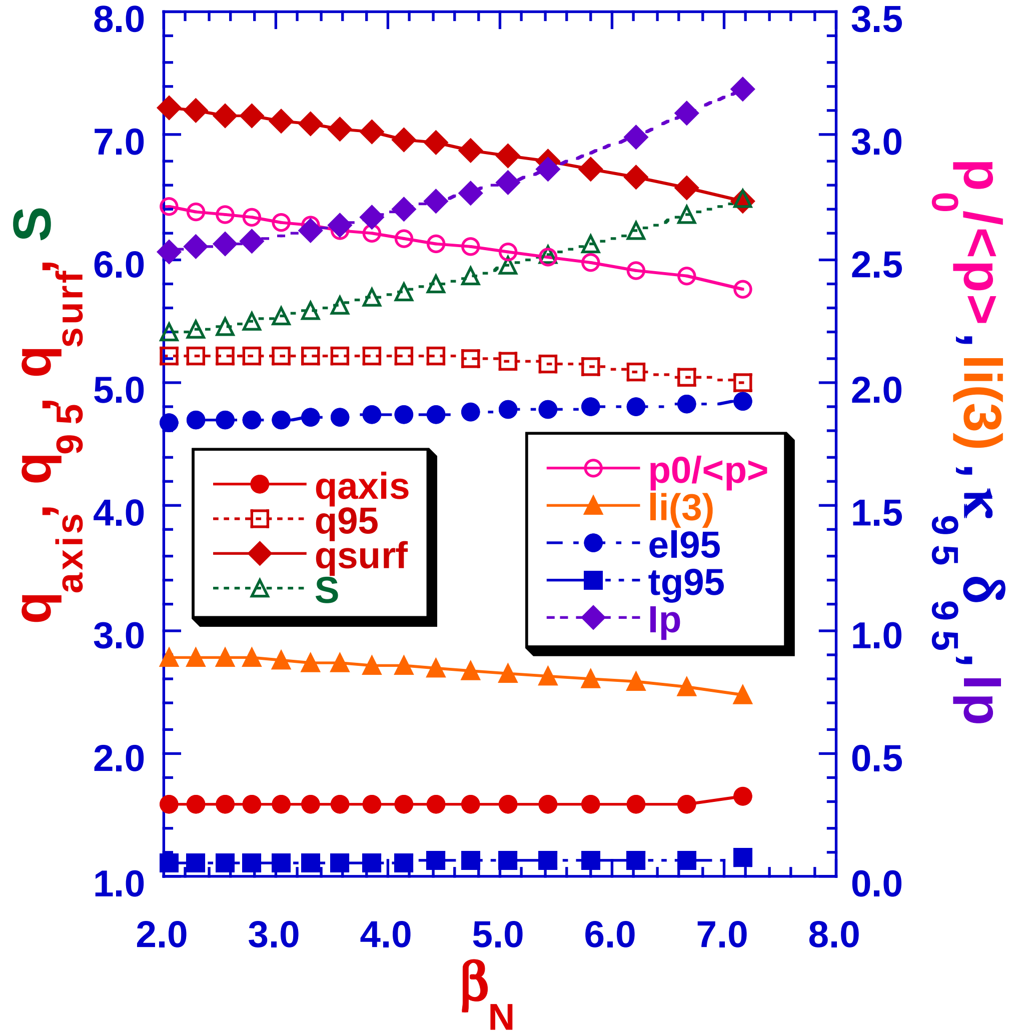
A=(R_c/a=2.98/1.135=) 2.63, I_p=2.5[MA], B_t=2.15[T]

