Configuration Effects on Local Transport in High Beta LHD Plasmas

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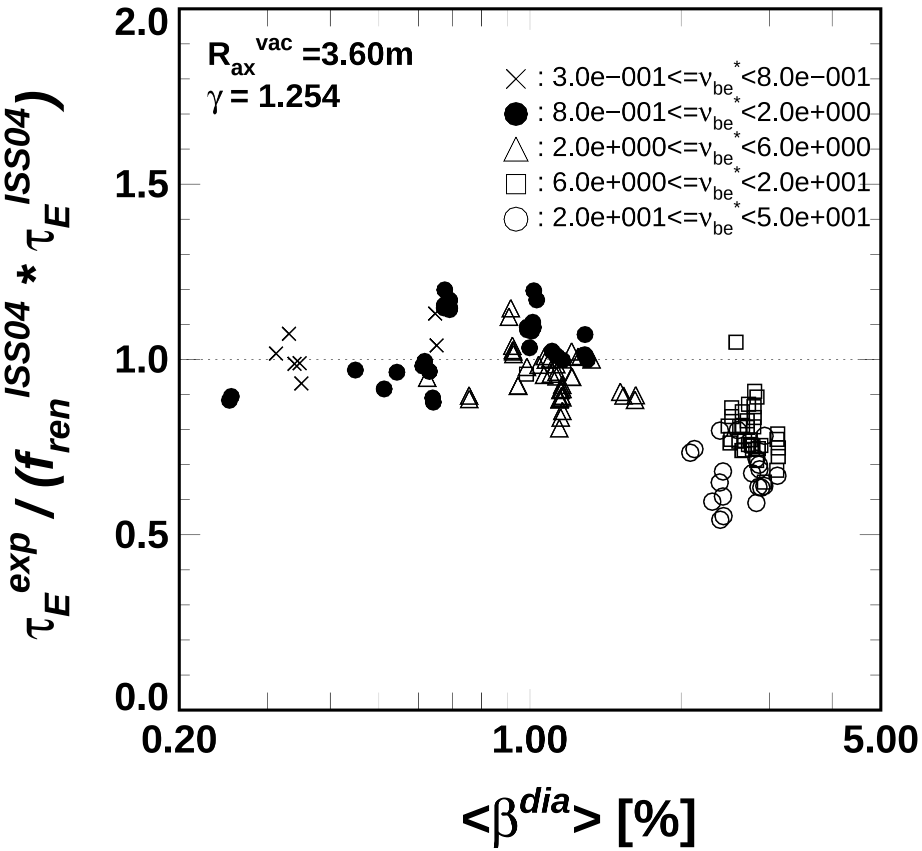
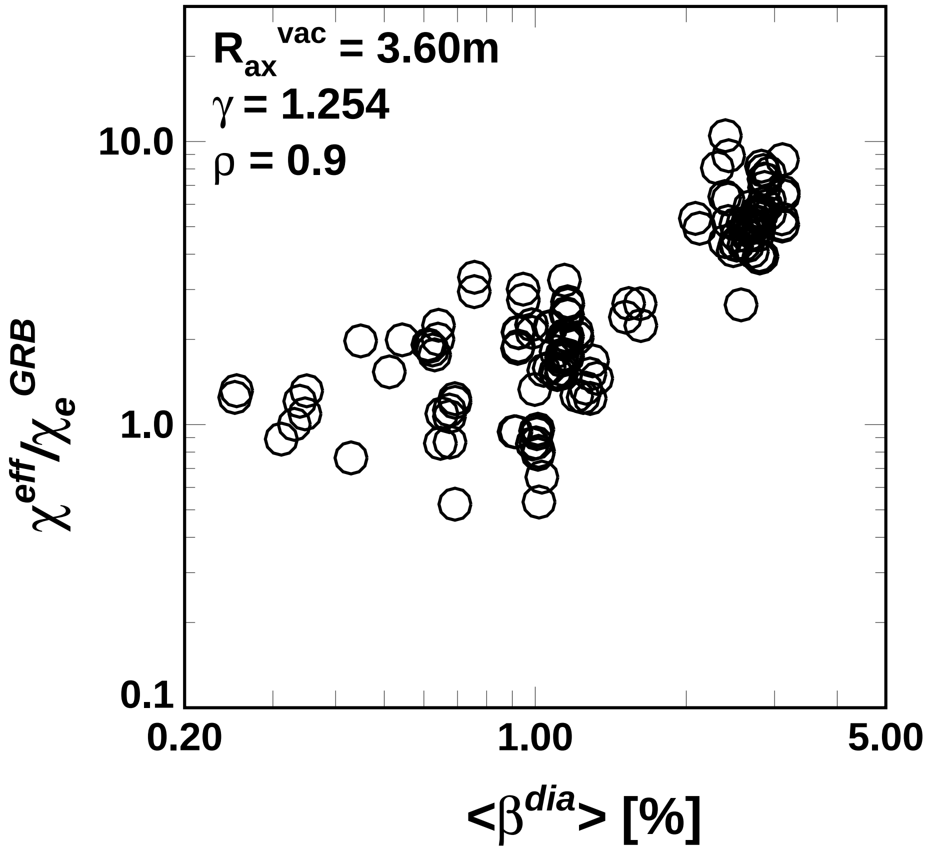
Background

