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Confinement study on the reactor relevant high beta LHD plasmas

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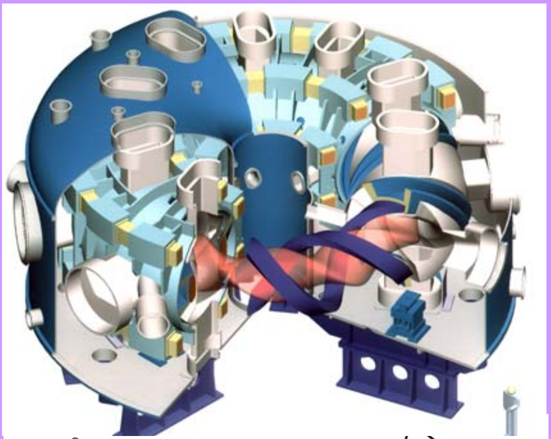
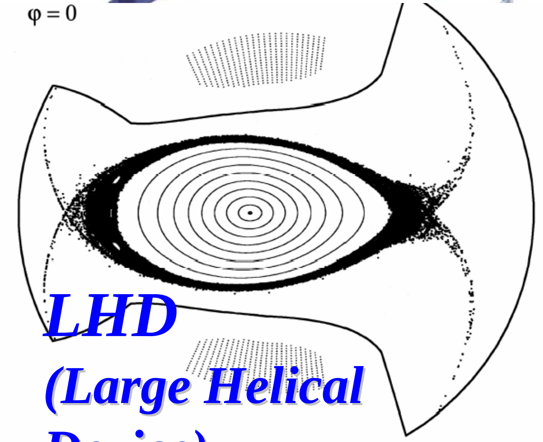
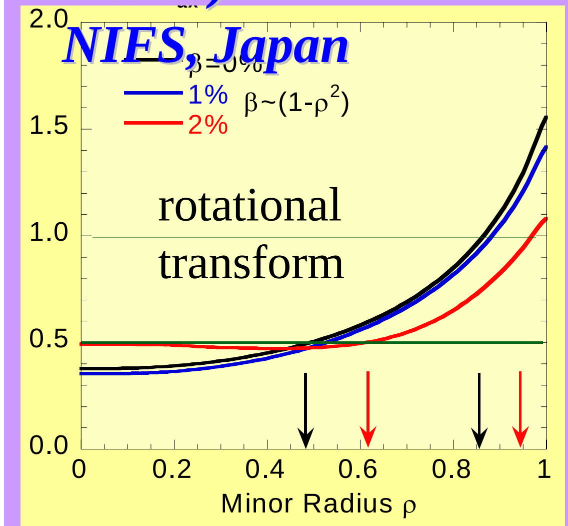
Special Thanks the LHD technical staff for their support of the experiments.

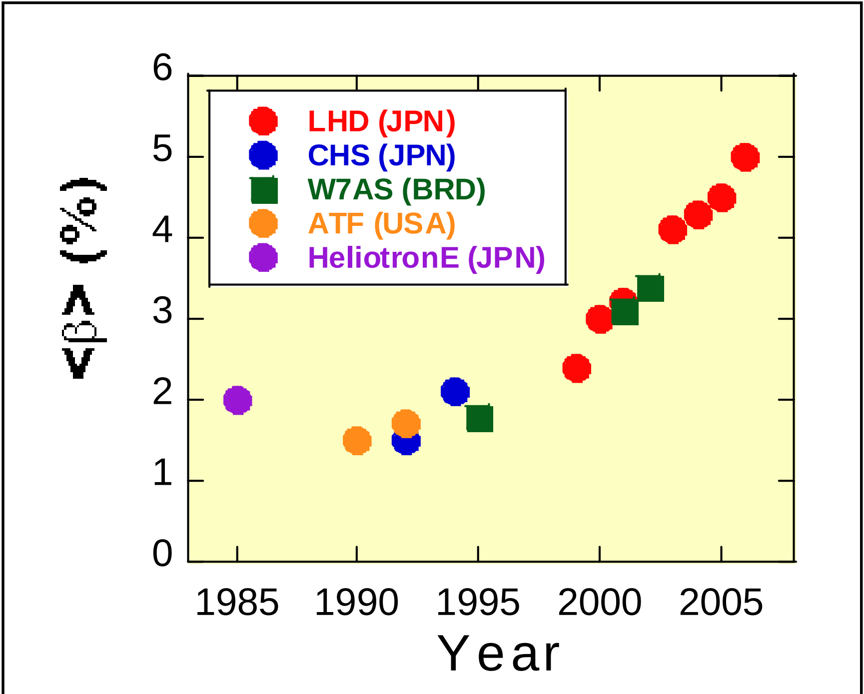




LHD
(Large Helical Device)
NIES, Japan



Buck ground



Progress of achievement of max. beta in helical devices

<β>=5%;
A targeted value of LHD project from the design phase

\# For an economical fusion reactor, <β>~5% is necessary.

\# Mainly by increasing the heating capabilities and optimizing configurations, heating efficiency of NBI.

\# Last exp. campaign in LHD, the 5.0% beta plasma is obtained.

\# Analysis of the plasma properties like the beta dependence up to the reactor relevant high beta regimes become possible.

Contents

Progress of high beta operation in LHD

Characteristics of LHD high beta plasmas with β~5%

Effects of global MHD instability (low-n,m modes) on LHD high beta plasmas
Through comparison between achieved pressure gradients and linear MHD numerical analyses

Confinement properties of LHD high beta plasmas
Through comparison between experimentally obtained thermal conductivities and some theoretically predictions

Recent results of ext. of operational β range in LHD

<β>=4.5% up to last IAEA conf.(2006)

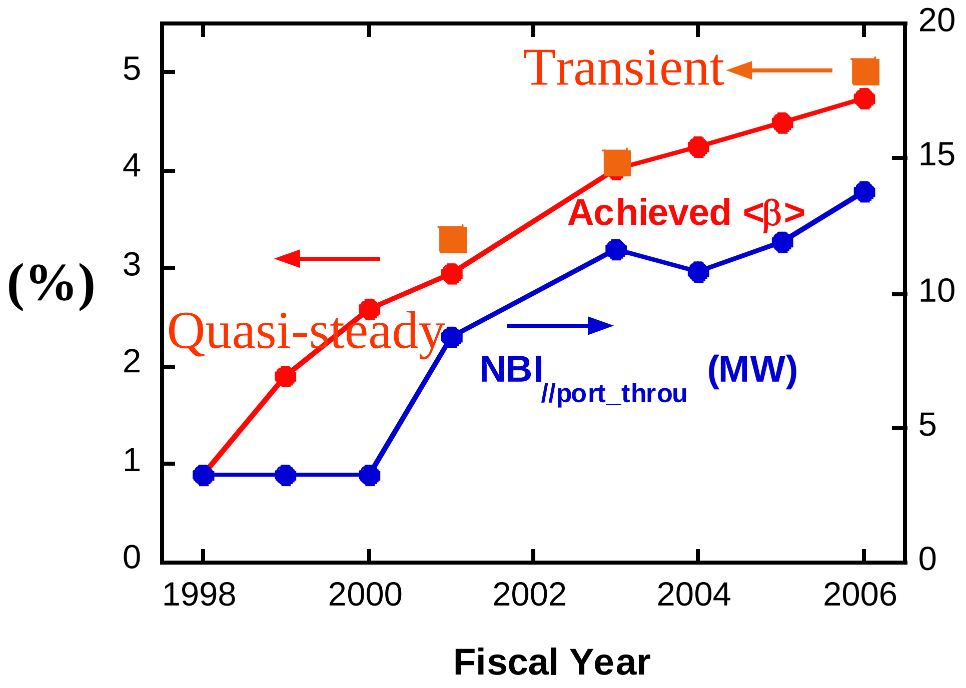
Quasi-steady (only gas-puffing and parallel NBI);

<β>=4.8%; **Increase //NBI power** (~1.8MW up; tot.13.8MW)

Transient (pellet inj.);

<β>=5.0%; **Improve heating efficiency of ⊥NBI(6.9MW)**

due to Suppression of Shafranov shift by pellet and //NBI modulation



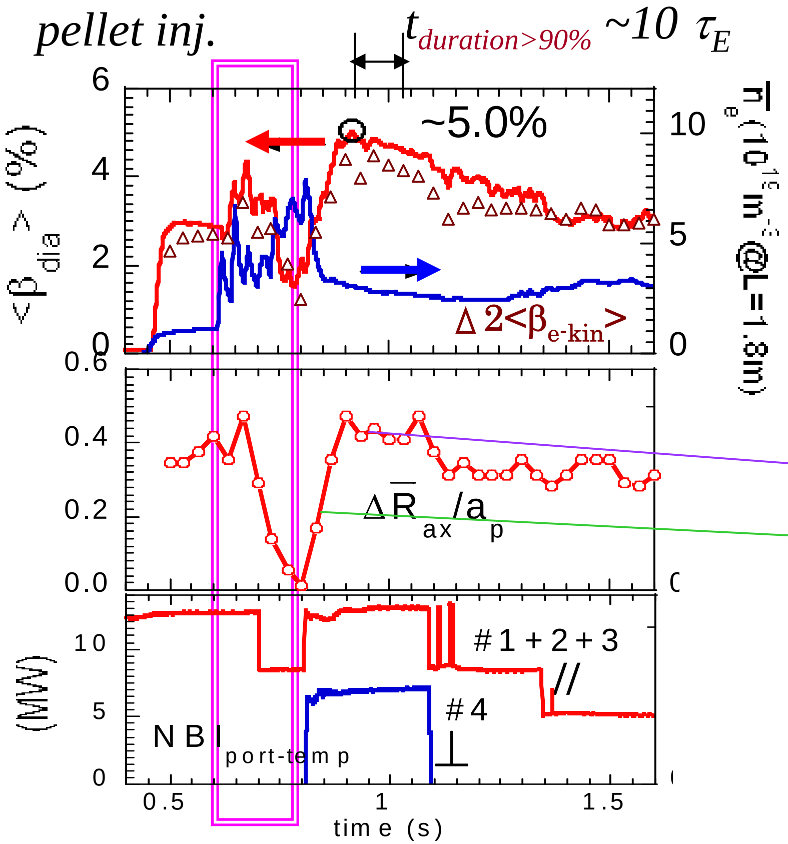
Optimized Config.

pre-set R_{ax}=3.6m,

A_p=6.6,

B_0=0.425 T

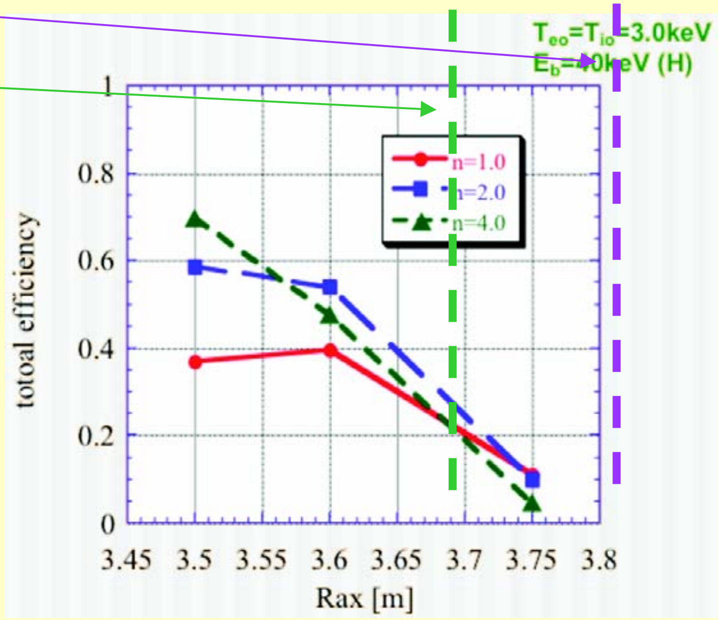
Transient (pellet inj.) high-β dischrage I



Shafranov shift is suppressed by pellet and //NBI power modulation $\Delta R_{ax}/a_{eff}$ ~ 0.4 => ~0

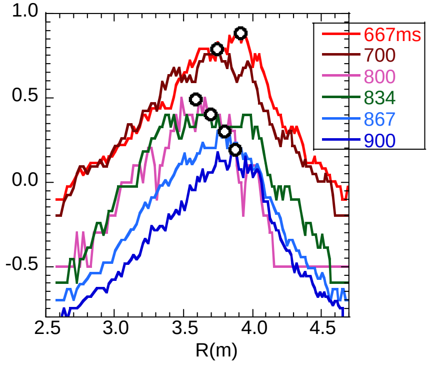
Increasing heating efficiency of ⊥NBI(6.9MW)

=> <β_{dia}>=5.0%

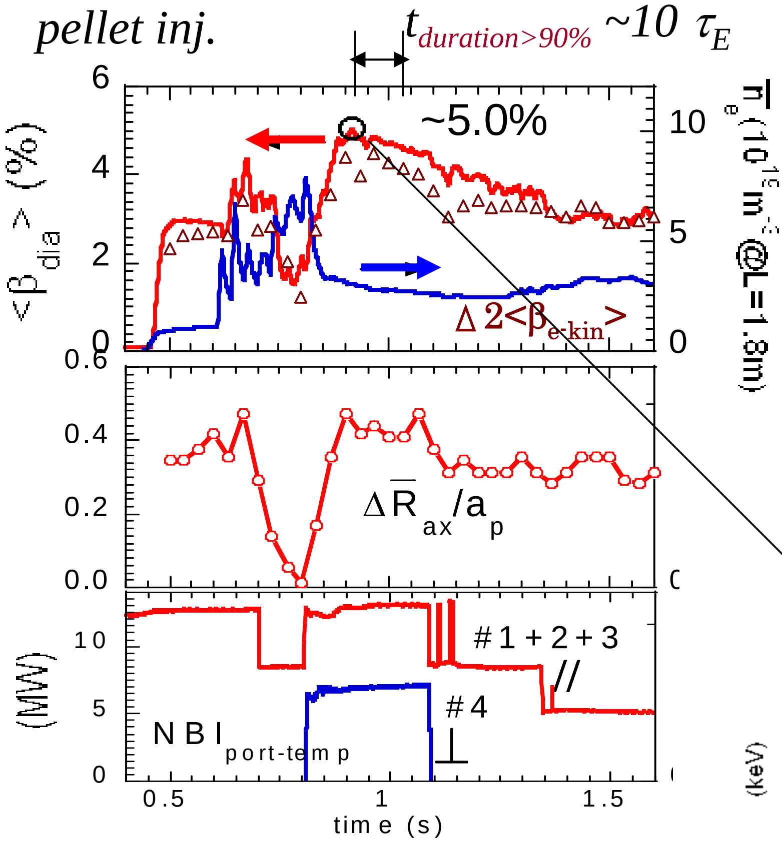


Heating efficiency of ⊥NBI (=>1.5T) Preliminary

Time evolution of T_e

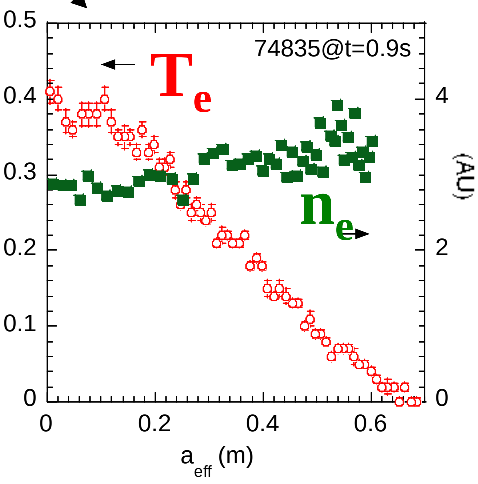


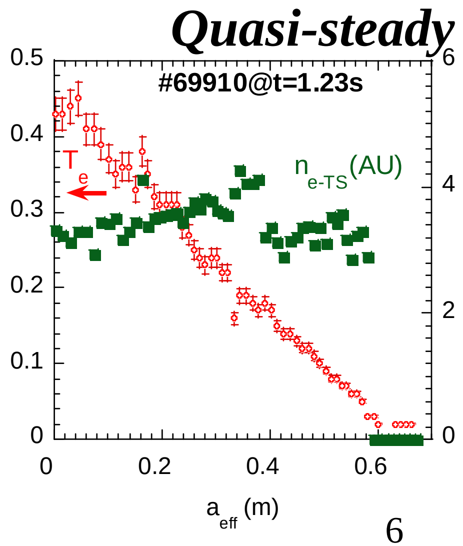
Transient (pellet inj.) high-β dischrage II



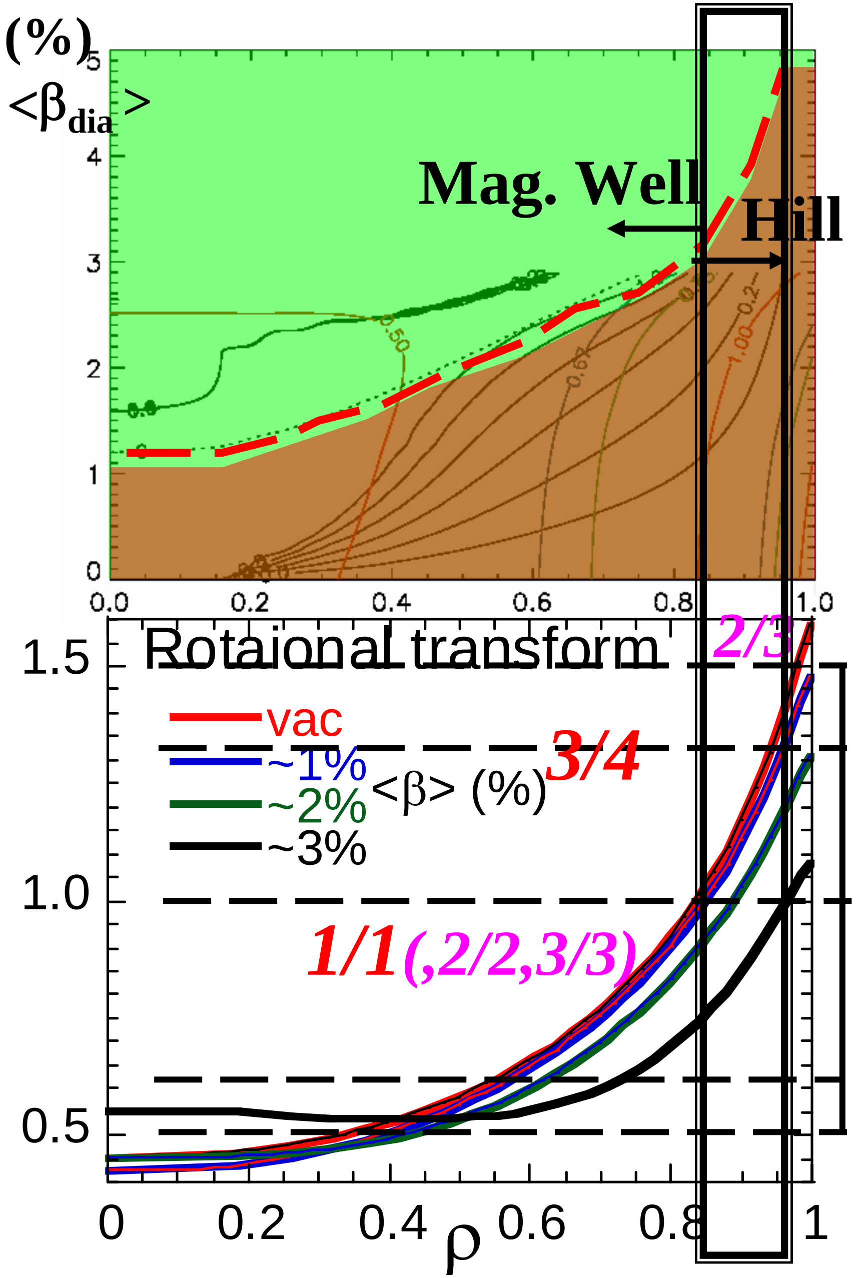
 # Just after pel. inj. for ~10 τ_E, high beta plasma, $<\beta_{dia}>$=5.0% is transiently achieved.