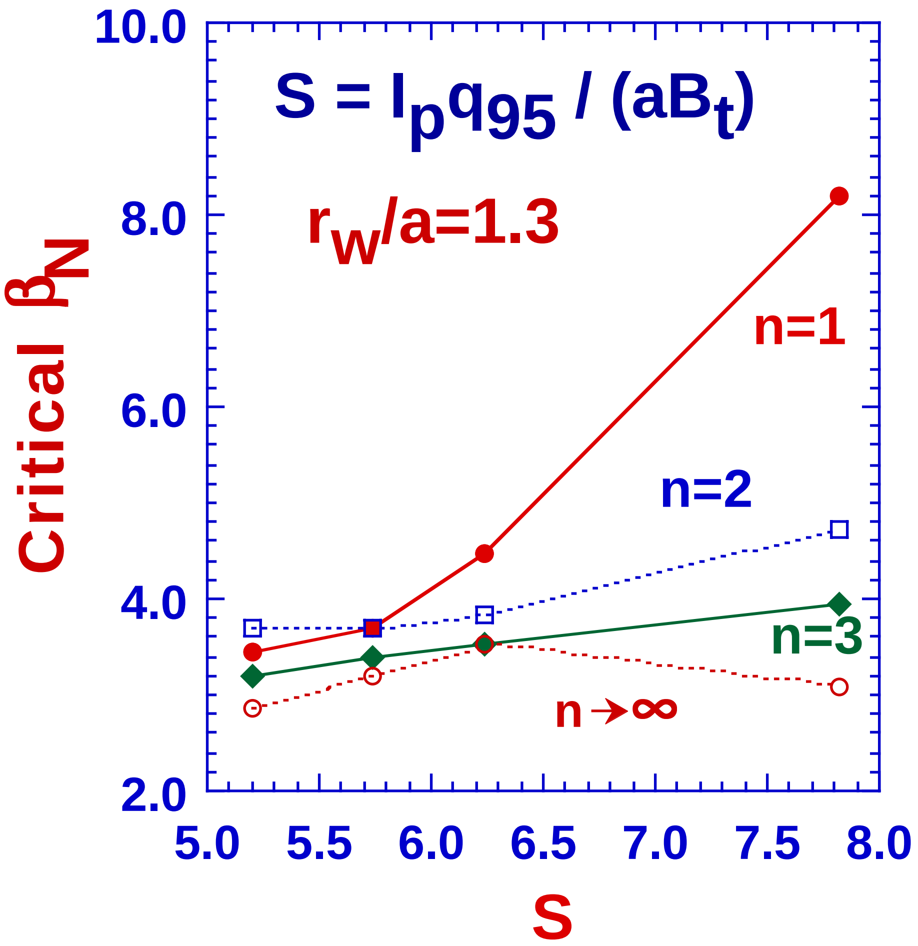
$q_0/q_{95}/q_{surf}$=1.59/5.21/7.17, li(3)=0.88, p_0/<p>=2.68



- **Profiles of normalized plasma current and pressure and safety factor**

Shaping (δ:triangularity) Effect on Critical β_N





S is evaluated at β_N=4.

- Change of equilibrium quantities with β_N

- Equilibria are calculated with almost fixed q_{axis} (=1.6) and q_{95} (=5.2) values.

Summary & Next Steps for "Shaping Effect" Analyses

- By choosing appropriate q values, q_{axis}, (q_{min}) and q_{95}, critical β_N values are shown to be increased by increasing S value (through aspect ratio or triangularity) for the pressure and current profiles considered here.

We must investigate

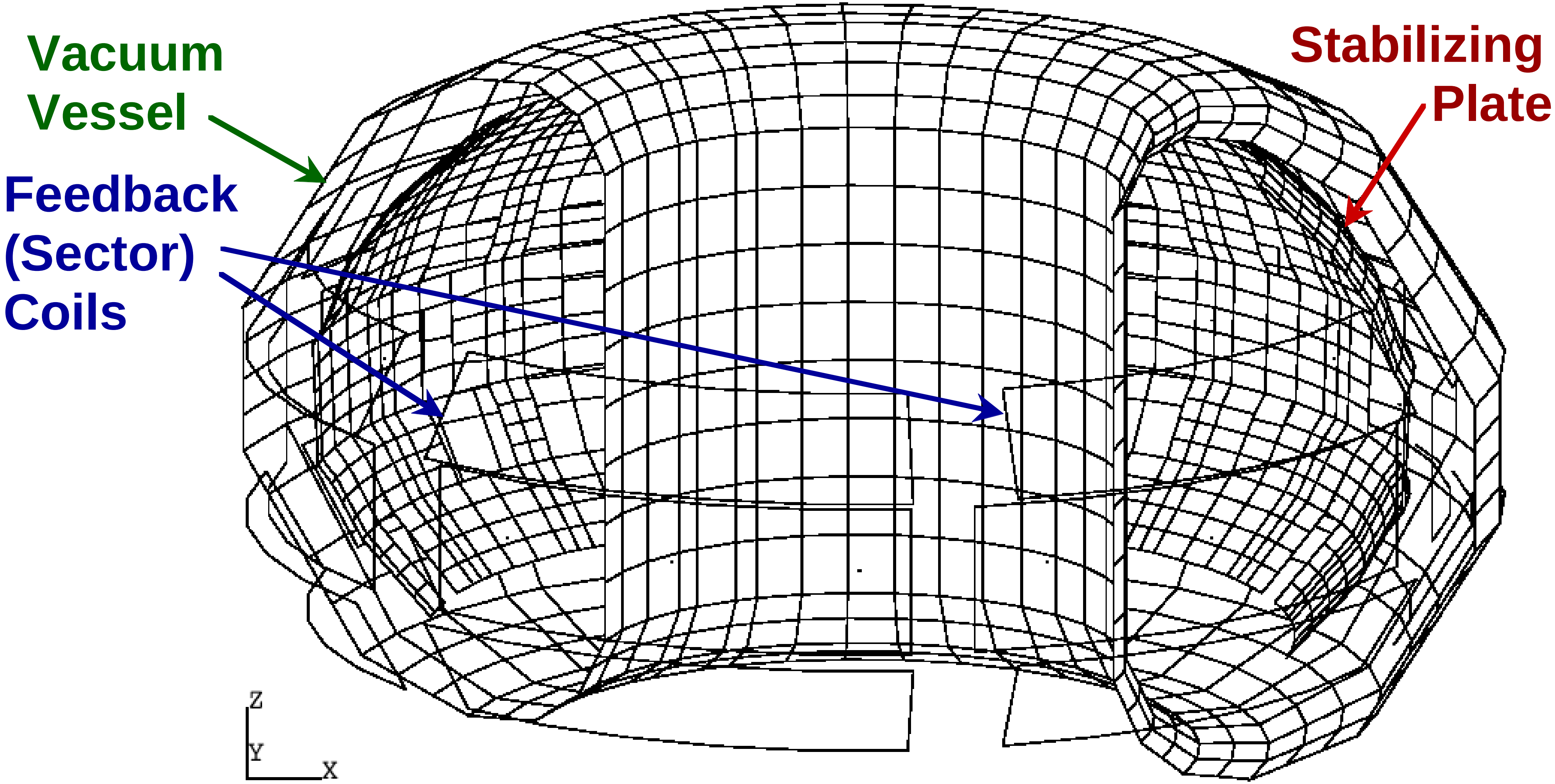
- Elongation effect
- Influence of plasma current and pressure profile for the shaping factor to increase critical β_N