- High beta (β) plasmas with up to 5% of $\langle\beta\rangle$ were obtained in the last experimental campaign of LHD.
- From the results of the global confinement analysis, the confinement degradation was observed in the high β regime comparing with the empirical scalings, such as ISS95 or ISS04.
- The local transport analysis in the high β regime has been made in ref. *H. Funaba, et al., Fusion Sci. Tech.,* **51** *129 (2007)* . The transport degradation was stronger in the peripheral region. It was found that the β dependence of χ^{eff} was similar to the β dependence of the resistive g-mode transport.
- In the high β plasmas on LHD, the magnetic flux surfaces are shifted torus outward due to the Shafranov shift. In the previous CWGM, a preliminary study concerning the effect of the change of the magnetic configuration on the local transport was made based on the global scaling, ISS04.

Dependence of $\tau_E/(f_{ren}\tau_E^{ISS04})$ and χ^{eff}/χ^{GRB} at $\rho = 0.9$ on $\langle\beta\rangle$.

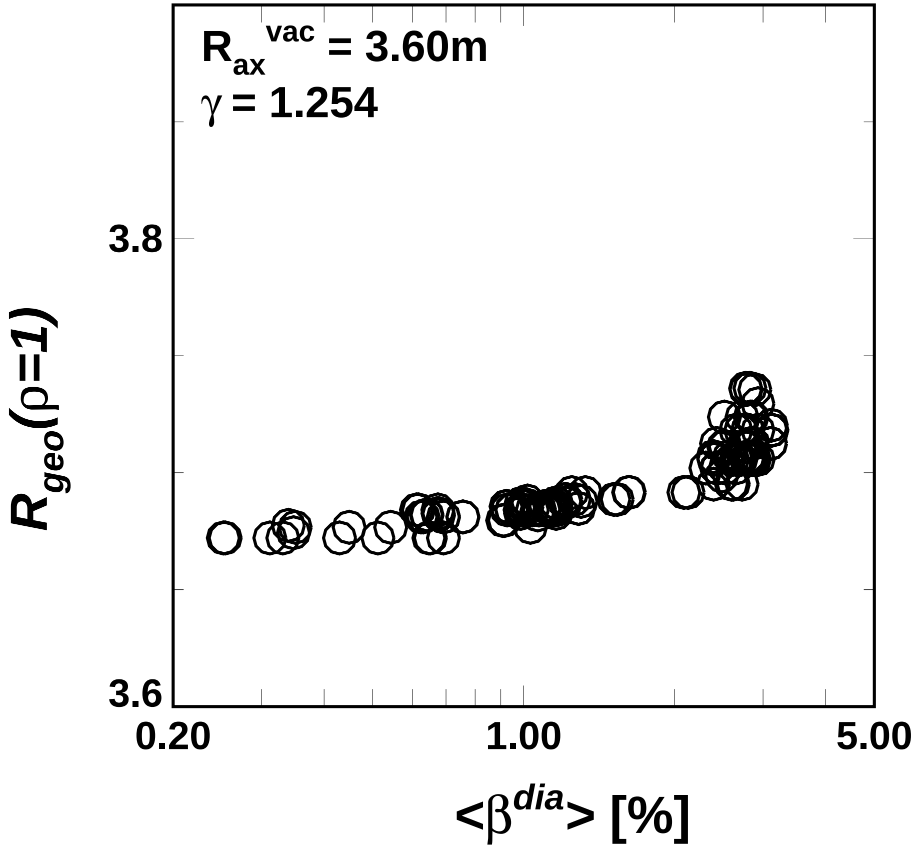


The $\langle\beta\rangle$ dependence of τ_E compared with the ISS04 scaling.

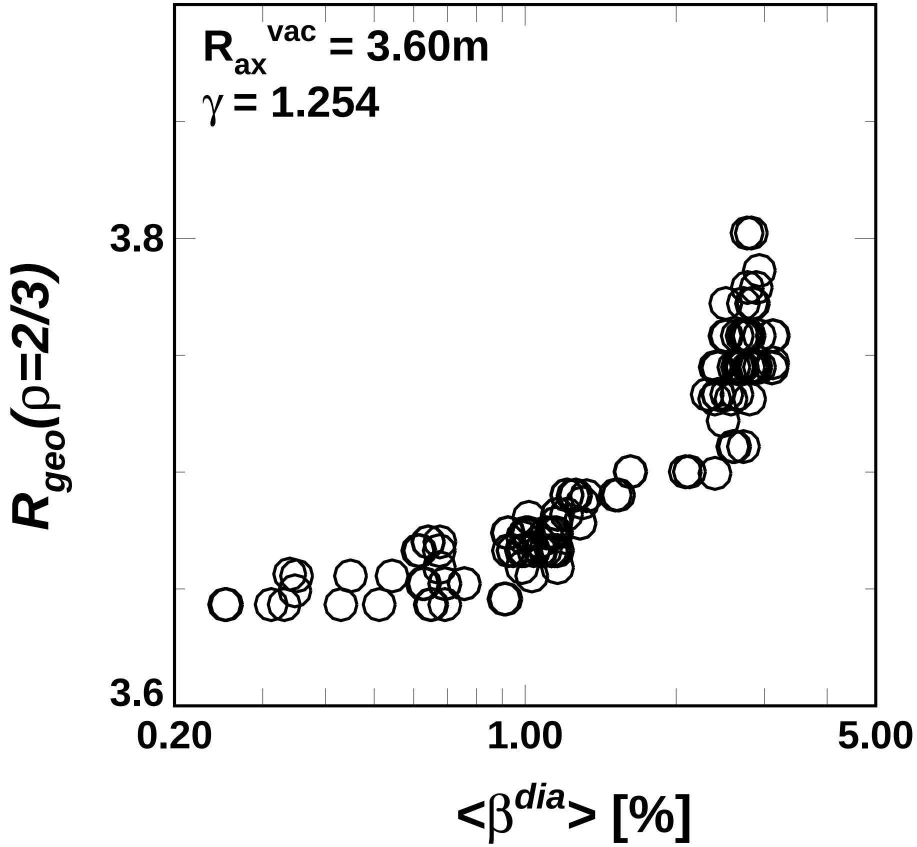


Dependence of χ^{eff}/χ^{GRB} on $\langle\beta\rangle$ at $\rho = 0.9$.

Change of $R_{geo}(1)$ and $R_{geo}(2/3)$ with increment in $\langle\beta\rangle$.



The $\langle\beta\rangle$ dependence of the major radius of the geometric center of LCFS.



The $\langle\beta\rangle$ dependence of the major radius of the geometric center of the $\rho = 2/3$ magnetic flux surface, $R_{geo}(2/3)$.

- $R_{geo}(2/3)$ will be used as the representative parameter of the magnetic configuration.