 # T_e and n_e profiles at max β almost same with Quasi-steady





Characteristics of MHD stability in LHD high β conf.



A_p=6.2, $p \sim (1-\rho^2)(1-\rho^8)$

Low order rational surface m<=3

m/n=2/1, 3/2,1/1(,2/2,3/3), 3/4,2/3

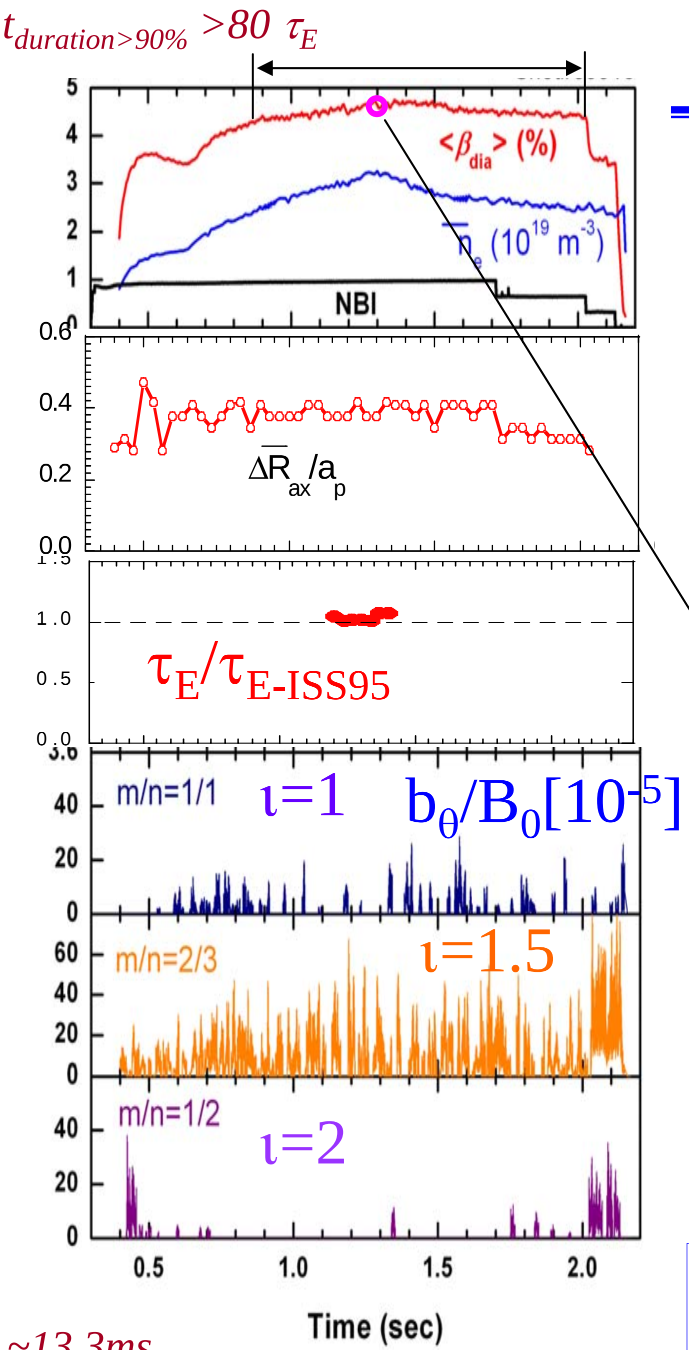
In high beta regime, magnetic hill still exists in peripheral region

=>

***Peripheral* MHD instabilities (pressure driven) are *important* in high beta regime.**

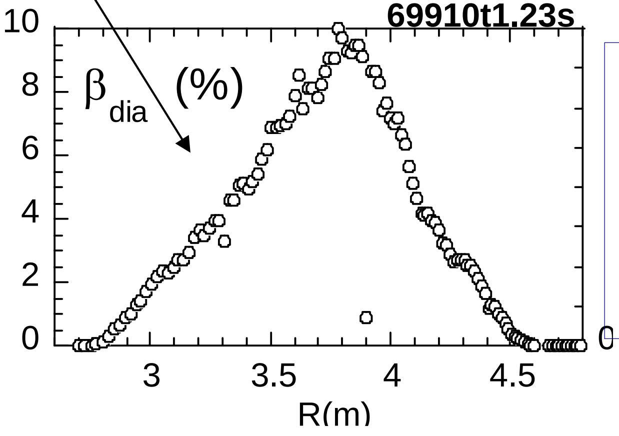
Quasi-steady high-β dischrage

<β>=4.8 %



τ_E~13.3ms

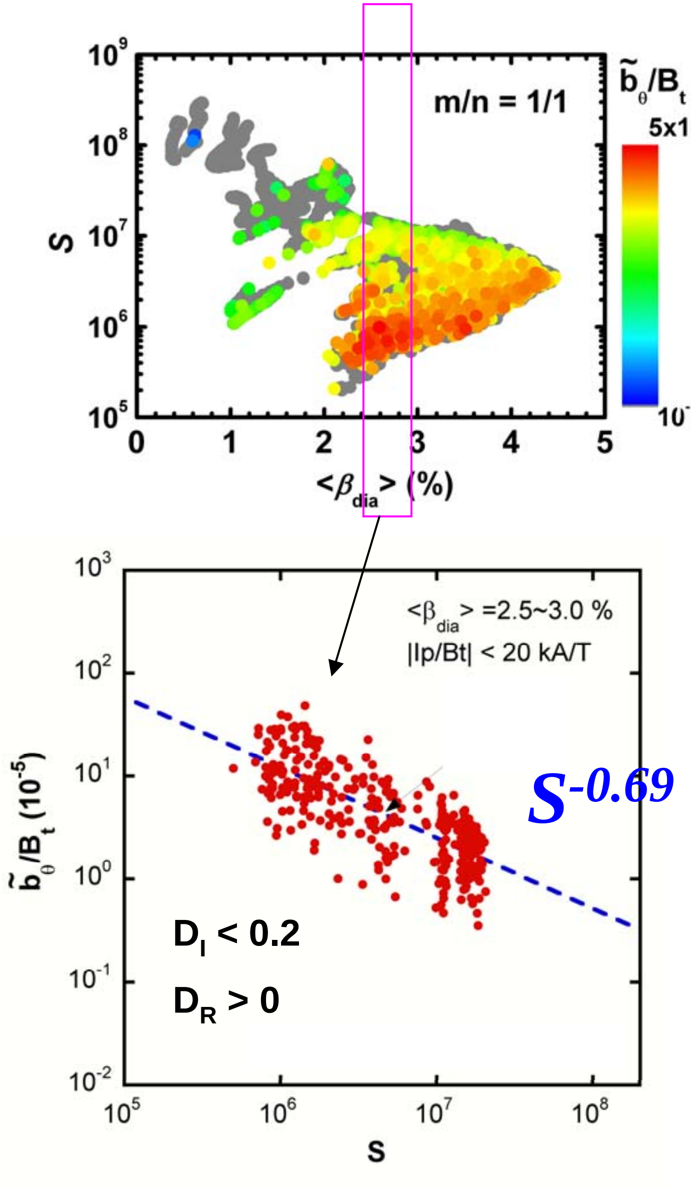
- # No disruptive high beta plasma is maintained during more than 80τ_E
- # Large shafranov shift Δ/a_p ~ 40%
- # Low-n,m MHD activities
  - No observation of core resonant modes.
  - Only resonating mode with peripheral surf. (m/n = 2/3 and 1/1) appear
- # Global confinement property is almost same with ISS95 scaling.



No large β flattening enough to affect a global confinement

Small flattening and asymmetric structures are observed

S (Reinolds#) dependence of MHD mode



Saturation of peripheral MHD mode strongly depends on S parameter.

By a simple model,

$$w \sim \sqrt{\tilde{b}_\theta / B_t}$$

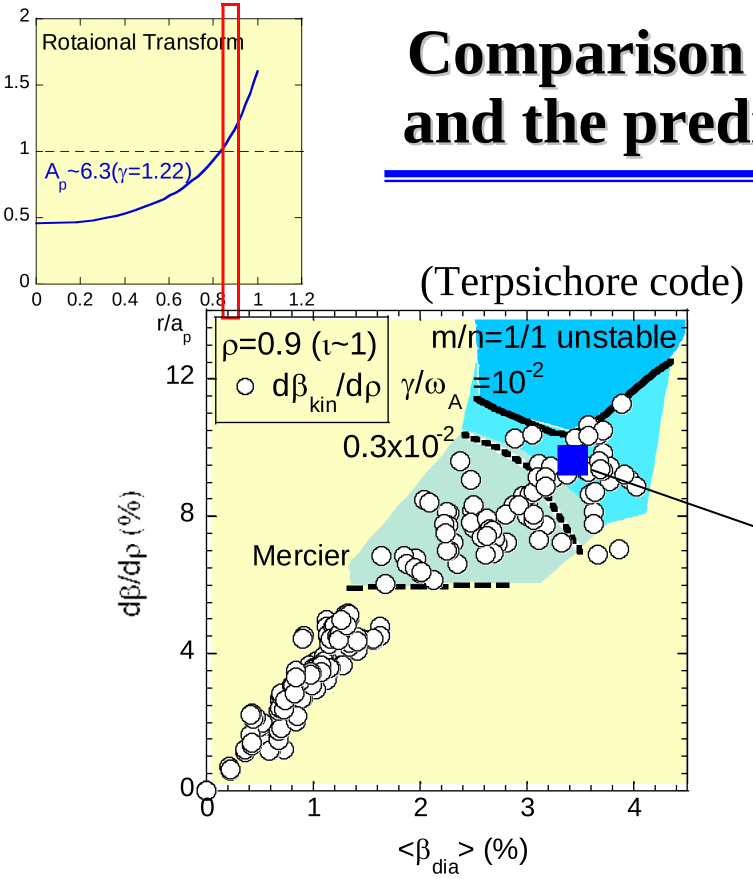
S dependence of w is close to that predicted by linear theory of resistive interchange mode (w $\propto \beta^{1/6} S^{-1/3}$).

Commonly observed modes in LHD high beta operation

=>

resistive (interchange) modes

Comparison between peripheral pressure gradient and the prediction of linear MHD stability analysis



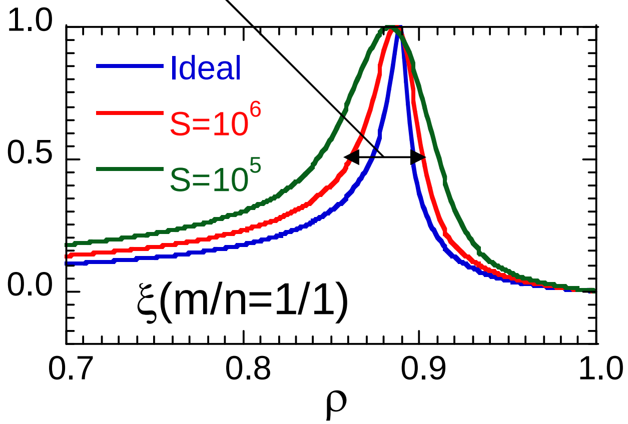
Observed kinetic beta gradients and a contour of growth rate of low-n ideal MHD mode

No strong reduction of gradients

 # The gradients are averaged for Δρ=0.1.

δ/a_p~3% (Ideal)

~5%($S=10^6$) consistent with exp.



Calc. by FAR3D

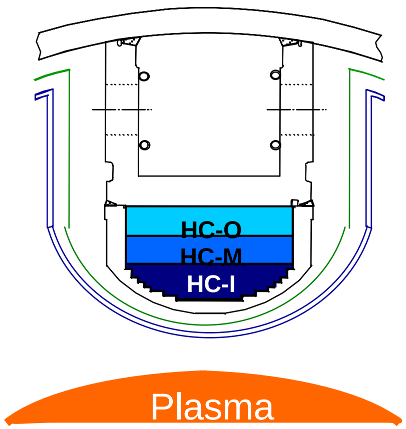
Radial structure of low-n ideal and resitive MHD mode

In $\langle\beta_{dia}\rangle$ ~4% plasmas, the global MHD mode is predicted unstable, but its radial mode width is narrow (~5% of a_p/ growth rate γ/ω_A~10^{-2})

even in the mode is even in the mode is expected linearly unstable, when the mode width is narrow, the effect on the confinement is quite small

No fatal effect of “global” mode on the helical plasma?

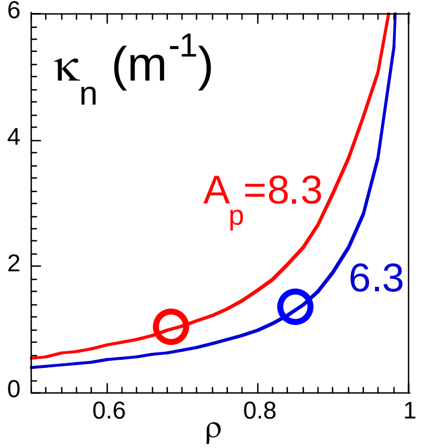
Helcal coil of LHD consists of 3 layers. By changing the current ratio in the 3 layers, plasma aspect ratio, mag.shear and mag. hill hight are controlled.



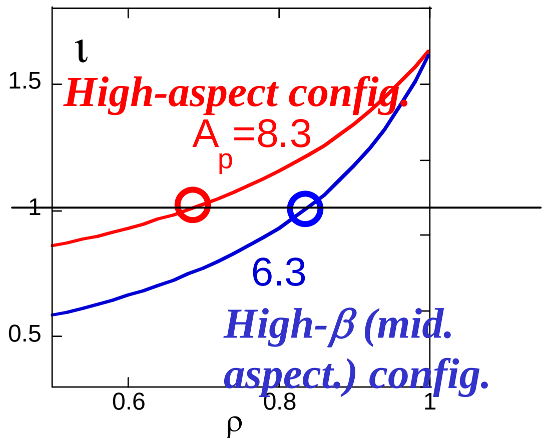
High aspect configuration (a special config.) has low magnetic shear and high magnetic hill in LHD

=> Interchange mode is more unstable

Magnetic curvature

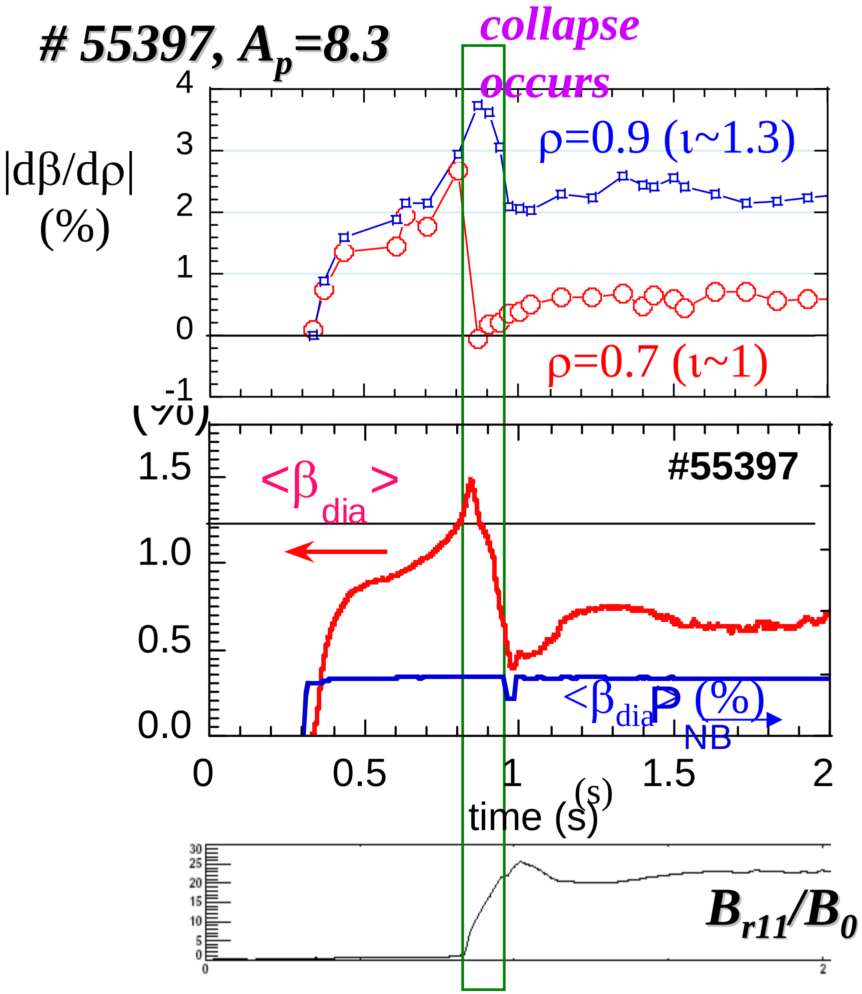


Rotaional transform

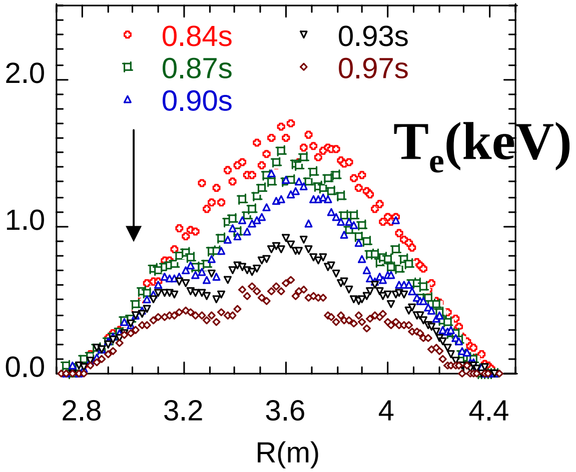


The magnetic shear of high aspect. conf. is much smaller than that of midium aspect. conf., and κ_n in both aspect ratio is almost same at the m/n=1/1 rational surface.