Resistive Wall Mode Analyses of NCT Plasma

- To get higher β_N values than no-wall β_N limit, to suppress or control Resistive Wall Mode is necessary.

- Critical β_N analyses of NCT plasma for n=1 mode using VALEN code are performed with real geometry of the stabilizing plate and vacuum vessel with finite conductivity.
- Critical β_N values for passive effect of stabilizing plate and vacuum vessel, and also with the effect of active feedback control are obtained.

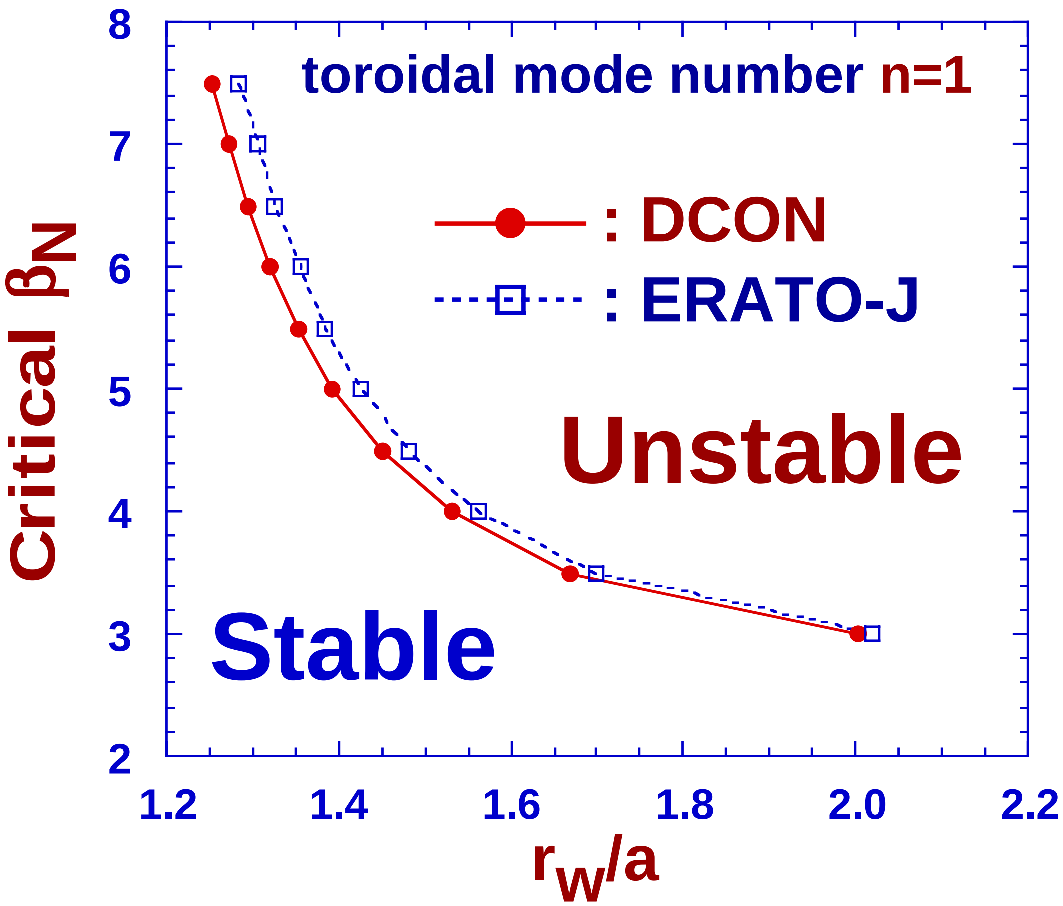
Cut Away View of Vacuum Vessel, Stabilizing Plate and Sector Coils of NCT