Main Purpose

- The main purpose of this study is to distinguish the causes of the gradual confinement degradation with β from following two effects: (1) the change of magnetic configuration by the increment inβ, (2) β value or the gradient of β.

Outline

(1) The change of the magnetic flux surface structure by the increment in β and its effect on the global confinement characteristics.

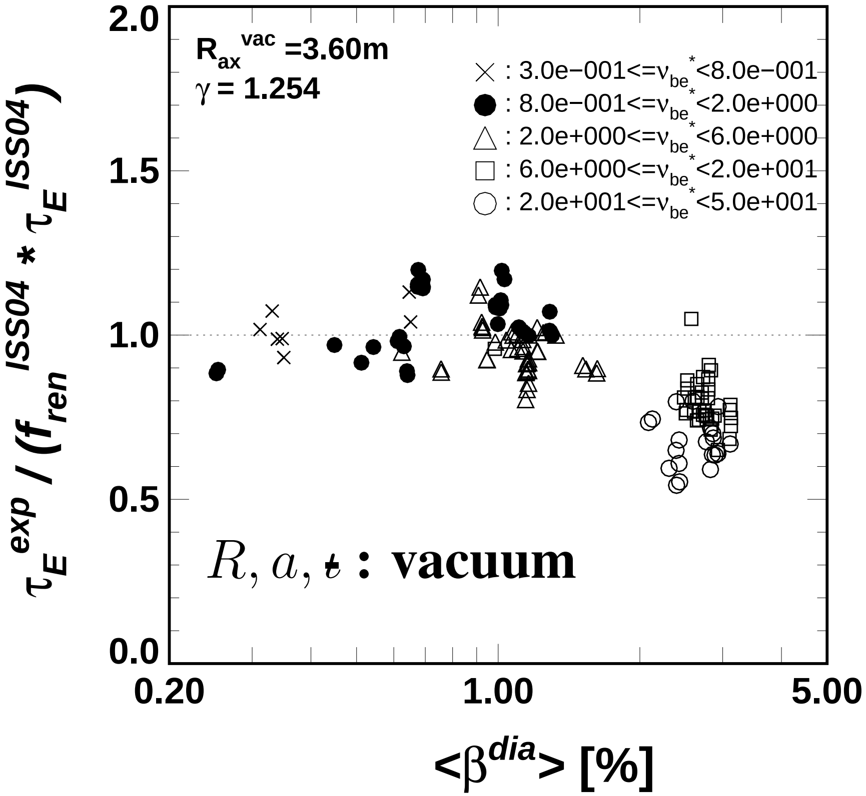
(2) The dependence of the local transport on the magnetic configuration in the low β regime.

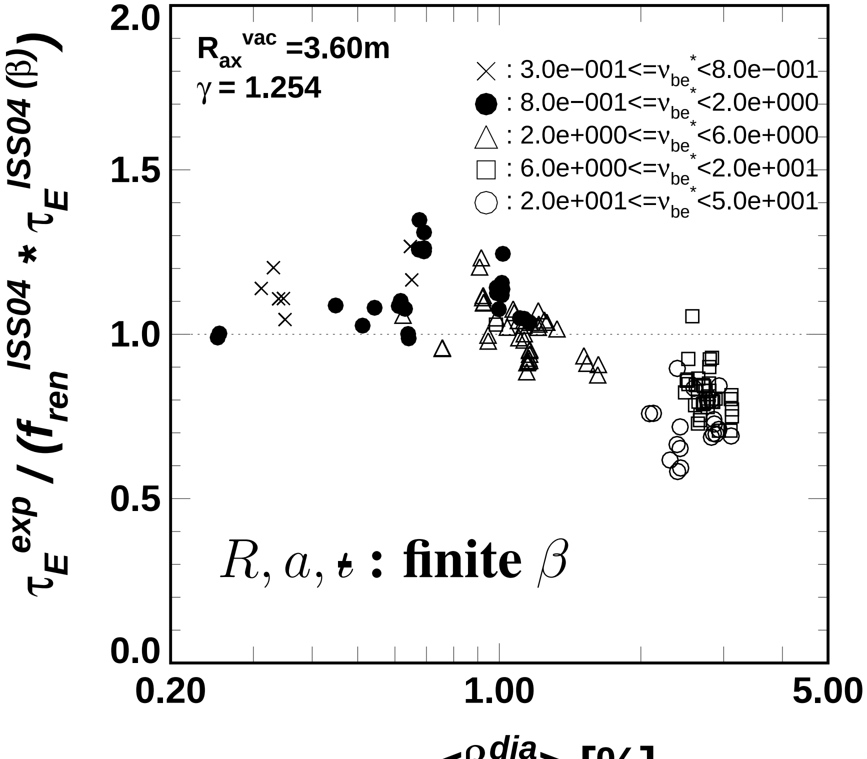
- The renormalization factor f_{ren} in ISS04 represents the configuration effects on global τ_E.
- The renormalization factor for transport coefficients $g_{ren\chi}$ is introduced. χ^{ISS04} is used for the evaluation of the dependence of transpport coefficients on the magnetic configurations.