m/*n* = 1/1 mode in high aspect config. (low shear/high hill)



non-rotating

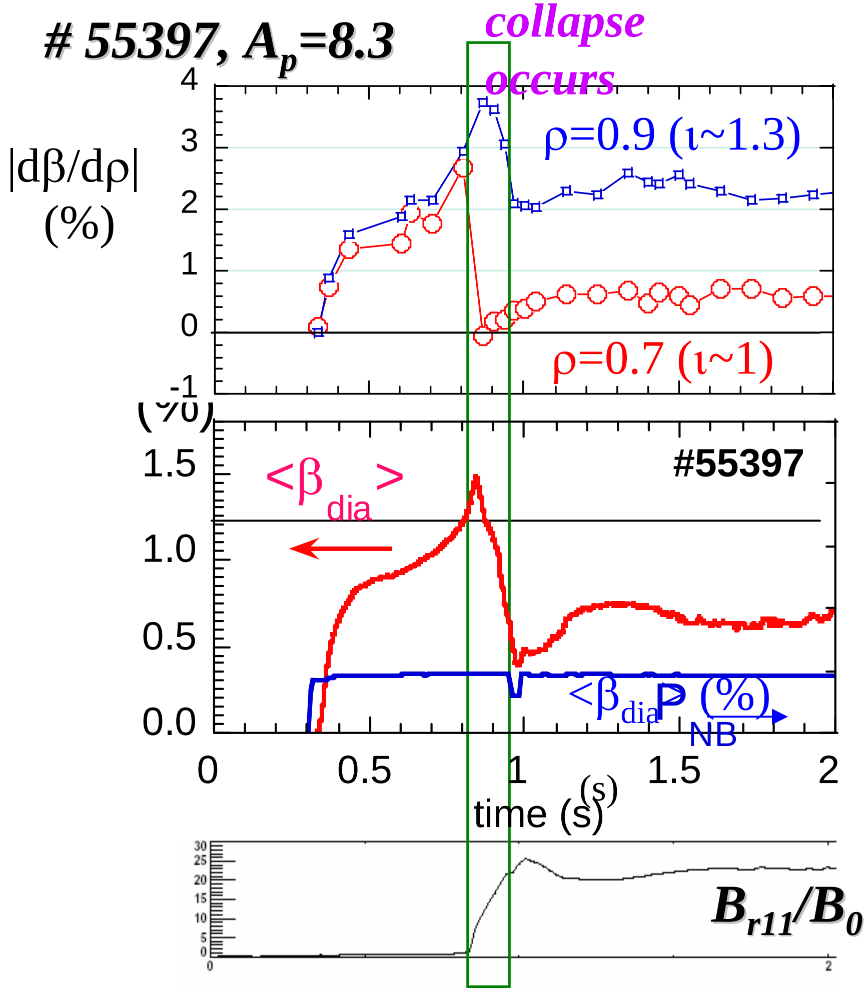


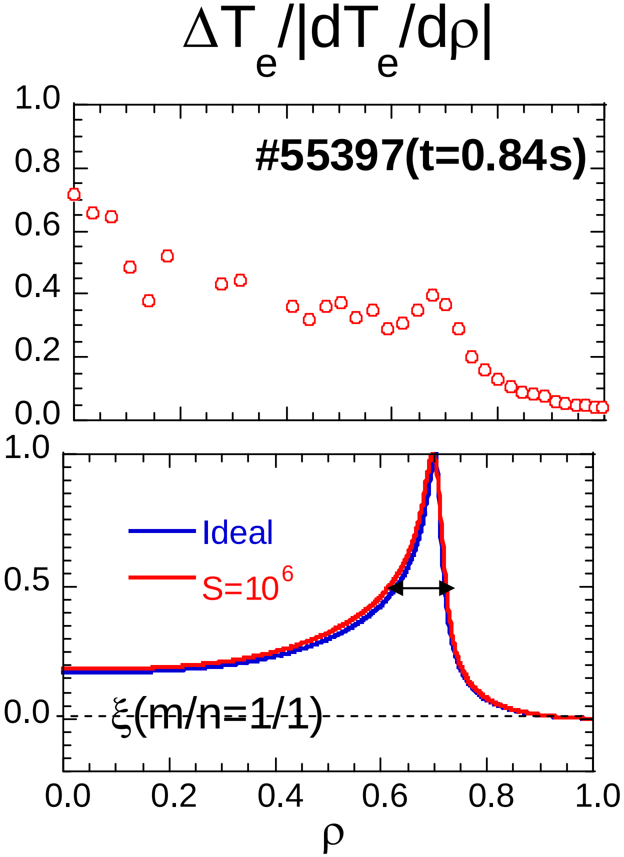
A collapse occurs in a high aspect plasma

Before the collapse occurs, stability condition of global MHD mode is strongly violated.

m/*n* = 1/1 mode in high aspect config. (low shear/high hill)

 # 55397, A_p=8.3





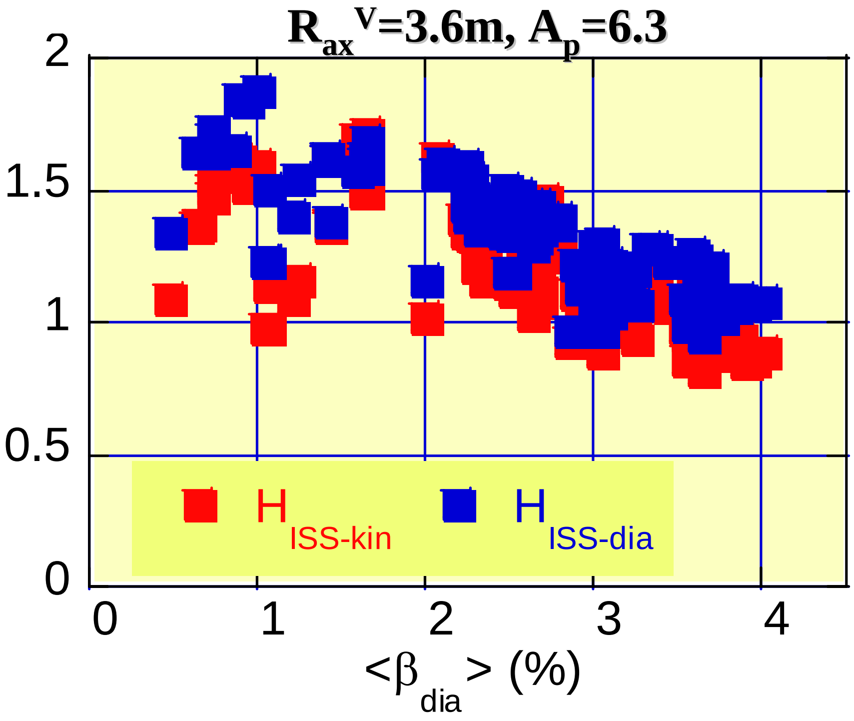
δ/a_p>10%
(ξ(0);finite)
$\gamma/\omega_A \sim 10^{-2}$

Predicted mode width before collapse by FAR3D

A collapse occurs in a high aspect plasma
Before the collapse occurs, stability condition of global MHD mode is strongly violated.

Mode width is much important for the effect on confinement!

τ_E normalized by ISS95 scaling



$$\tau_{ISS95} \propto a^{2.21} R^{0.65} P^{-0.59} n_e^{0.51} B^{0.83} \iota_{2/3}^{0.4}$$

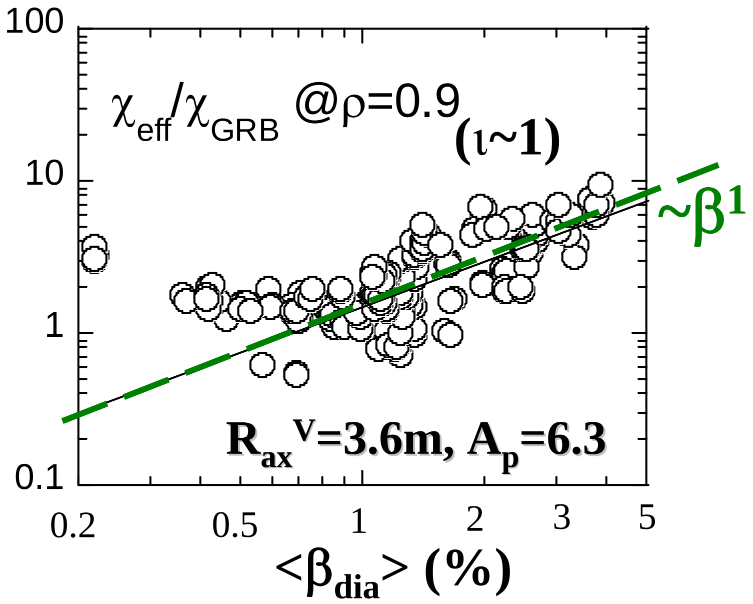
A disruptive degradation has not been observed up to high-β regime, in both τ_E based on the diamagnetic energy and the kinetic energy.

However, the enhancement factors are gradually reduced as beta increases.

Beta dependence of peripheral local transport

χ/χ^{GRB} in peripheral region increases with β in more than 1%.

$$\chi_{GRB} \propto \beta^{0} \nu_{p*}^{\ 0} \rho_{*}^{\ 1} \chi_{B}$$



Normalized thermal conductivity by GB (Gyro-reduced Bohm) model （Global property of GB is quite similar with ISS95)

 # χ dependence on β is similar with a prediction based on MHD (resistive interchange mode) driven turbulence.

$$\boxed{\chi_{GMTe} \propto \beta^{1} \nu_{p*}^{\ 0.67} \rho_{*}^{\ 0.33} \chi_{B}}$$

proposed by Carreras et al. (PoF B1 (1989))

 # Resistive interchange (g-) mode is always unstable in the peripheral region of LHD finite beta.

=> high m,n MHD modes would affect it!

Other possibilities: *Not important!!*

 # Invasion of stochastic region with beta is predicted *See P2-043 by Y.Suzuki*

 # Configuration effect as proposed in ISS04 scaling *See P2-049 by H.Funaba*

Effect of resistive interchange mode on peripheral transport

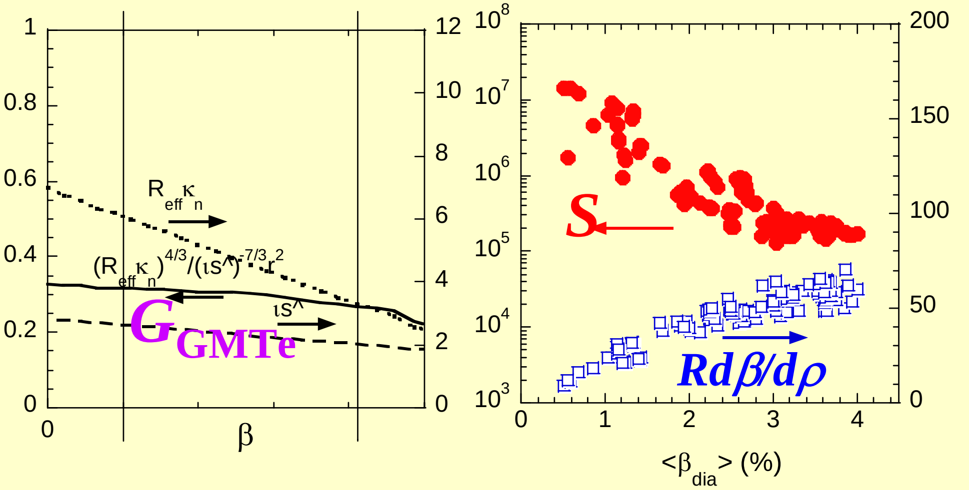
Thermal conductivity based on resistive interchange (g) mode turbulence (induced through the magnetic field diffusion)

Today's Model

$$\chi_e = \sqrt{\frac{\pi}{4}}\,\frac{\hat{S}}{R_0 q}\,V_T\,\frac{\mu_0}{\eta}\,\gamma_{\langle m\rangle}^{(0)}\,(W_{\langle m\rangle}^{(0)})^4\,\Lambda^{4/3}.$$

Λ; Renormalization factor
γ; Linear growth rate
W; mode width of g-mode

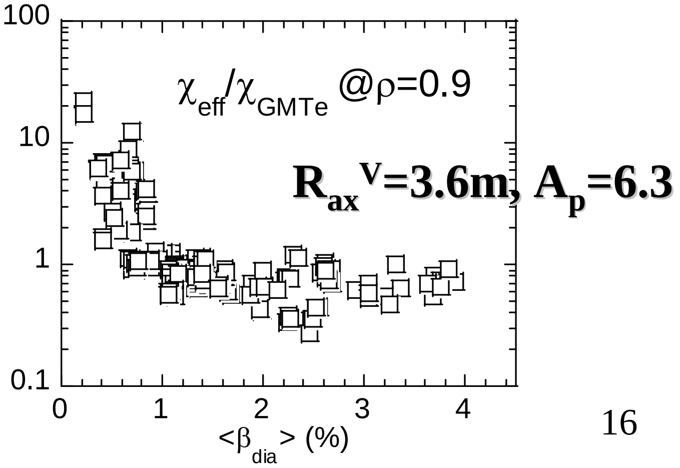
refs. B.A.Carrears et al. Phys.Fluids 30, 1388 (1987)
B.A.Carreras et al. Phys.Fluids B1, 1011 (1989)



G_{GMTe}

$$\chi \propto \frac{q}{\hat{s}}\left(\kappa_n R_0\right)^{\frac{4}{3}} a_{eff}^{\;2}\left(\frac{\beta R_0}{L_p}\right)^{\frac{4}{3}} S^{-\frac{2}{3}}\,\frac{v_{Te}}{R_0}$$

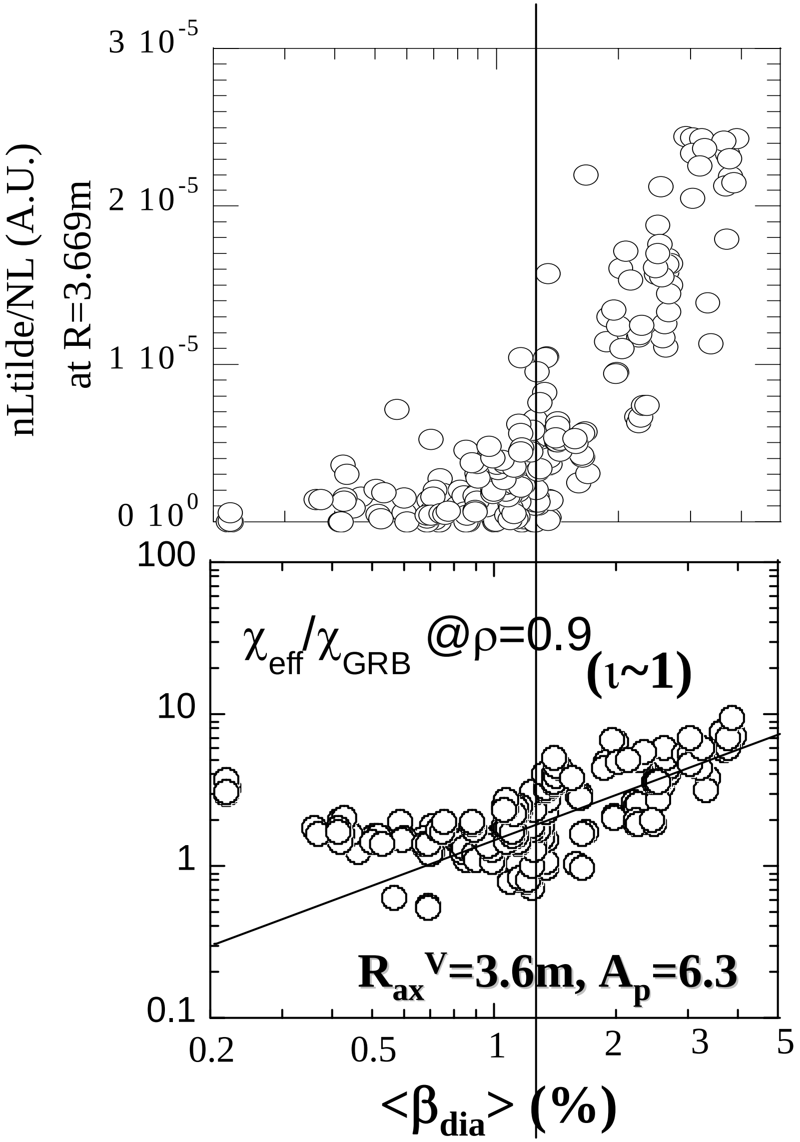
Normalized thermal conductivity by g-mode turbulence model is constant in a high beta regime with β>1%.