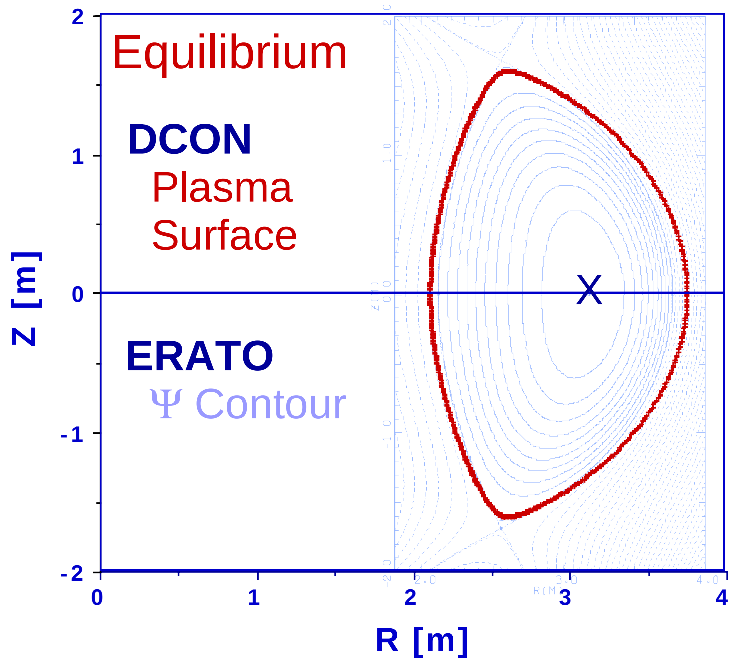
- There are many supports of stabilizing plate to vacuum vessel, which are not shown in the figure.