(3) Local transport property in the high β regime and its dependence on the magnetic configuration.

(1) The change of the magnetic flux surface structure by the increment in β and its effect on the global confinement characteristics.

τ_E dependence on $\langle\beta\rangle$.





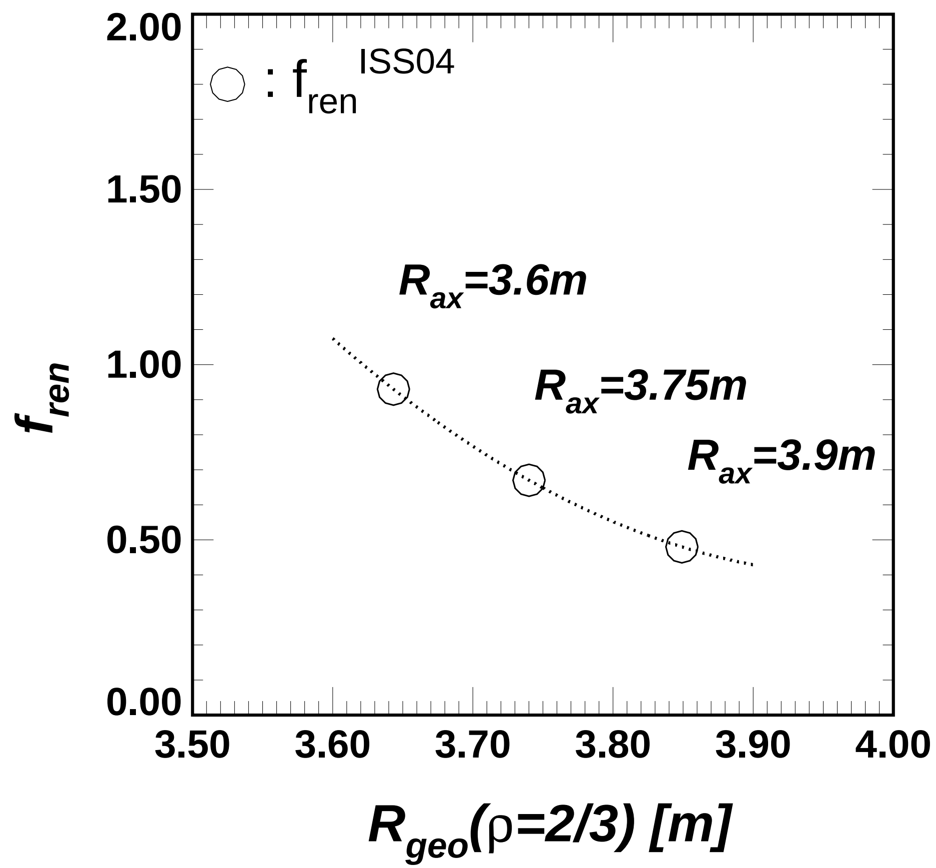
ISS04 scaling [4] :

$$\tau_E^{ISS04} = 0.134 \cdot a^{2.28} R^{0.64} P^{-0.61} \overline{n}_e^{\,0.54} B^{0.84} \iota_{2/3}^{0.41}$$

R, a and $\iota_{2/3}$ for the finite β values are used.