[ref] H.Funaba et al, Fusion Sci. Tech. to be published in 2006, Proc. in 15th Int. Stell. WS in Madrid (2005).

Collateral evidence

Density fluctuation amplitude with relatively long wavelength increases with β



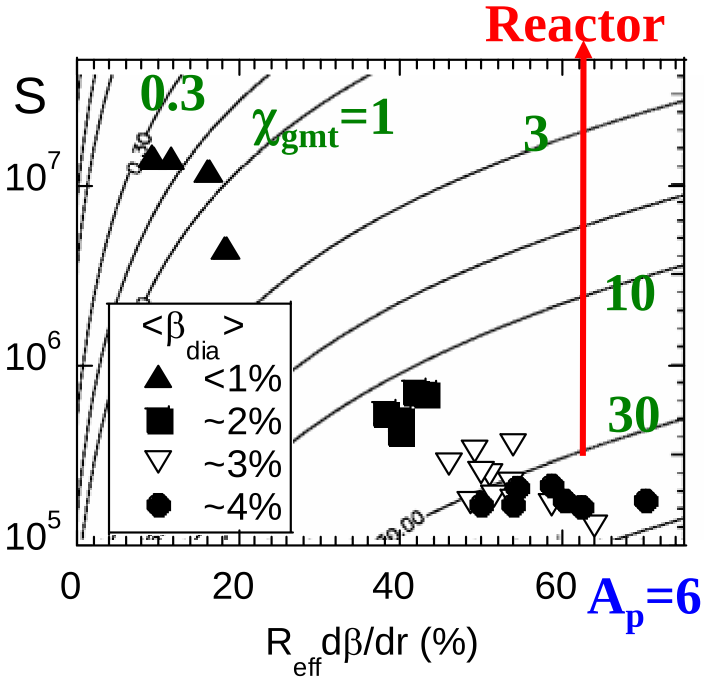
Beta dependence of the density fluctuation amplitude with relatively long wavelength, λ>~30mm(m<100)

 # Sight line passes the relatively peripheral region

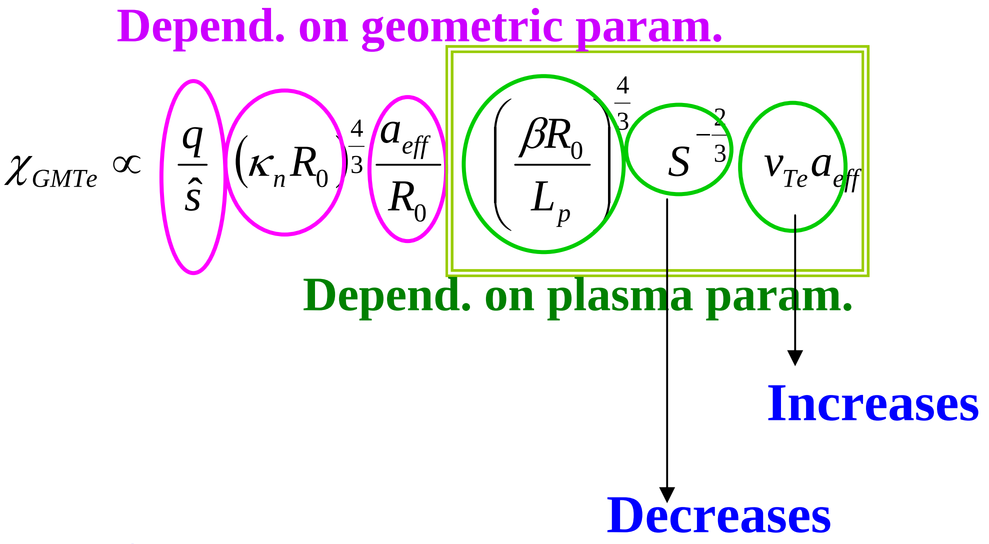
 # Inflection point of thermal conductivity looks synchronized with that of the density fluctuation amplitude with relative long wave length

Effect of g- mode turbulence on confinement of reactor

Contour of pred. χ based on g-mode turbulence



A_p=6.3 config. ρ=0.9



Depend. on geometric param.

$$\chi_{GMTe} \propto \frac{q}{\hat{s}} \left(\kappa_n R_0\right)^{\frac{4}{3}} \frac{a_{eff}}{R_0} \left(\frac{\beta R_0}{L_p}\right)^{\frac{4}{3}} S^{-\frac{2}{3}} v_{Te} a_{eff}$$

Depend. on plasma param.

Increases

Decreases

LHD high beta plasmas are obtained under low mag. field operations. Then S is reduced as beta increases.
=> The prediction of large value of χ in high beta regimes.

In a reactor, B_0 and n_e are larger by 10 times, and $v_{Te}a_{eff}$ is by 15~20 times than LHD high beta operations. => S would be larger by 300-400 times.
=> $\chi \sim 1 m^2/s$ (Not negligible but not large)

Summary

 # LHD transiently achieved the 5% beta and the 4.8 % beta in quasi-steady

Improving the heating efficiency of ⊥NBI due to the suppression of the Shafranov shift

In addtion to the increment of the //NBI power and the optimization of the configuration.

 # No observation of disruptive phenomena in LHD high beta discharges would result from the radial localization of the predicted global MHD modes

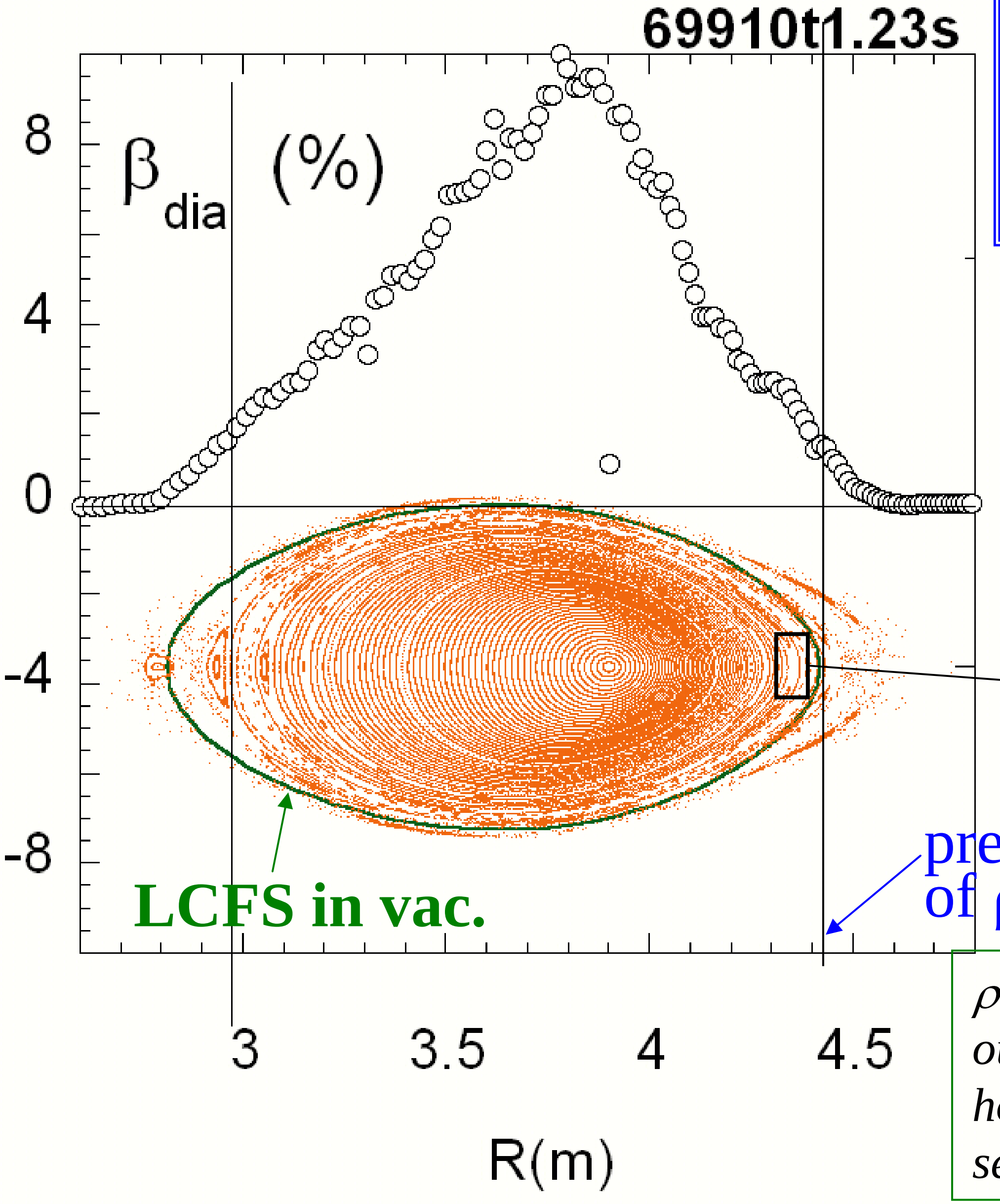
Through comparison between achieved pressure gradients and linear MHD numerical analyses in 2 different configurations

 # Degradation of peripheral local transport with beta is observed. But for a fusion reactor, that would not be strong obstacle.

The above degradation is is fairly consistent with an anomalous transport model based on a g-mode turbulence (GMT) model . For the fusion reactor, GMT would not be strong obstacle because it is significantly reduced in the high magnetic Reynolds number comparatively with a reactor.

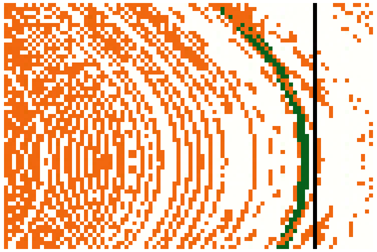
Options

Observed b profile and Poincare map by HINT calculation for $<\beta_{dia}>=4.8\%$ plasmas



LCFS in vac.

present def. of ρ=1



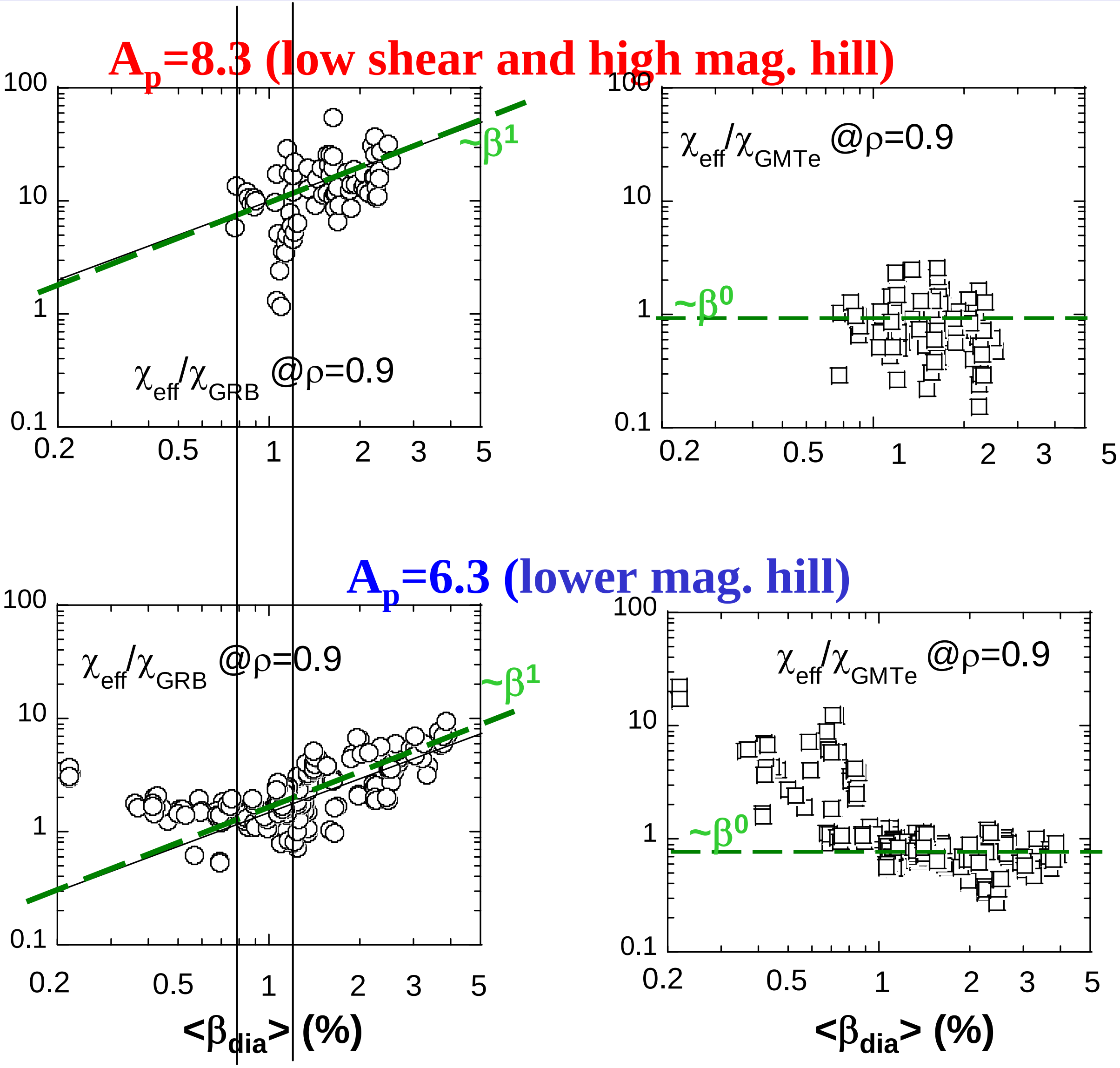
Invasion of stochastic region up to ρ~0.9 surf. is not predicted.

ρ=1 suf. passes the torus outboard side of LCFS of vac. at holizontally elongated cross-section.

See P2-043 by Y.Suzuki

Collateral evidence 1

Peripheral transport properties in another configuration



A_p=8.3 (low shear and high mag. hill)

A_p=6.3 (lower mag. hill)

$$\chi_{GRB} \propto \beta^0 \nu_{p*}{}^0 \rho_*{}^1 \chi_B,$$

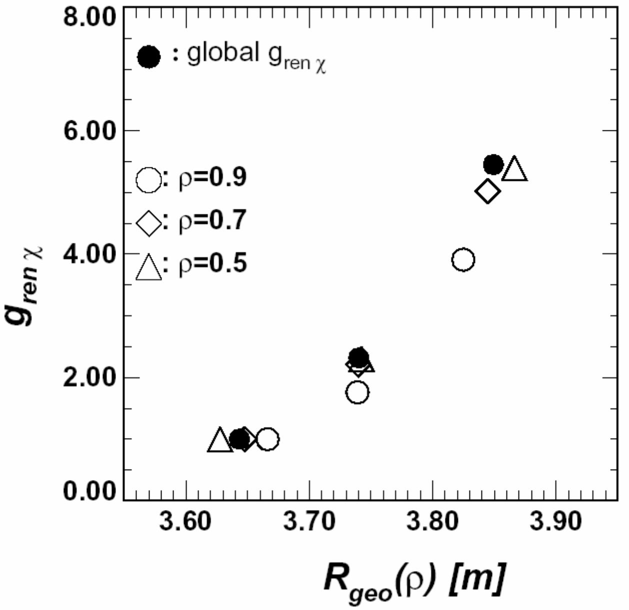
$$\chi_{ISS95} \propto \beta^{0.16} \nu_{p*}{}^{0.04} \rho_*{}^{0.71} \chi_B,$$

$$\chi_{GMTe} \propto \beta^1 \nu_{p*}{}^{0.67} \rho_*{}^{0.33} \chi_B$$

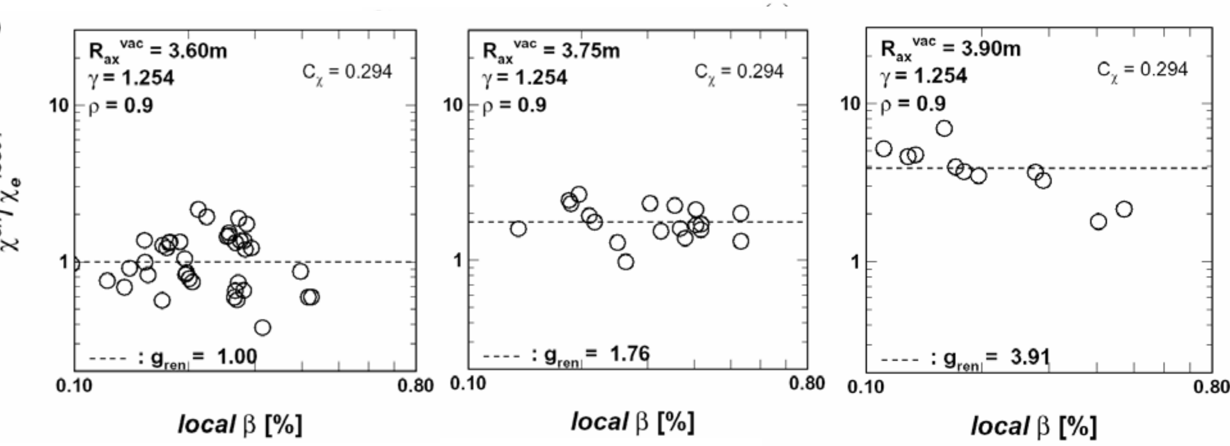
GMT (g-mode turbulence) model is more consistent with experimental thermal conductivity in a high beta range than GB (Gyro-reduced Bohm) model.

(The dispersion of data in a high aspect config. is fairly large.)