Benchmark between DCON & ERATO-J

- Conformal ideal wall

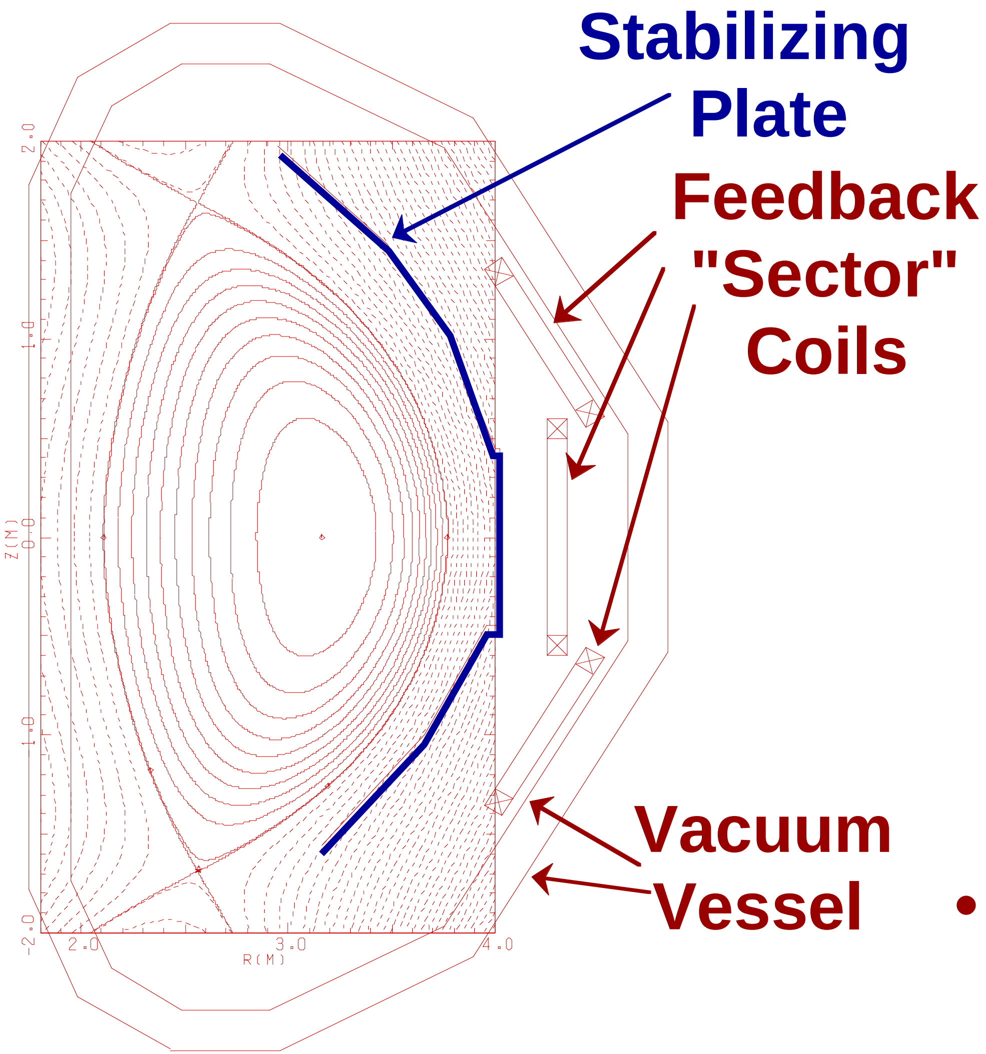


Stability Diagram



Equilibrium Comparison

Double-Null Equilibrium for NCT Plasma



Typical Double-Null Equilibrium of β_N=5

- Parameters

β_N= 5.0

A=(R_c/a=2.94/0.83=) 3.54

I_p=2.03[MA], B_t=1.84[T]

κ=1.97 : κ_{95}=1.89

δ=0.41 : δ_{95}=0.32

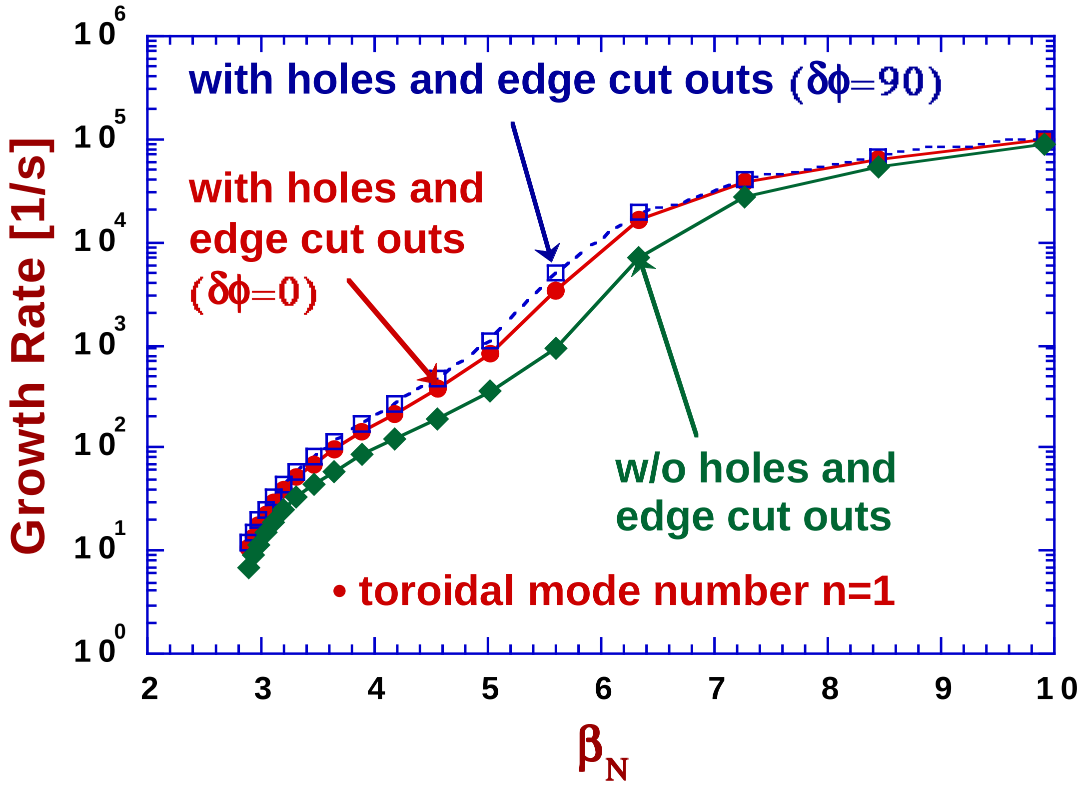
$q_0/q_{95}/q_{min.}$=3.89/3.36/2.30

li(3)=0.45, p_0/<p>=2.18

- Up-down symmetric double-null equilibria shown are used in the following critical beta analyses.