- The experimentsl τ_E is compared with $f_{ren}\tau_E^{ISS04}$.
- The NBI heated plasmas with $B_q = 100\,\%$, $A_p = 5.8$ are analyzed in this study.
- The data are limited in the parameter region of $1.5 \times 10^{19} \leq \overline{n_e} \leq 4.3 \times 10^{19}\,\mathrm{m}^{-3}$, $I_p/B \leq 30\,\mathrm{kA/T}$, $W_b/W_{kin} \leq 0.5$.

renormalization factor f_{ren} in ISS04

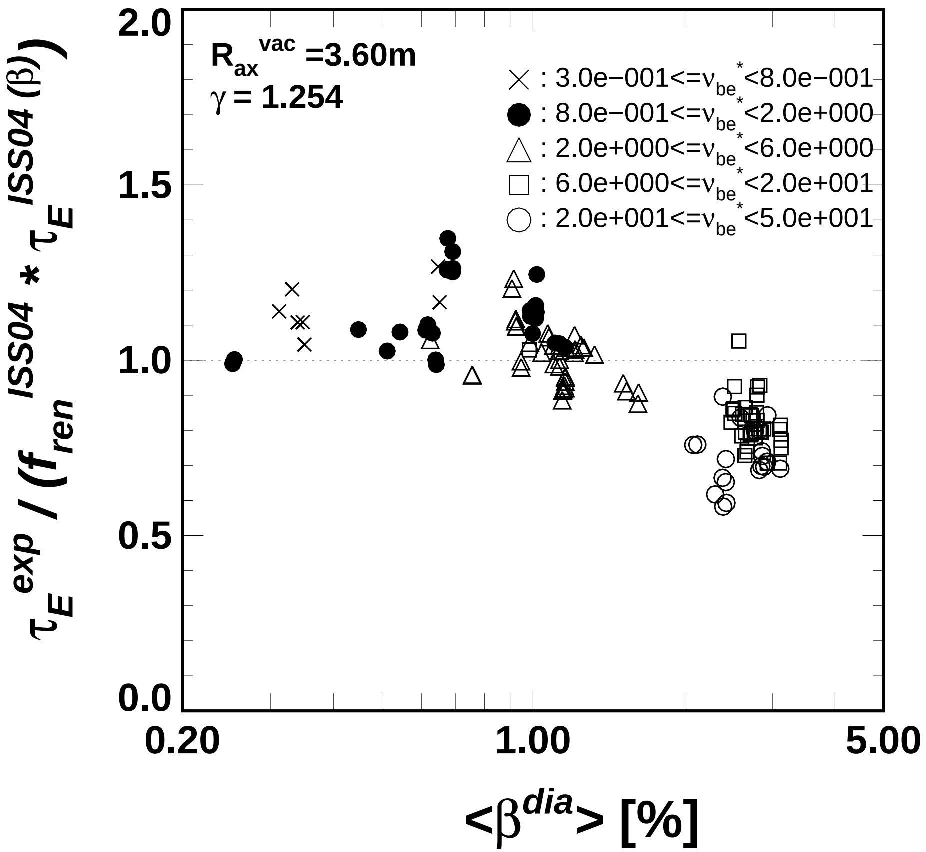


f_{ren} is interpolated assuming that f_{ren} is expressed as a function of $R_{geo}(2/3)$.