Normalized thermal conductivity by GB model and GMT model



(a)

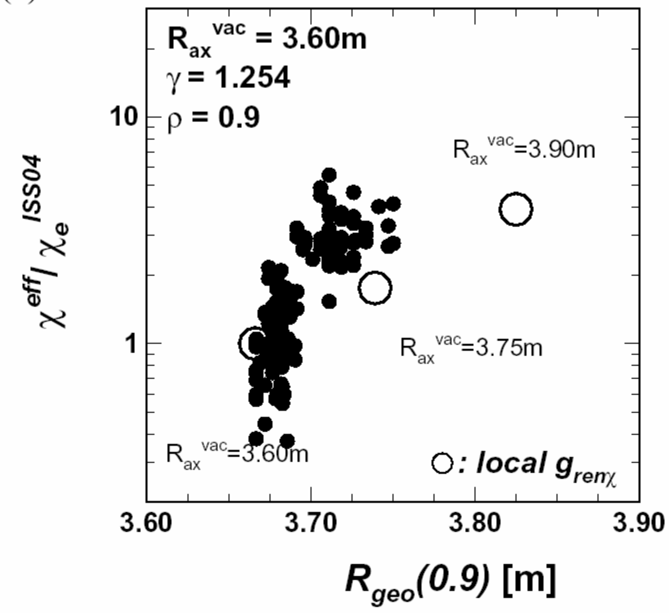


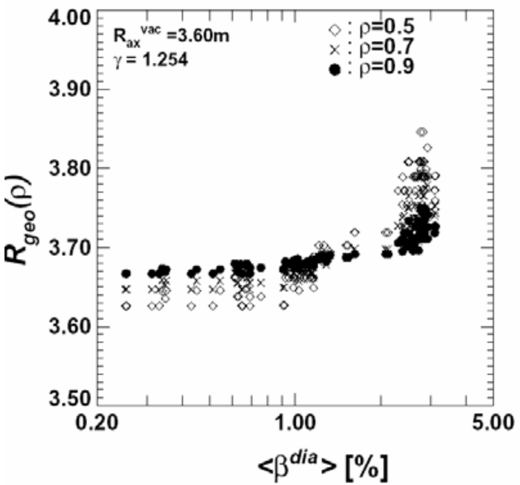
$$g_{ren\chi}=\chi^{eff}/\chi^{ISS04}$$

$$\chi^{ISS04}=C_\chi\cdot\chi^{Bohm}\cdot\rho^{*0.79}\beta^{0.19}\nu_b^{*0.00}A_p^{-0.07}\iota_{2/3}^{-1.06}$$

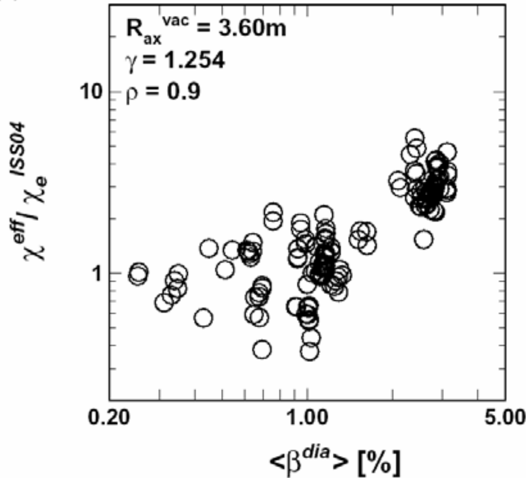
See P2-049 by H.Funaba

(c)





(c)



Why is the predicted χ_{GMTe} (χ induced by g-mode turbulence) of a high aspect (A_p=8.3) plasma much large??

G_{GMTe}

$$\chi \propto \frac{q}{\hat{s}} \left(\kappa_n R_0\right)^{\frac{4}{3}} a_{eff}^{\,2} \left(\frac{\beta R_0}{L_p}\right)^{\frac{4}{3}} S^{-\frac{2}{3}} \frac{v_{Te}}{R_0}$$

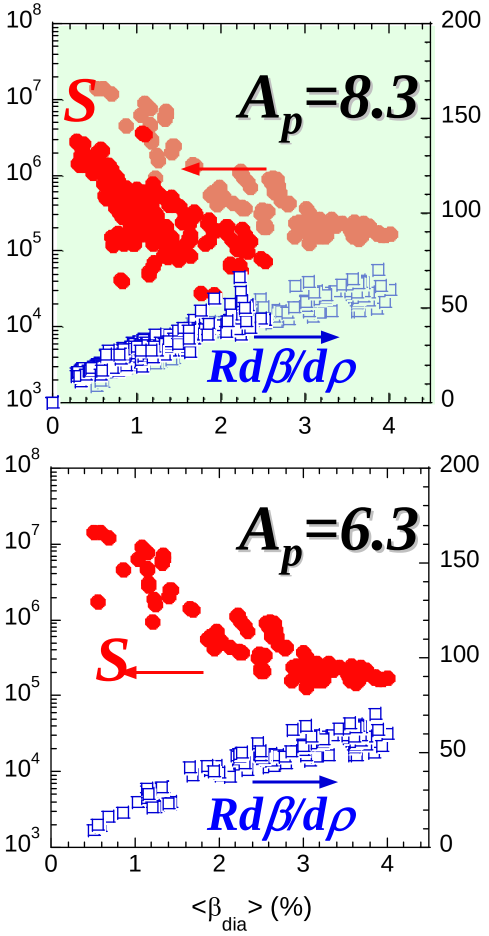
Peripheral Rdβ/dρ both in A_p=8.3 and 6.3 are almost same.

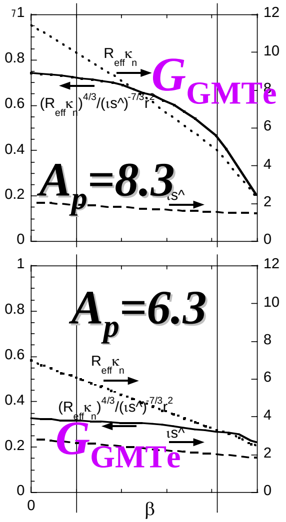
=> $p_{@\rho=0.9}$ in A_p=8.3 < $p_{@\rho=0.9}$ in A_p=6.3

=> $T_{@\rho=0.9}$ in A_p=8.3 < $T_{@\rho=0.9}$ in A_p=6.3 if n_e is same.(Reason not clear)

=> $S_{@\rho=0.9}$ in A_p=8.3 > $S_{@\rho=0.9}$ in A_p=6.3

Peripheral S in A_p=8.3 is smaller by ~10 times than A_p=6.3.





Beta dependence of plasma parameter and geometric facter determining χ_{GMTe}

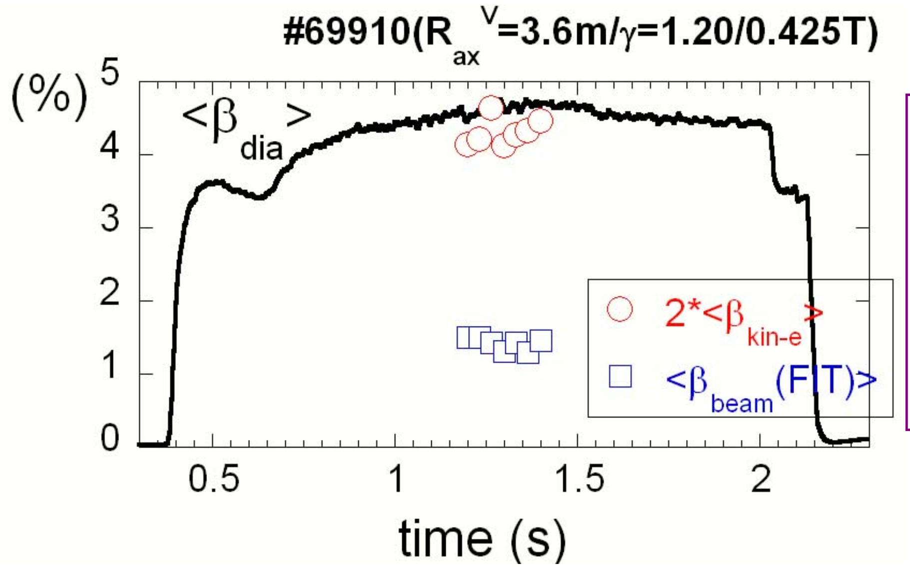
Geometric factor of g-mode turbulence model (G_{GMTe});

G_{GMTe} in A_p=8.3 is larger by 2~2.5 times than A_p=6.3.

G_{GMTe}; 2~2.5=> χ_{GMTe}; 2~2.5

S; ~1/10=> χ_{GMTe}; ~4.5

=> χ_{GMTe}; ~10 times larger



Port-through power //NBI *13.8MW*

$<\beta_{dia}>$; 4.8% (β_{perp}~3.2)

$<\beta_{kin}>$; *4.3%* (=2*$<\beta_{kin\text{-}e}>$)

$<\beta_{beam}>$; *1.5%* (Cal. by FIT code)

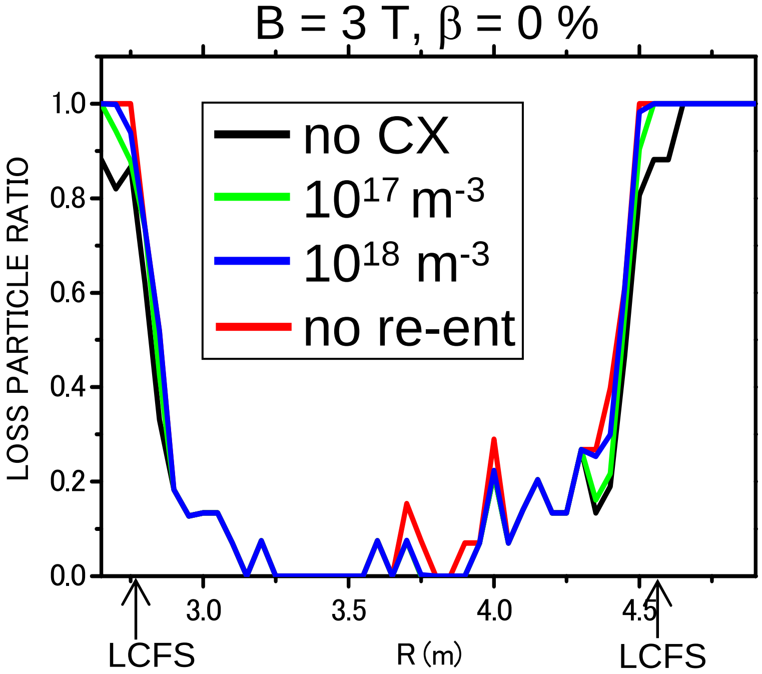
$<\beta_{dia}>$; based on the diamagnetic measurement.
defined as $(2W_{dia}/3V_{p0})/(B_{av0}^2/2\mu_0)$.
B_{av0} and V_{p0} are based on a vacuum calculation.

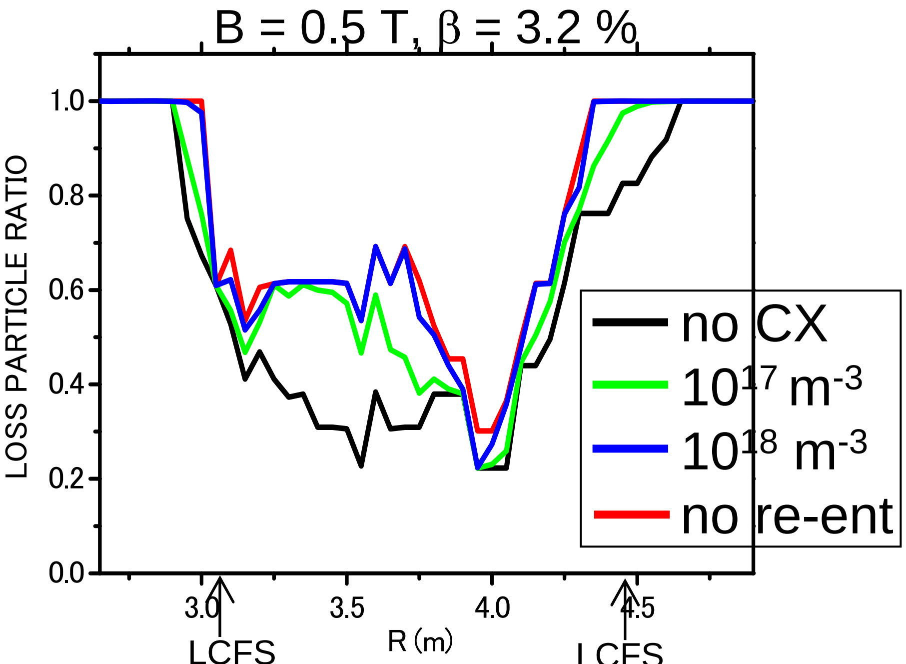
$<\beta_{kin}>$; based on the T_e and n_e profile measurements
$Z_{eff}=1$ and $T_i=T_e$ are assumed.

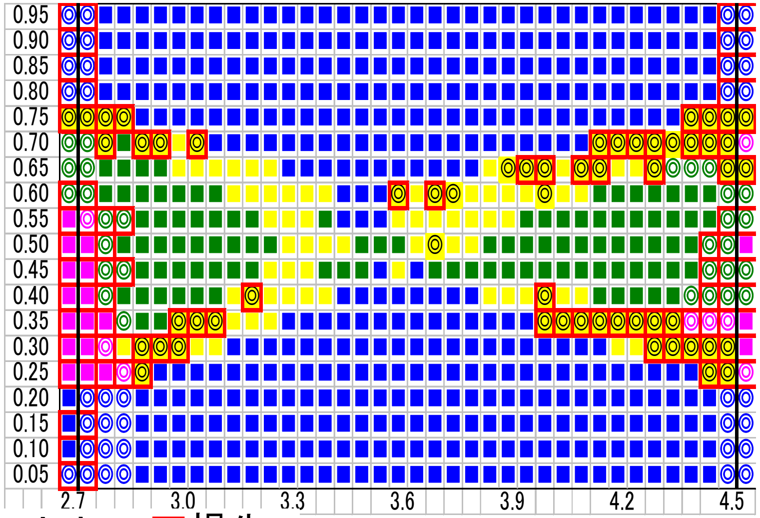
(When $Z_{eff}=2.5$, $<\beta_{kin}>$~3.6%(β_{perp}~2.45), $<\beta_{beam}>_{perp}$~0.75%, $<\beta_{beam}>_{ara}$~0.75%)

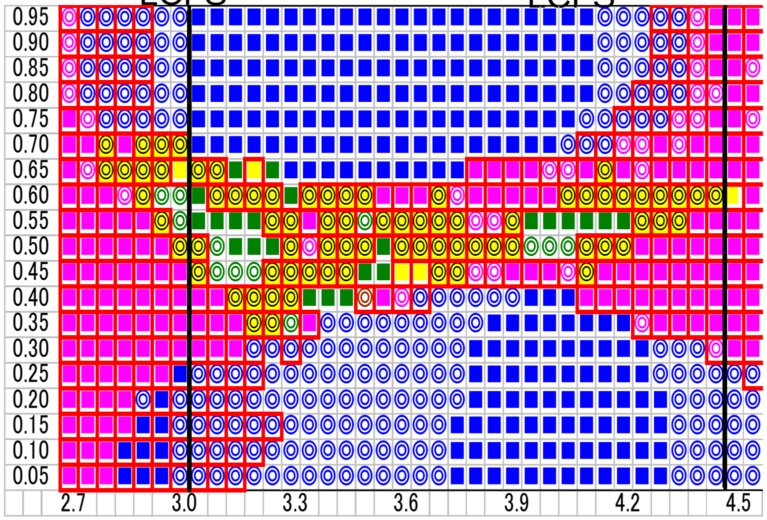
$<\beta_{beam}>$; based on the calculation
with Monte Carlo technique and the steady state Fokker-Plank solution.

Loss particle ratio based on HINT data $R_{ax}^{V}=3.6\text{m}, A_p=5.8$









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Summary

\# By improving the heating efficiency of ⊥NBI due to the suppression of the Shafranov shift and the NBI power modulation, in addition to the increment of the parallel NBI power, LHD transiently achieved the 5% beta value.

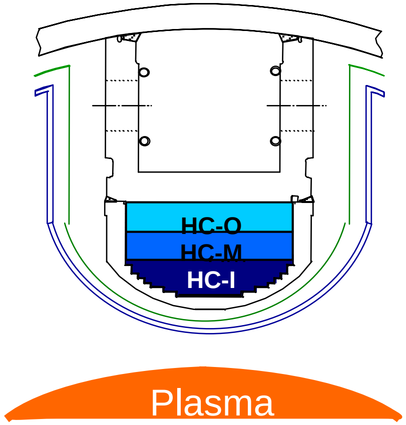
\# According to the numerical analysis of the g-mode for a typical high beta discharge, the radial mode width is quite narrow, Δ/a_p~5%. This fact supports that we have never observed disruptive phenomena in the LHD high beta discharges because the predicted MHD instabilities are quite localized.

\# According to the transport properties on beta, the gradual degradation of the local transport with beta comparing with GB (Gyro-Bohm) model is observed. The above degradation is is fairly consistent with an anomalous transport model based on a g-mode turbulence (GMT) model .

\# For the fusion reactor, the anomalous transport based on the GMT is still important, but it would not be strong obstacle for the production of the high performance plasmas because it is significantly reduced in the high magnetic Reynolds number comparatively with a reactor.

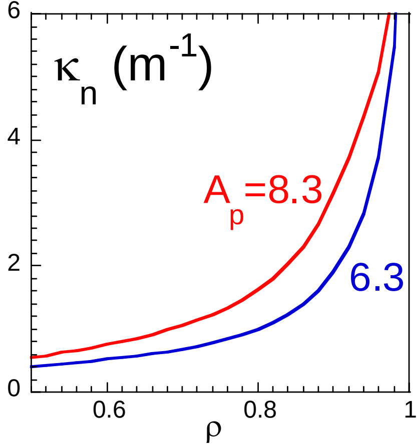
他の配位での検証は?

Helcal coil of LHD consists of 3 layers.
By changing the curennt ratio in the 3 layers, plasma aspect ratio, mag.shear and mag. hill hight are controlled.