Passive Stabilizing Effect of Stabilizing Plate

---- with and without holes and edge cut outs -----

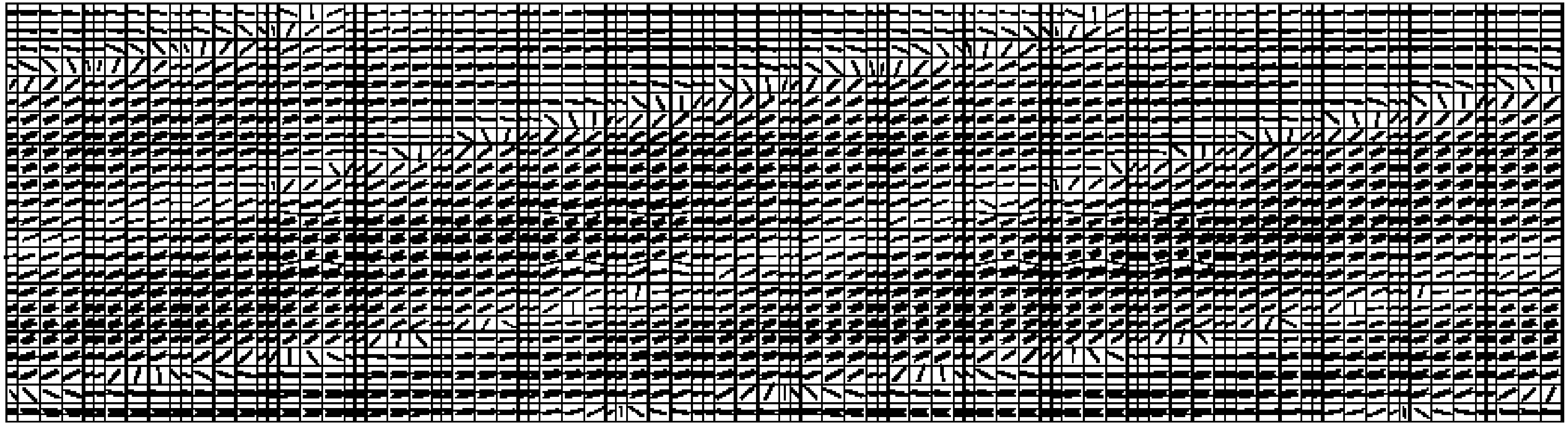


$\delta\phi$: phase shift between mode and holes and cut outs

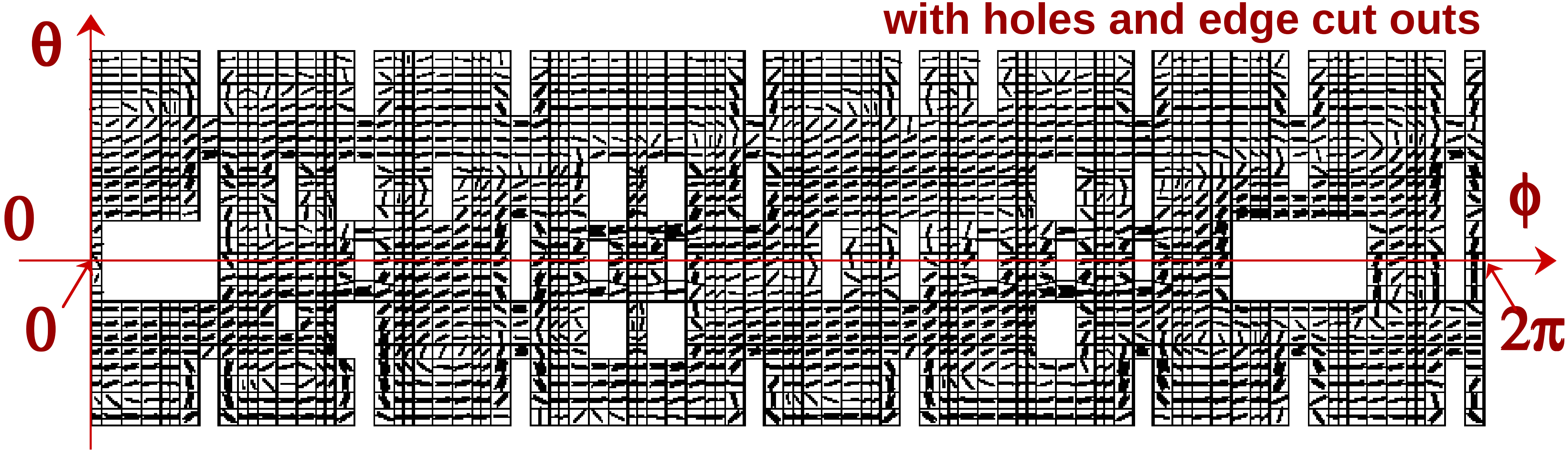
- **Growth Rates are increased by considering holes and edge cut outs in stabilizing plate and reduces ideal β_N limit about 8%.**
- **They are further increased by considering phase shift between mode and holes and edge cut outs in stabilizing plate.**