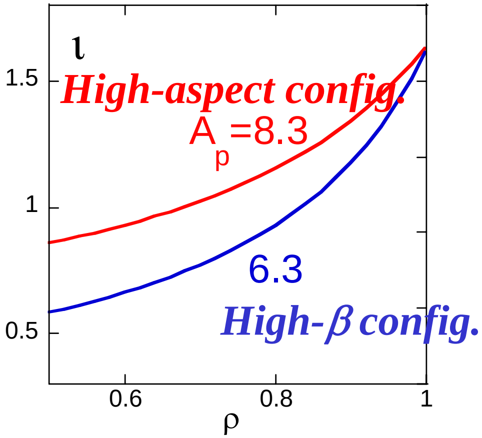


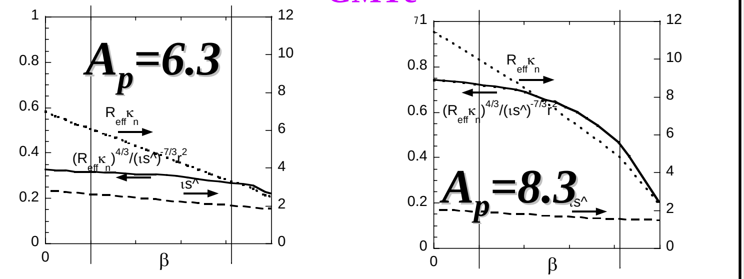
High aspect configuration has low magnetic shear and high magnetic hill in LHD

Magnetic curvature

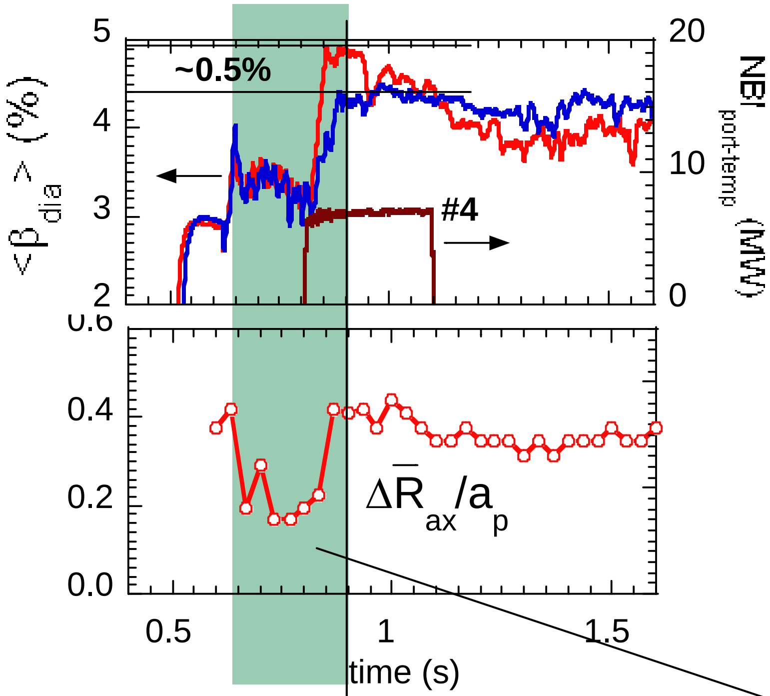


Rotaional transform



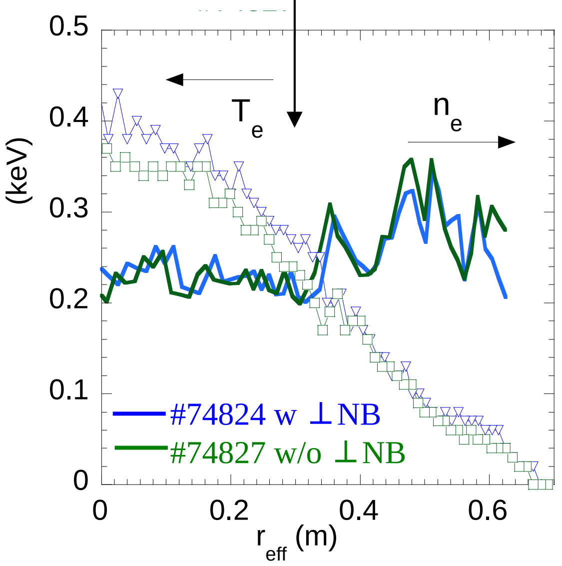


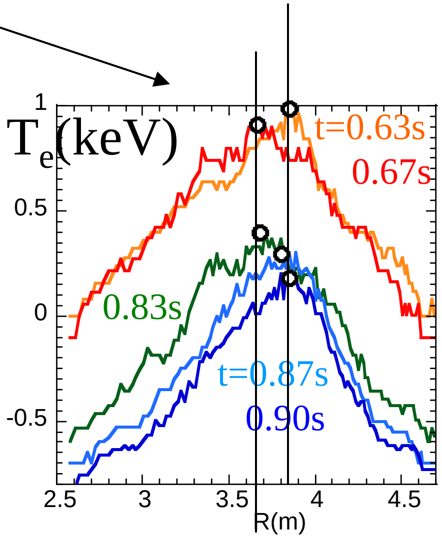
垂直NBIの高ベータ領域拡大への寄与



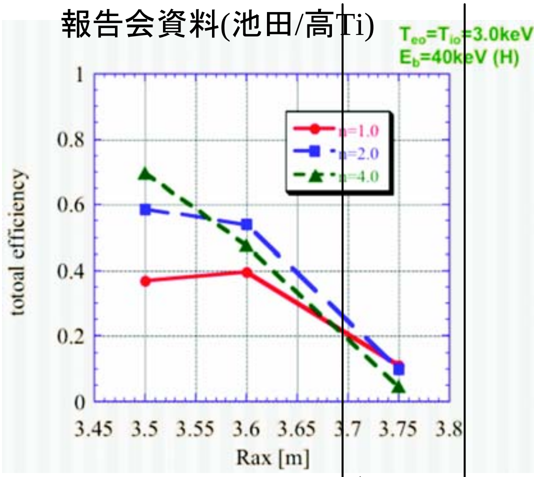
⊥NBI;6.9MW(ポートスルー)
=> $\Delta<\beta_{dia}>$~0.5%
@$<\beta_{dia}>$~4.4%/ペレット入射直後
電子温度がコア領域で上昇。
密度はほとんど変化なし

//NBIパワーモジュレーションによる
ベータの押し上げ効果は小さい
($\Delta<\beta_{dia}>$~0.1%)





平成17年度LHD実験成果
報告会資料(池田/高Ti)

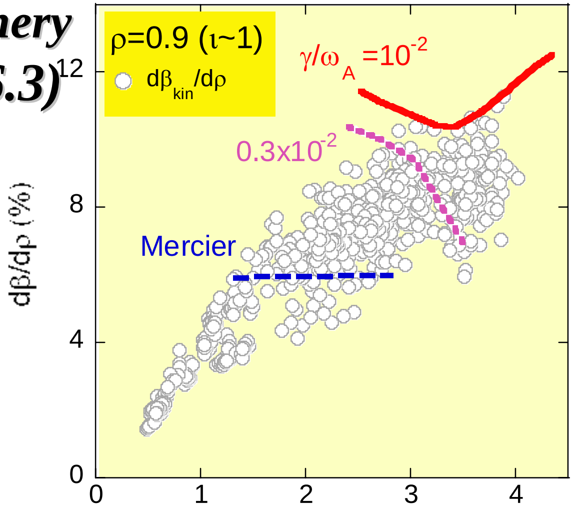


⊥NBIの加熱効率(真空
/>1.5T)

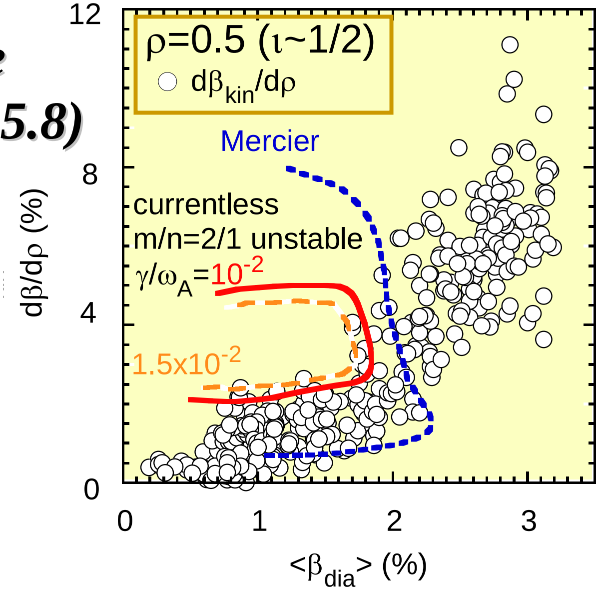
Discussion I

What is a good index for the limitation of the operational regime in stellarator/heliotron?

Periphery (A$_p$=6.3)



Core (A$_p$=5.8)

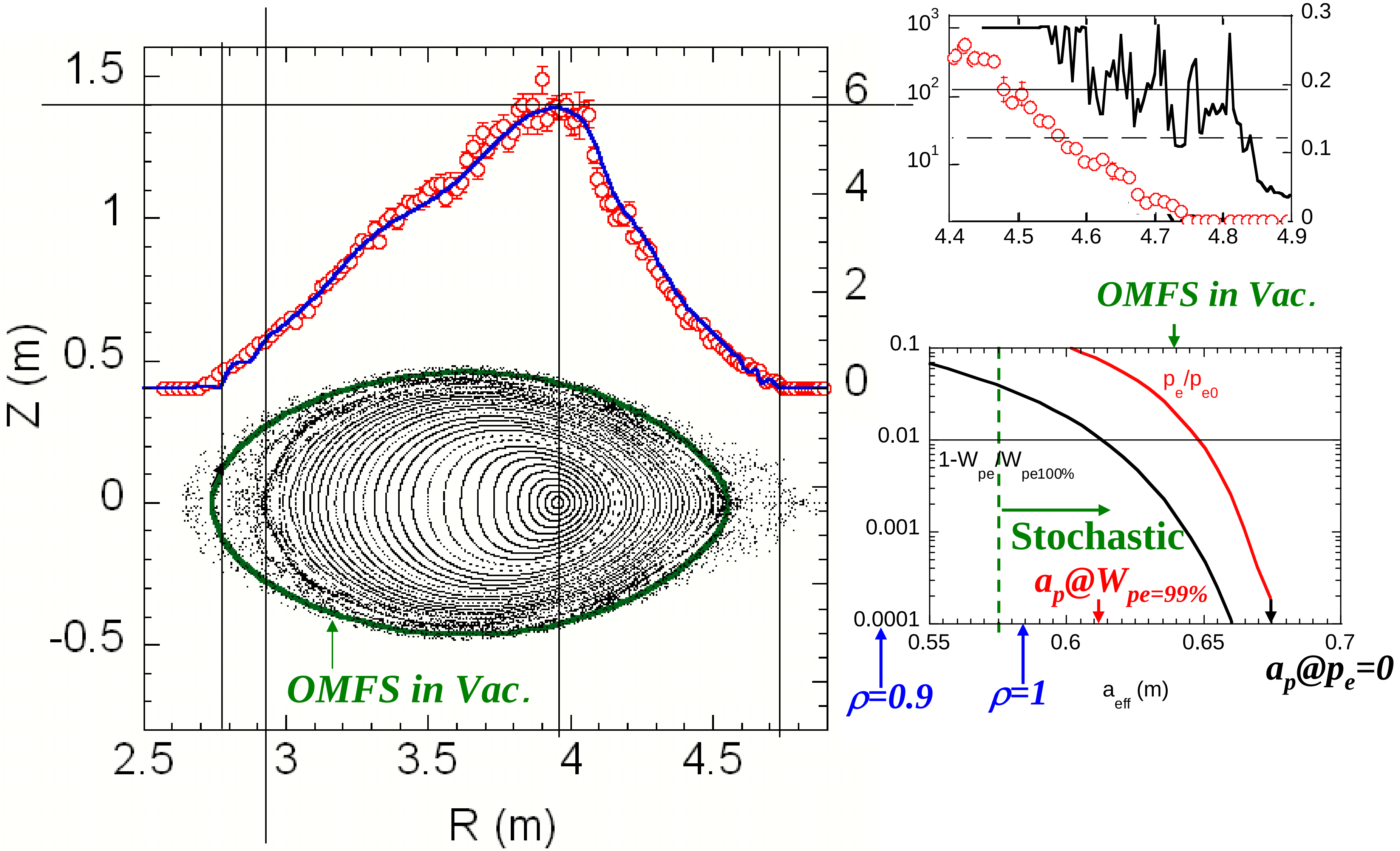


Though the observed pressure gradients are in non-linear saturation phases, a linear MHD theory could be a reference for more complicated non-linear analyses, and/or a criterion for a reactor design.

Peripheral region: the maxima of the achieved pressure gradients are less than $\gamma_{low\text{-}n}/\omega_A = 10^{-2}$.
Core region; the maxima of the achieved pressure gradients saturate against the contour of $\gamma_{low\text{-}n}/\omega_A = 1.5\times10^{-2}$ in the range of $\langle\beta_{dia}\rangle$ = 1~1.8%.

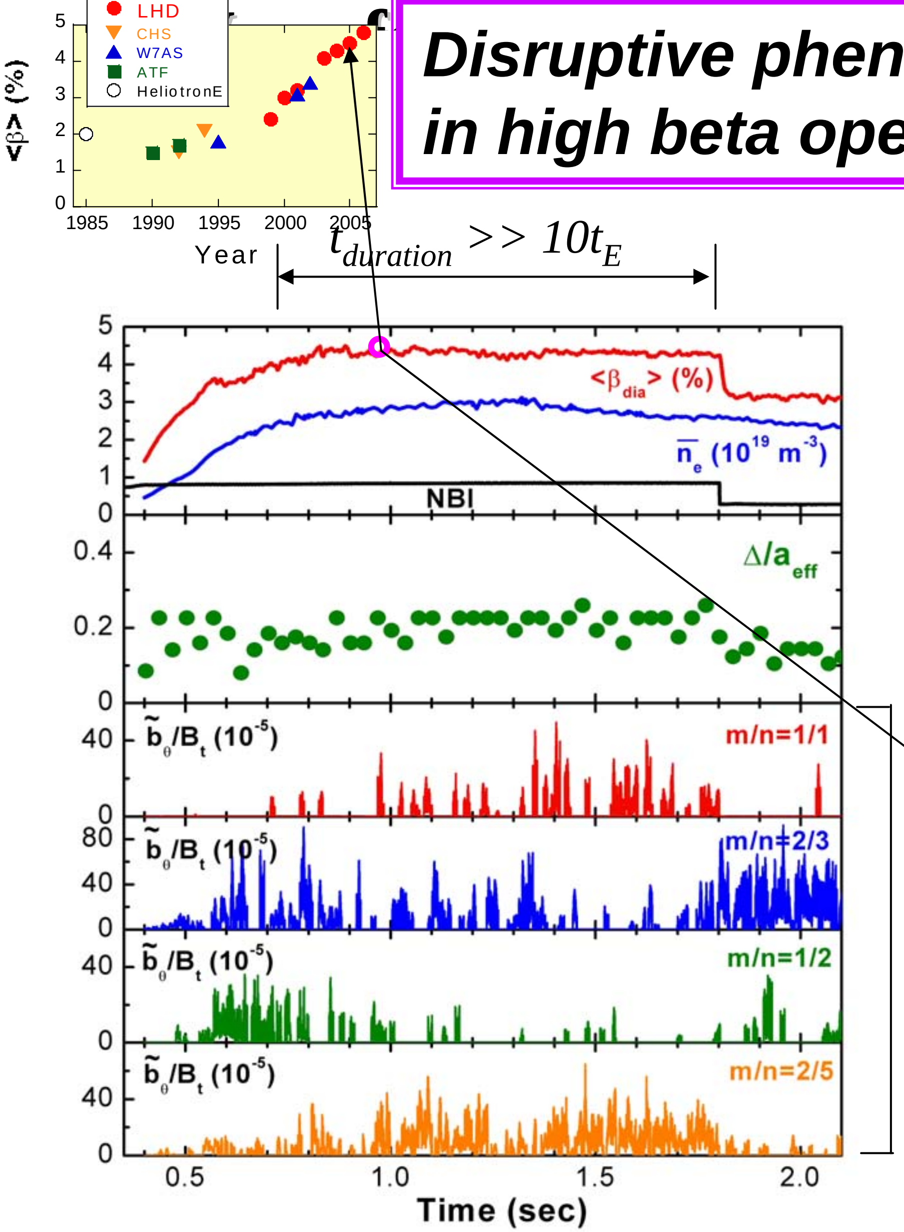
Roughly speaking, $\gamma_{low\text{-}n}/\omega_A = 1\sim1.5\times10^{-2}$ is considered a good index to determine the condition that the global ideal MHD instability limits the LHD operational regime.

For further verification, we need to extend the above comparative analyses between the experimental results and the theoretical prediction based on a linear theory to a wide range of magnetic configurations in LHD!!



Predicted magnetic field structure by HINT and observed pressure profile in a high beta LHD discharge with R_{ax}^V=3.6m, B_0=0.5T and $<\beta_{dia}>$~2.9%.

Disruptive phenomena have not been observed in high beta operation with <β_{dia}> >4%



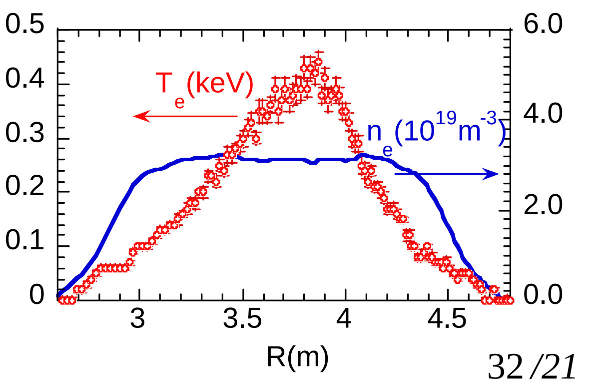
Achieved max. averaged beta : 4.8 %

Long sustainment of 4 % plasma

Shafranov shift D/a_{eff} ~ 0.25

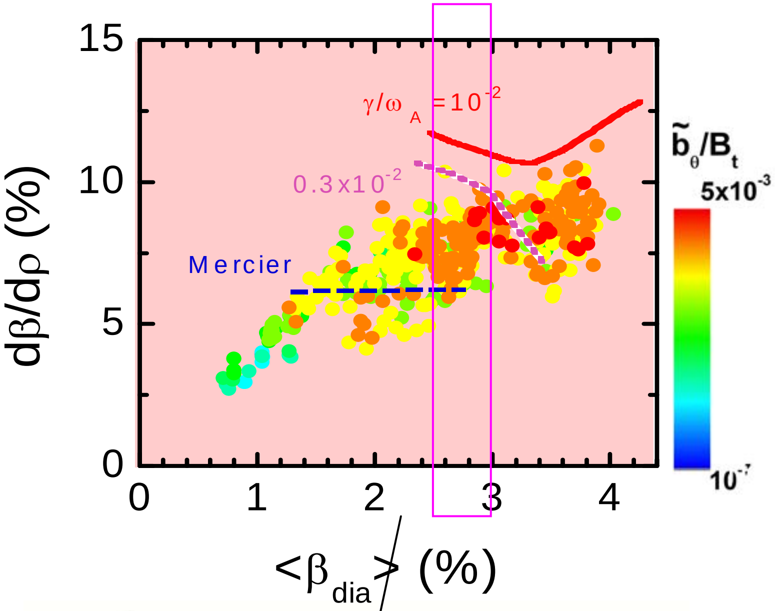
Low-*n*,*m* activities

- *No observation of core resonant modes.*
- *m*/*n* = 2/3 and 1/2 modes (peripheral resonant surfaces, *Resonances are located outside ρ ~ 0.9*) appear (< 4 %), but behave intermittently with increasing beta.
- Mercier criterion D_I < 0.2 @ι=1/ρ~0.9



Though some flattening and asymmetric structures are observed in the T_e profile, they are not large enough to affect a global confinement.

S (Reinolds#) dependence of MHD mode

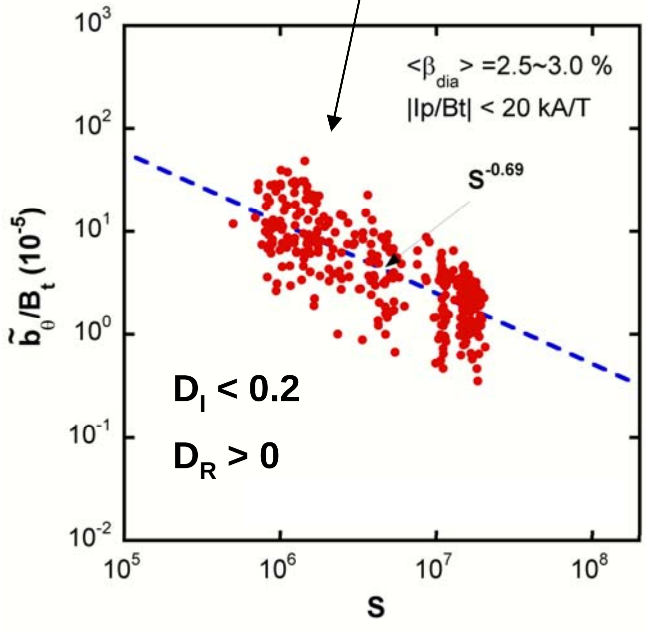


Saturation of peripheral MHD mode strongly depends on S parameter. If w ~ $(b_\theta/B_t)^{1/2}$, S dependence of w is close to that predicted by linear theory of resistive interchange mode (w ∝ $\beta^{1/6}S^{-1/3}$).

=>

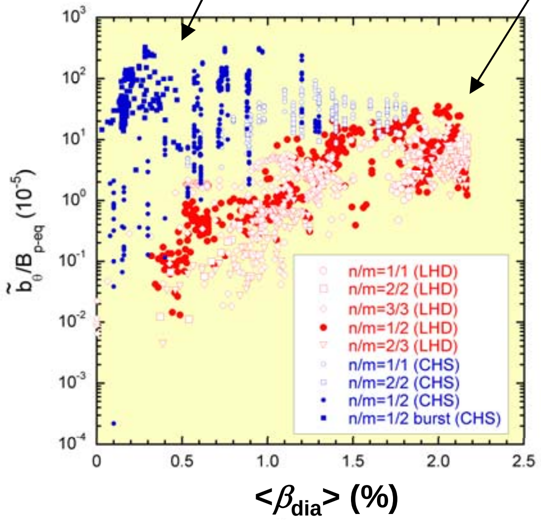
Commonly observed modes in LHD

=> resistive (interchange) modes



CHS: *S*=10^3 ~10^5

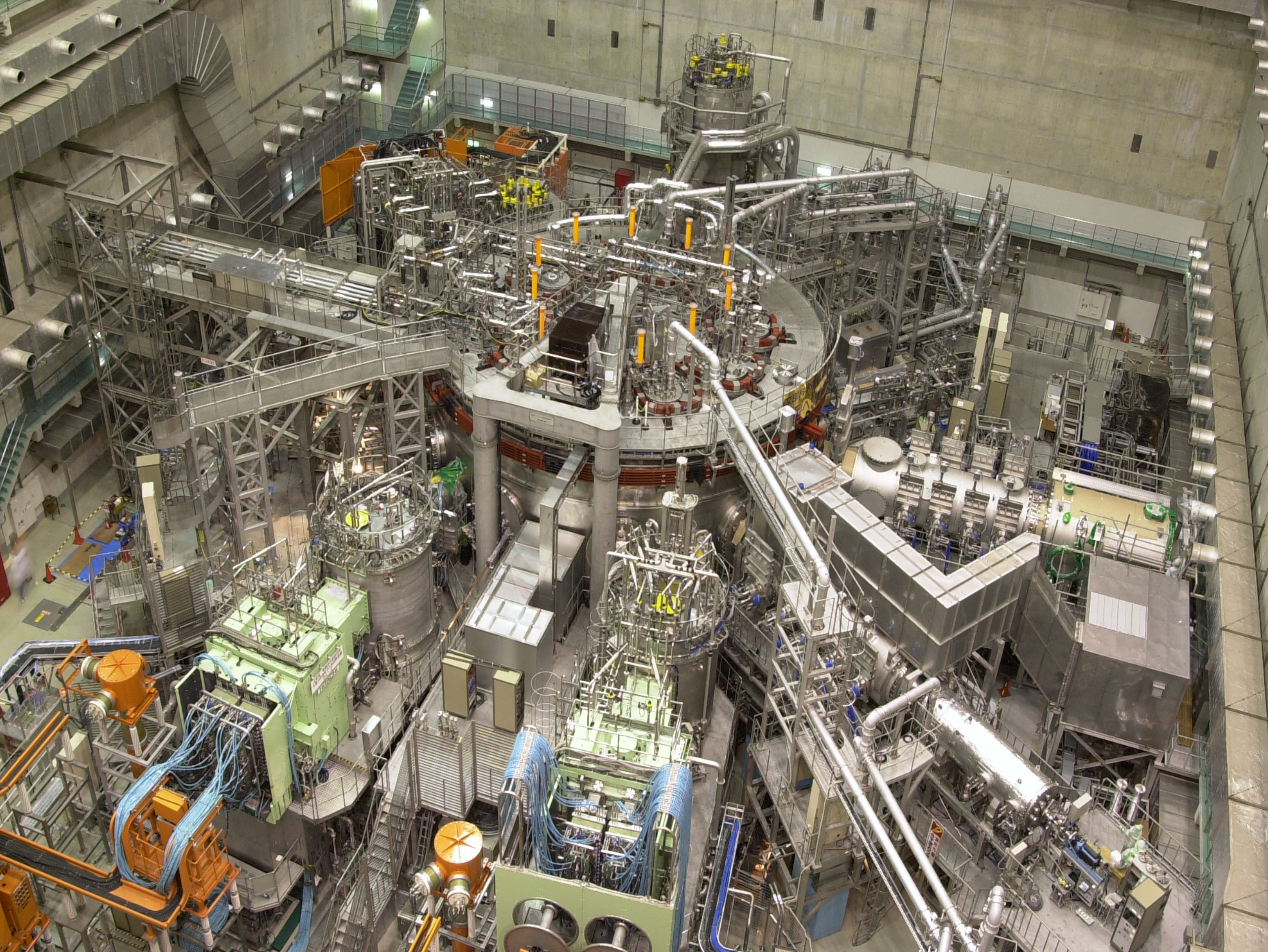
LHD: *S*=10^6 ~10^8



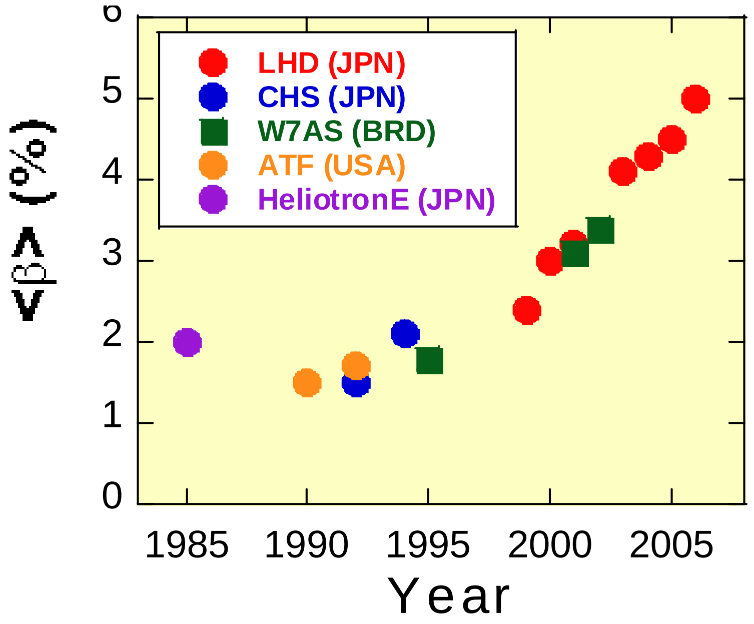
Amplitudes in LHD (high-S) are much smaller than that in CHS (low-S).

Summary (Cont.)

4. In higher aspect config. with lower magnetic shear and higher magnetic hill compared with high-β config., a minor collapse occurs. Before the collapse occurs, stability condition of ideal global MHD mode is strongly violated. The predicted mode width and growth rate are δ/a_p=15~25% and γ/ω_A~0.5~1x10^{-2}. The observed magnetic fluctuation is not rotating. It is observed more easily as S is larger. The above facts suggest that the observed modes in the collapse is the ideal interchange mode.
5. From Aabove results suggest a possibility that the ideal low-m,n MHD instability with large mode width affects the large effect of on the confinement in heliotron devices.
6. Both the observed modes in high beta plasmas and in a minor collapse can be suppressed by using the external resonant field. However, the mechanism has not been clear. The non-linear calculation of the MHD instability in wide range of S is necessary taking static error fields into account.



Buck ground



Progress of achievement of max. beta in helical devices

For an economical fusion reactor, achievement and sustainment of high beta plasma (β~5%) is necessary.

In order to predict the behavior of reactor plasma with β~5%, we need the extension of the operational beta regime, and the analysis of the properties of the high beta plasmas like the beta dependence.

The <β>=5% is a targeted value in the LHD projects from the design phase. We have made big effort aimed at achieving <β>=5% by increasing the heating capabilities and optimizing the operational conditions like configurations and so on.

The achieved beta value is increasing yearly, and last exp. campaign of LHD we transiently had the 5.0% beta plasma.

Contents

Progress of high beta operation in LHD

Characteristics of LHD high beta plasmas with β~5%.

Effects of global MHD instability (low-n,m modes) on LHD high beta plasmas
Through comparison between achieved pressure gradients and linear MHD numerical analyses

Confinement properties of LHD high beta plasmas
Through comparison between experimentally obtained thermal conductivities and some theoretically predictions

Progress of ext. of operational β range in LHD

(~F.Y.2005/9th exp.campaign)

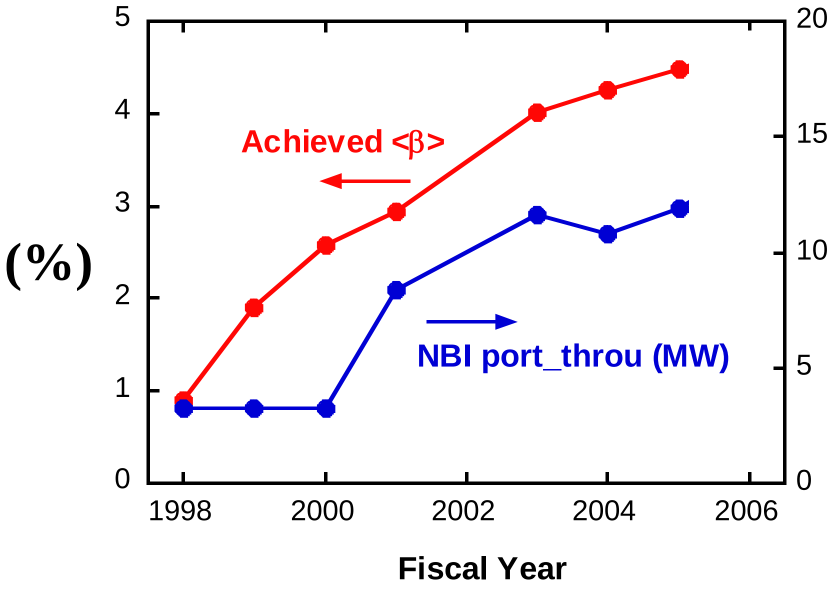
$\langle\beta\rangle_{max}$ (A_p, B_0, (R_{ax}))

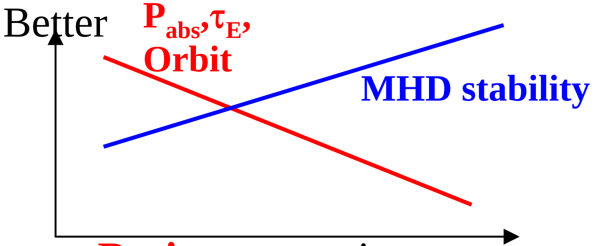
~FY'02 (R_{ax}; opt. B_0;reduc., P_{NB};inc.) : 3.2 % (5.8, 0.5 T, (3.6m))

FY'03 (A_p;reduc.) : 4.1 % (6.2, 0.5 T)

FY'04 (A_p;opt.) : 4.3 % (6.6, 0.45T)

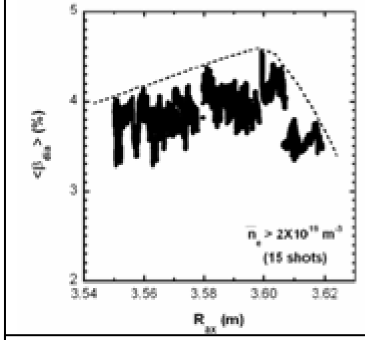
FY'05 (B_0;opt.) : 4.5 % (6.6, 0.425 T)



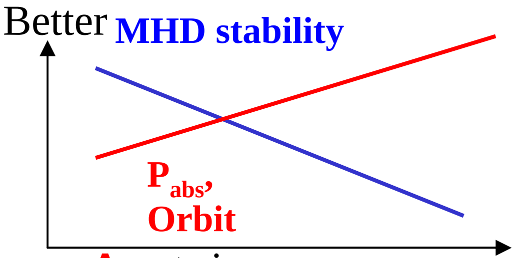


R_{ax} in vac. --> increase

R_{ax} in high-β --> increase

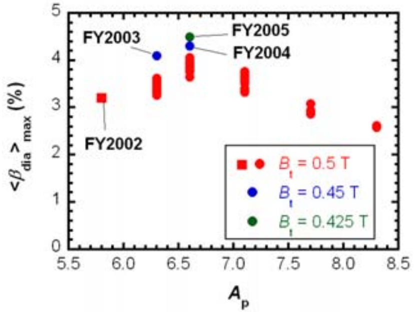


R_{ax}^V=3.6m optimized.



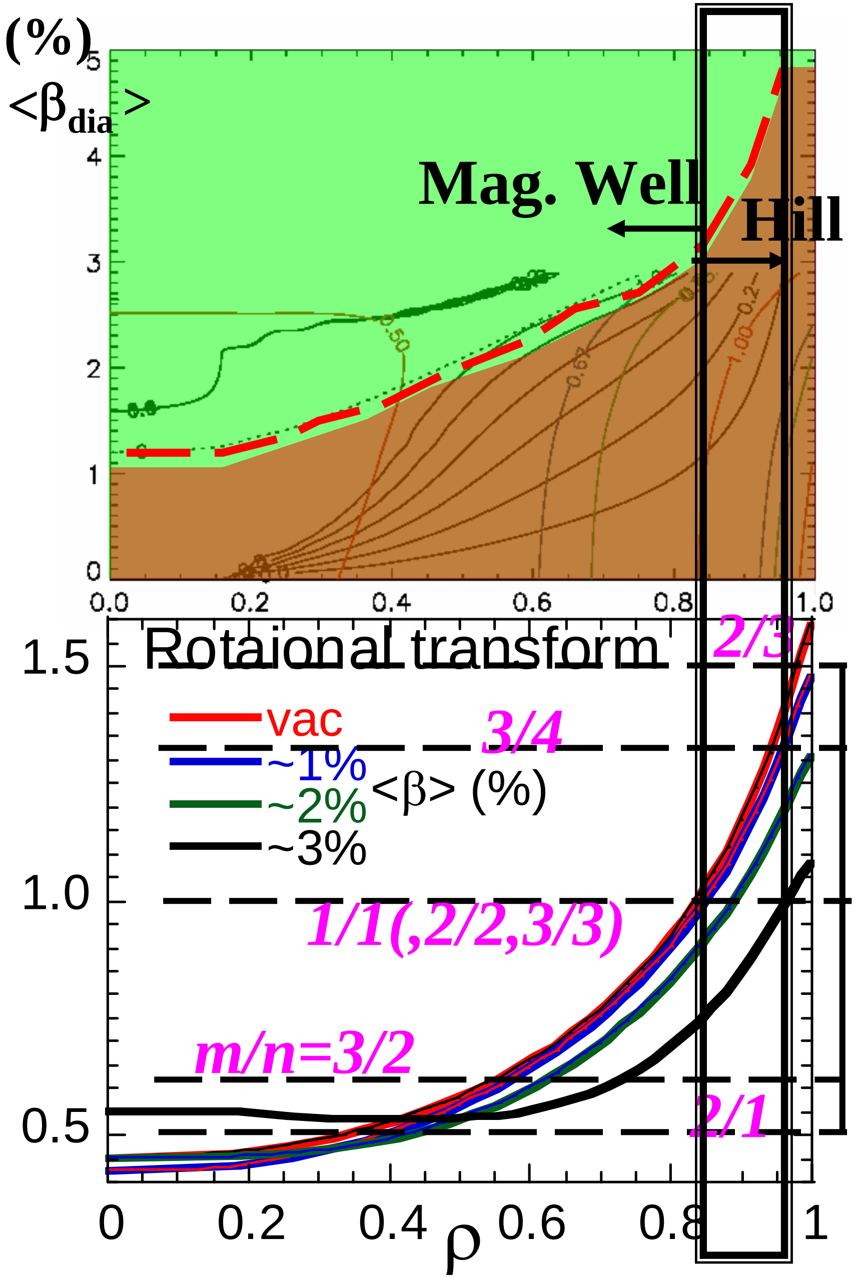
A_p --> increase

R_{ax} in high-β --> decrease



A_p=6.6 optimized.