Eddy Current Pattern on Stabilizing Plate

without holes and edge cut outs

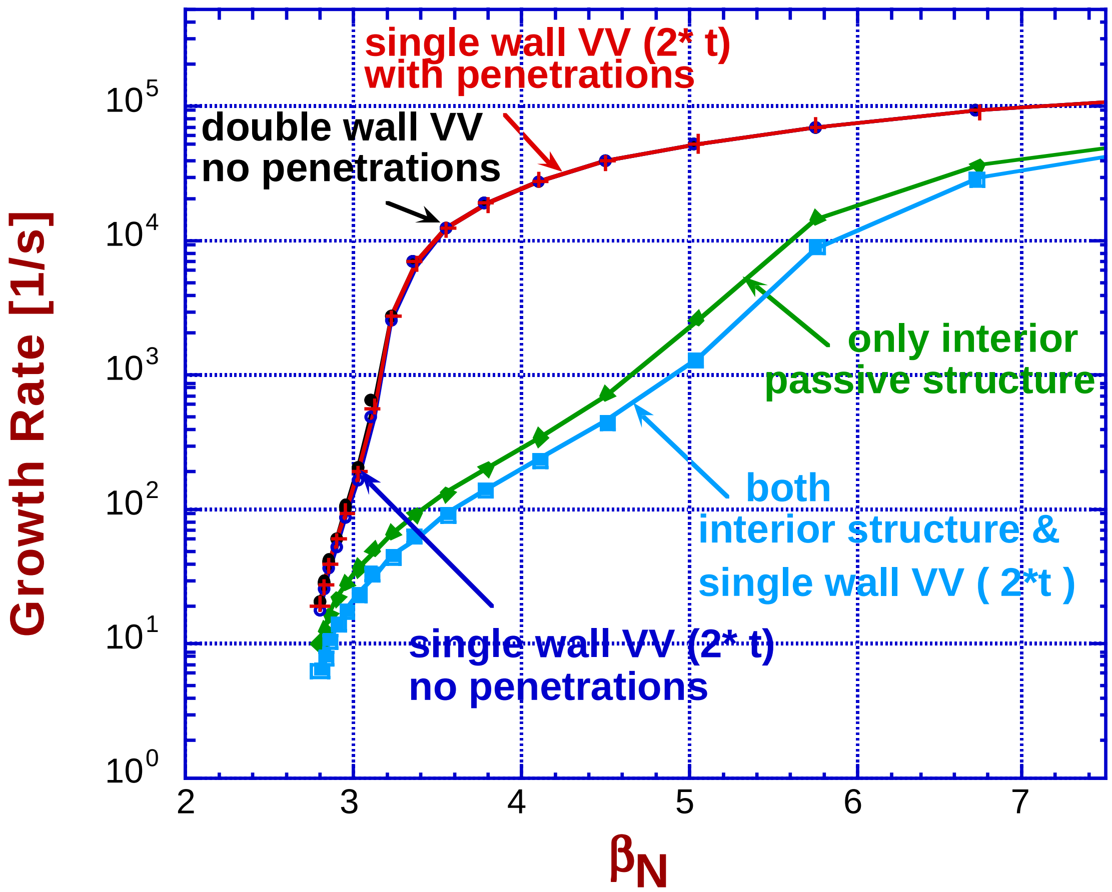


with holes and edge cut outs



- Distortion of eddy current pattern increases the growth rates.