Characteristics of MHD stability in LHD high beta conf.

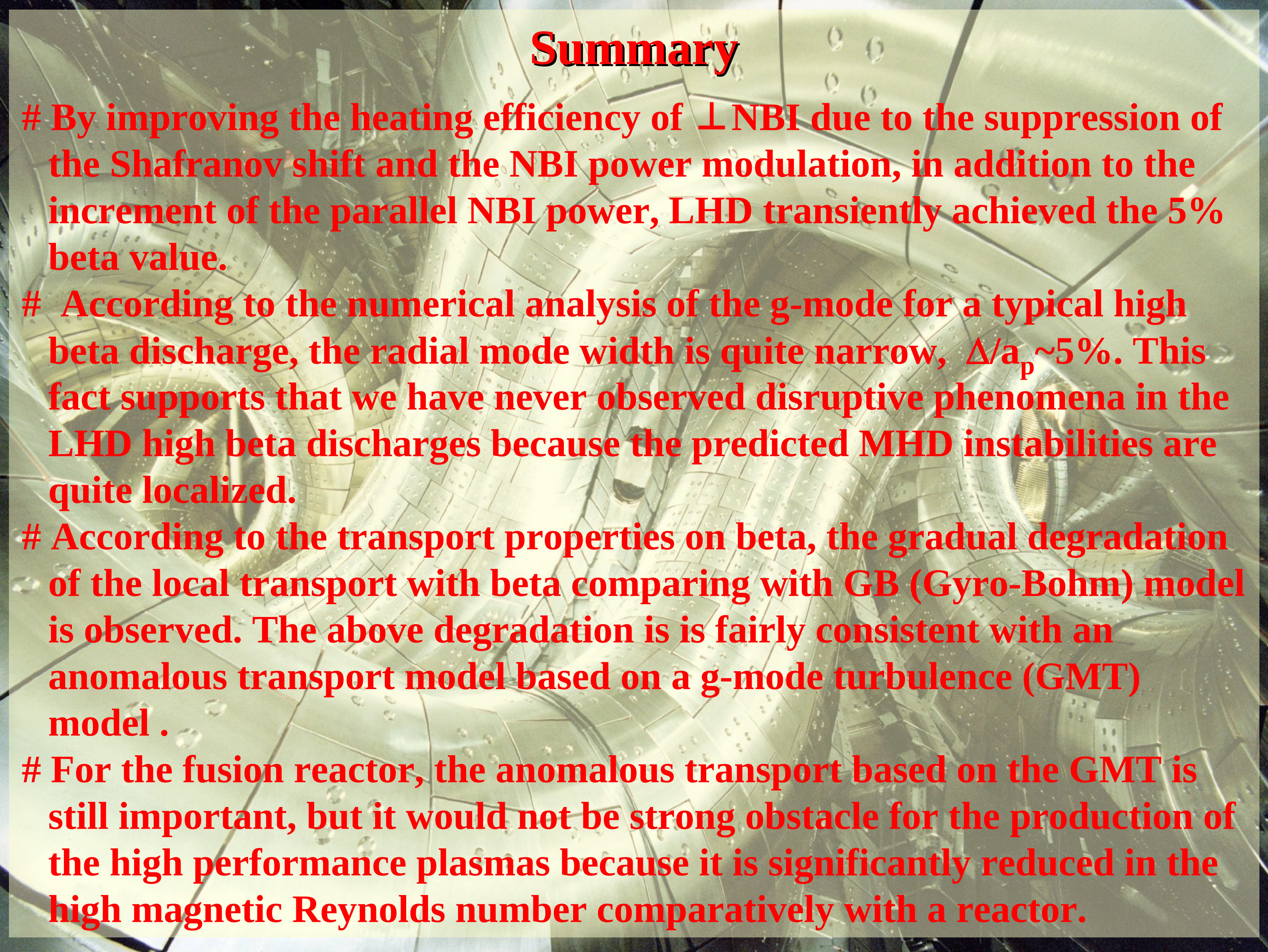


A_p=6.2, p~$(1-\rho^2)(1-\rho^8)$

In high beta regime,
magnetic hill exists in the
peripheral region
=>
MHD *instabilities* (interchange/
pressure driven) resonated with
***peripheral rational surface* would**
be *important* in high beta regime.
m/n=1/1(,2/2,3/3),3/4,2/3,,,, .

Low order
rational
surface
m<=3

m/n=2/1,
3/2,1/1(,2/2,3/3),
3/4,2/3



Summary

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\# According to the numerical analysis of the g-mode for a typical high beta discharge, the radial mode width is quite narrow, $\Delta/a_p \sim 5\%$. This fact supports that we have never observed disruptive phenomena in the LHD high beta discharges because the predicted MHD instabilities are quite localized.

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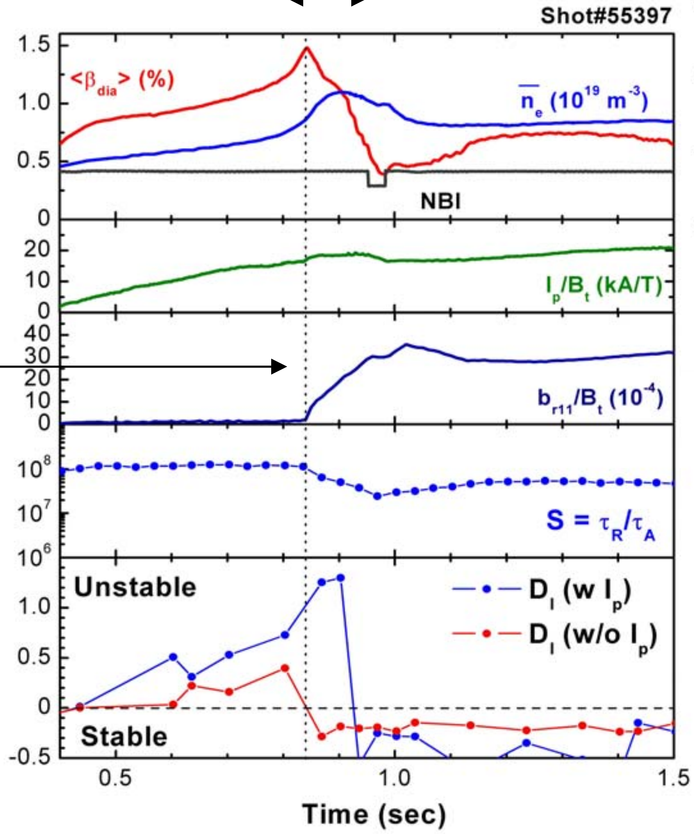
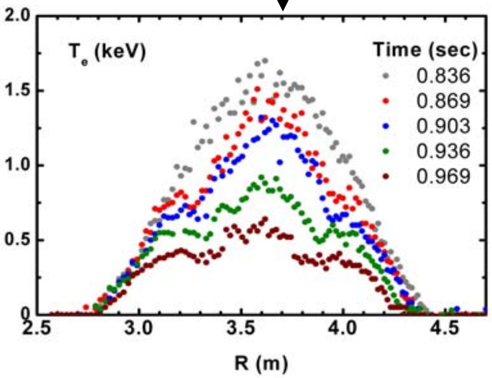
Minor collapse due to *m*/*n* = 1/1 mode in high aspect config.

Minor collapse due to abrupt profile-fattening near *m*/*n* = 1/1 resonance

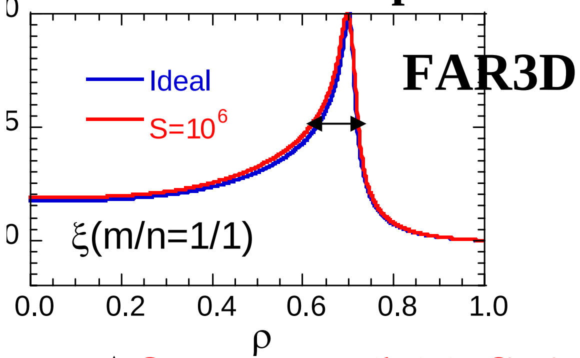
Growth of radial component of *m*/*n* = 1/1 mode (**Non-rotate**)

No observation of clear precursor





Predicted ideal MHD mode width before collapse



δ/a_p>10%($\xi(0)$;finite)

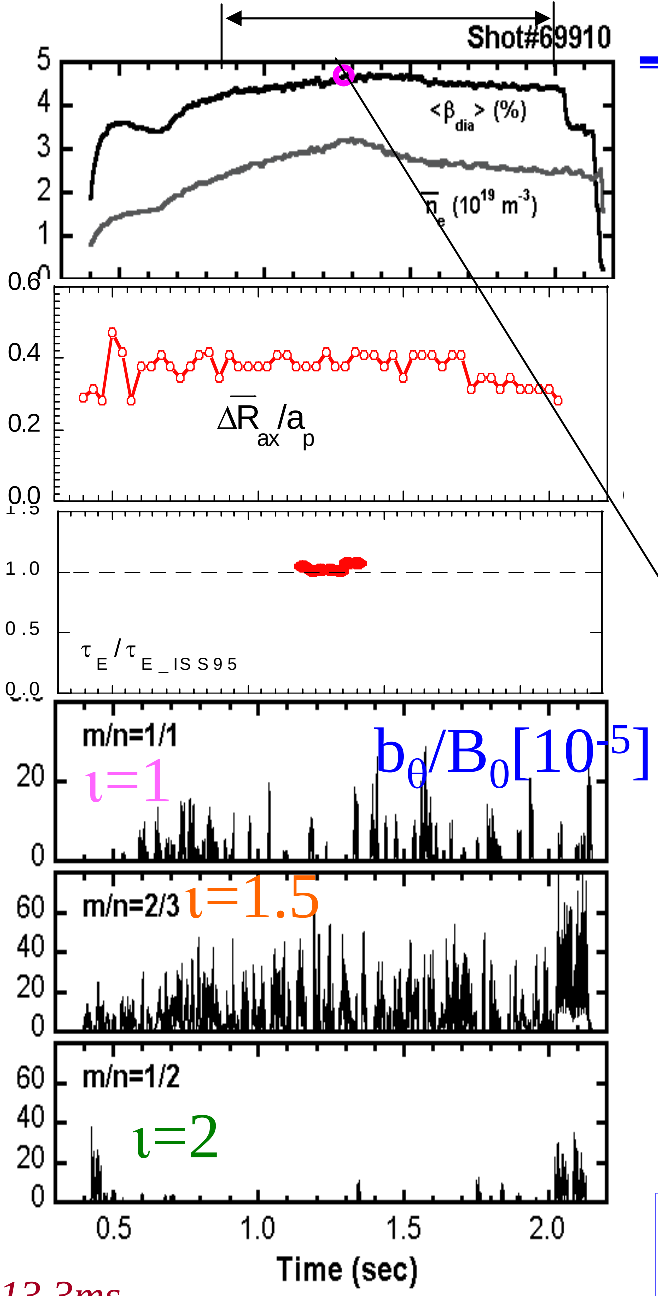
γ/ω_A=0.6~1.1x10^{-2}

A collapse occurs in a high aspect plasma with low magnetic shear and high magnetic hill. Before the collapse occurs, stability condition of **global ideal** MHD mode is **stromgly violated**. ***Mode width is much important for the effect on confinement.***

Quasi-steady high-β dischrage

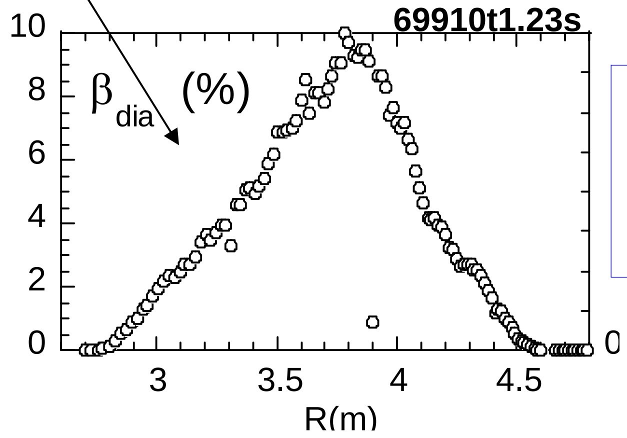
$<\beta>=4.8$ %

$t_{duration>90\%}$ $>80\ \tau_E$



τ_E~13.3ms

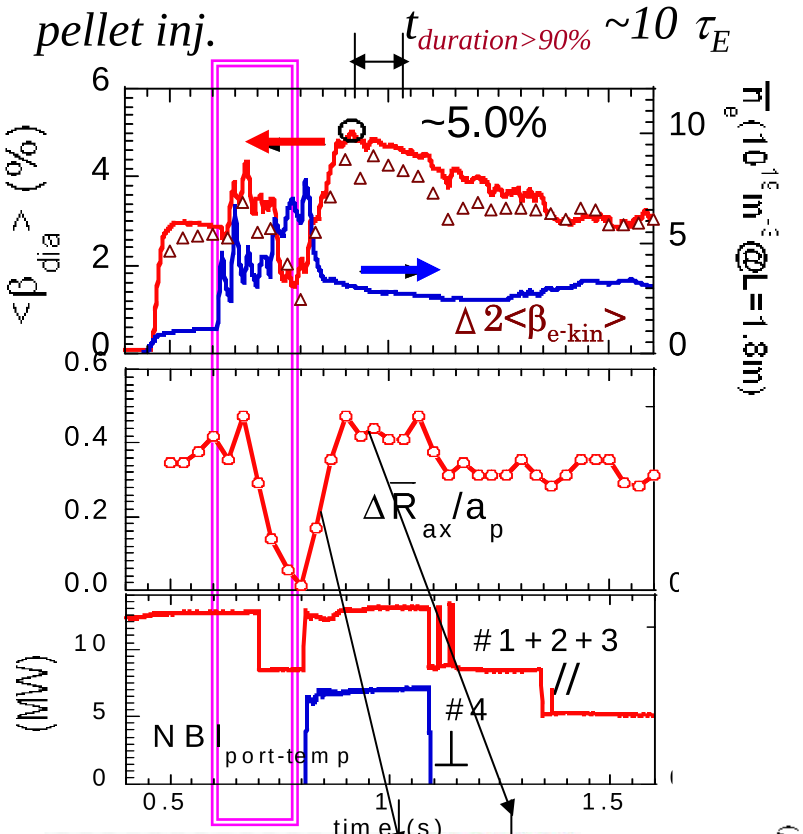
- # **No disruptive high beta plasma is maintained during more than 80τ_E**
- # **Large shafranov shift Δ/a_p ~ 40%**
- # **Low-n,m MHD activities**
  - **No observation of core resonant modes.**
  - **Only resonating mode with peripheral surf. (m/n = 2/3 and 1/1) appear**
- # **Global confinement property is almost same with ISS95 scaling.**

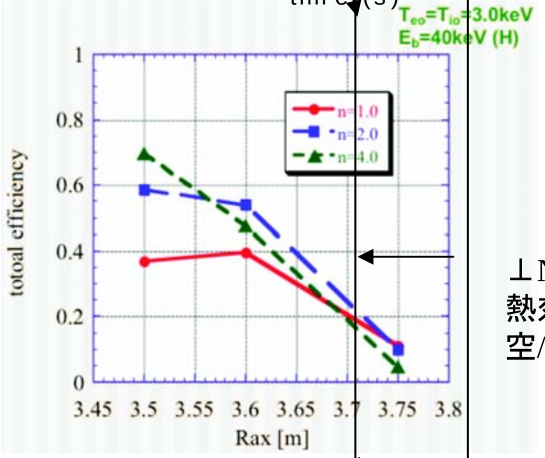


No large β flattening enough to affect a global confinement

Small flattening and asymmetric structures are observed

Transient (pellet inj.) high-β dischrage





⊥NBIの加熱効率(真空/>1.5T)

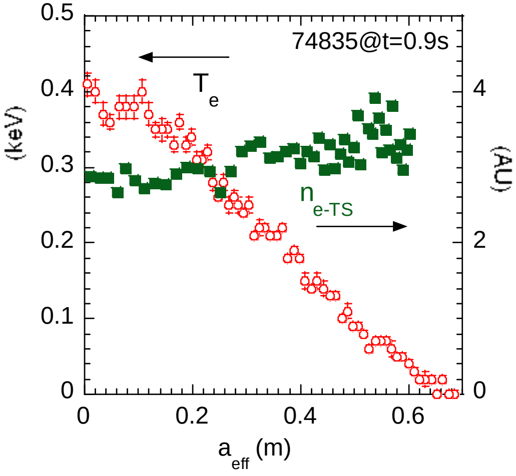
Just after pel. inj. for ~10 τ_E, high beta plasma, $<\beta_{dia}>$=5.0% is transiently achieved.

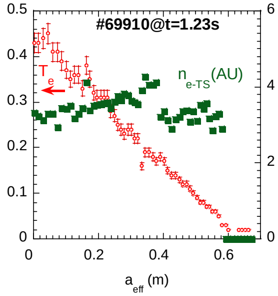
Shafranov shift is suppressed by pellet and //NBI power modulation

$\Delta R_{ax}/a_{eff}$ ~ 0.4 => ~0

Increasing heating efficiency of ⊥NBI(6.9MW)

=> $<\beta_{dia}>$=5.0%





ガスパフ
4.8%

電子密度、温度分布はガスパフ時とほとんど変わらず