Passive Growth Rate for Different Vacuum Vessel Models



- minor radii of vacuum vessel and stabilizing plate at equatorial plane

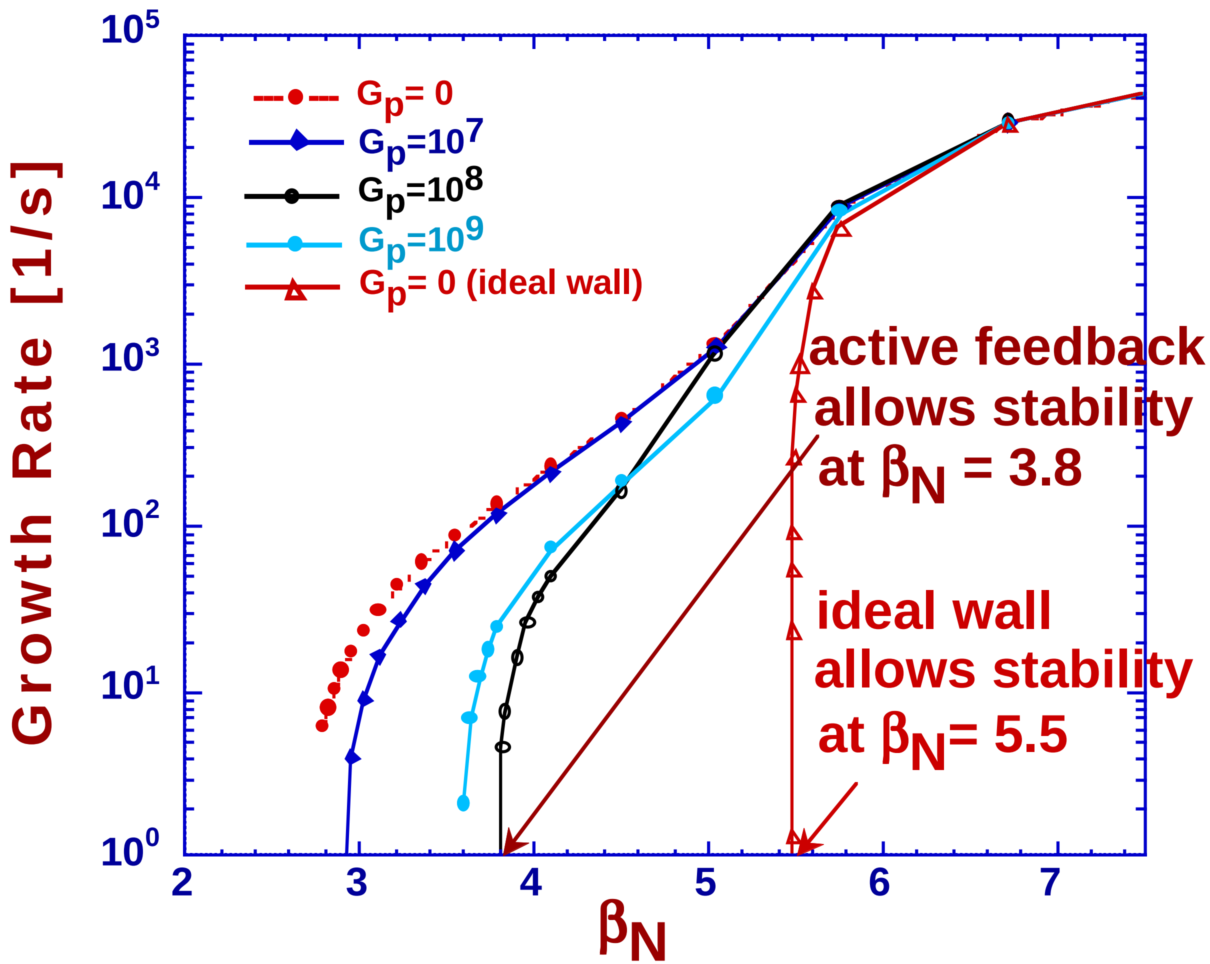
  $r_{v.\,v.}/a = 2.04$
  ---> Critical $\beta_N \sim 3$

  $r_{s.\,p.}/a = 1.31$
  ---> Critical $\beta_N \sim 6$

  from conformal wall analyses by DCON

- **Passive structure provides most of the passive stabilization and the vacuum vessel wall is a secondary effect.**

Critical β_N with Active Feedback Control



$V_{coil} = G_p\ \Phi_{sensor}$

- G_p is proportional gain.
- Φ_{sensor} is perturbed poloidal flux detected by poloidal field sensor placed at center of each coil.

$$C_\beta = \frac{\beta_N^{critical} - \beta_N^{no\text{-}wall}}{\beta_N^{ideal\text{-}wall} - \beta_N^{no\text{-}wall}}$$

- Maximum critical β_N with active feedback control for the present design of NCT plasma is 3.8, which corresponds to C_β=0.37.
- Without holes and edge cut outs, ideal β_N limit is expected to be increased to about 6, almost hits the β_N limit by DCON.

Summary & Next Steps for "Real Geometry" Analyses

- Maximum critical β_N with active feedback control, obtained as a first step for present design of NCT plasma, is 3.8, which corresponds to C_β=0.37.

- To increase critical β_N values by changing the design of "Sector" coils to improve response time of feedback field to the plasma
- To obtain critical β_N for single-null equilibria