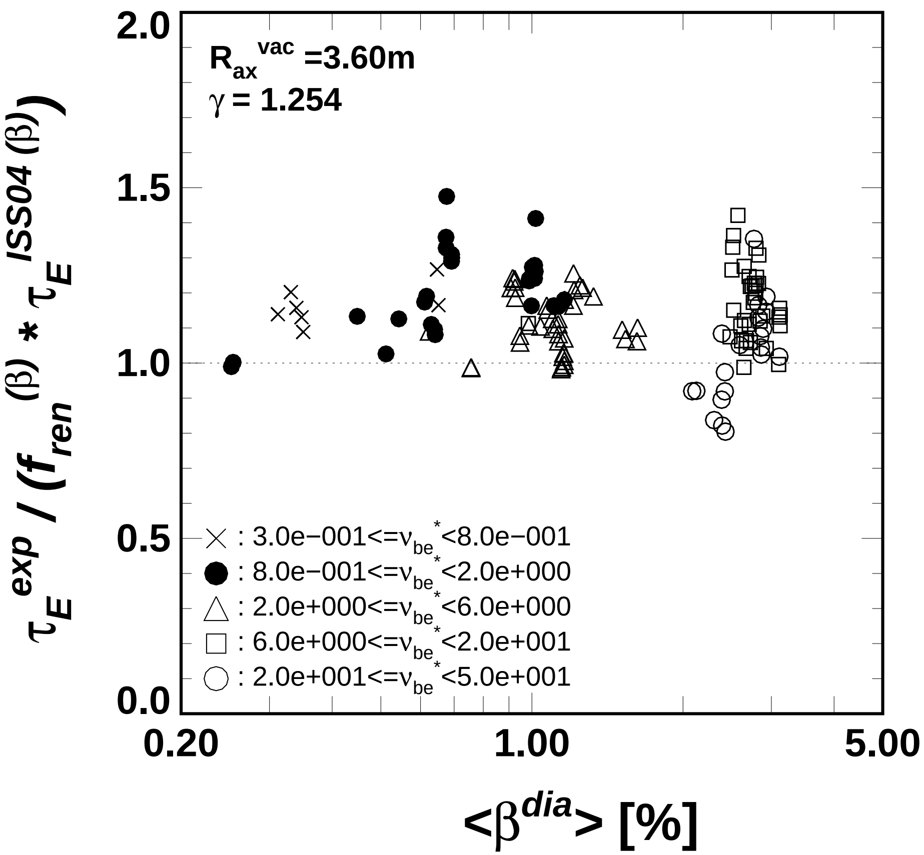
The renormalization factor f_{ren} represents the dependence on the device or the magnetic configuration [4].

Device, R_{ax}^{vac}	$R_{geo}^{vac}(2/3)$ [m]	f_{ren}^{ISS04}
LHD 3.60 m	3.643	0.93 ± 0.15
LHD 3.75 m	3.740	0.67 ± 0.06
LHD 3.90 m	3.849	0.48 ± 0.05

$\langle\beta\rangle$ dependence of τ_E with f_{ren} (renormalization factor) effect



$f_{ren}(R_{ax}^{vac} = 3.6\mathrm{m})$ **is used for the scaling values.**



Comparison with the ISS04 scaling τ_E by using the interpolated f_{ren}.

- The degradation with increment in β is not clear. It seems that the global confinement degradation with $\langle\beta\rangle$ may be explained by the change of the magnetic configuration, if $R_{geo}(2/3)$ represents the magnetic configuration.

(2) The dependence of the local transport on the magnetic configuration in the low β regime.

The experimental transport coefficients for electrons and ions, χ_e^{exp} and χ_i^{exp} are derived by using PROCTR [6] code.

Here, $T_i = T_e$, $n_i = f n_e$, are assumed, where f is determined by the following relation

$$W_p^{dia} = \int \frac{3}{2}(1+f) n_e T_e dV \tag{1}$$

The effective transport coefficients are evaluated by $\chi^{eff} = (\chi_e^{exp} + f\chi_i^{exp})/(1+f)$.

Reference χ^{ISS04} which has the same non-dimensional parameter dependence as τ_E^{ISS04}.

τ_E^{ISS04} is expressed as follows by using the Bohm type transport coefficient, χ^{Bohm}, the non-dimensional parameters, such as ρ^*, ν^*, β, A_p and $\iota_{2/3}$,

$$\tau_E^{ISS04} = C_\tau \cdot \tau_{Bohm} \cdot \rho^{*-0.79} \beta^{-0.19} \nu_b^{*0.00} A_p^{0.07} \iota_{2/3}^{1.06} \quad (2)$$

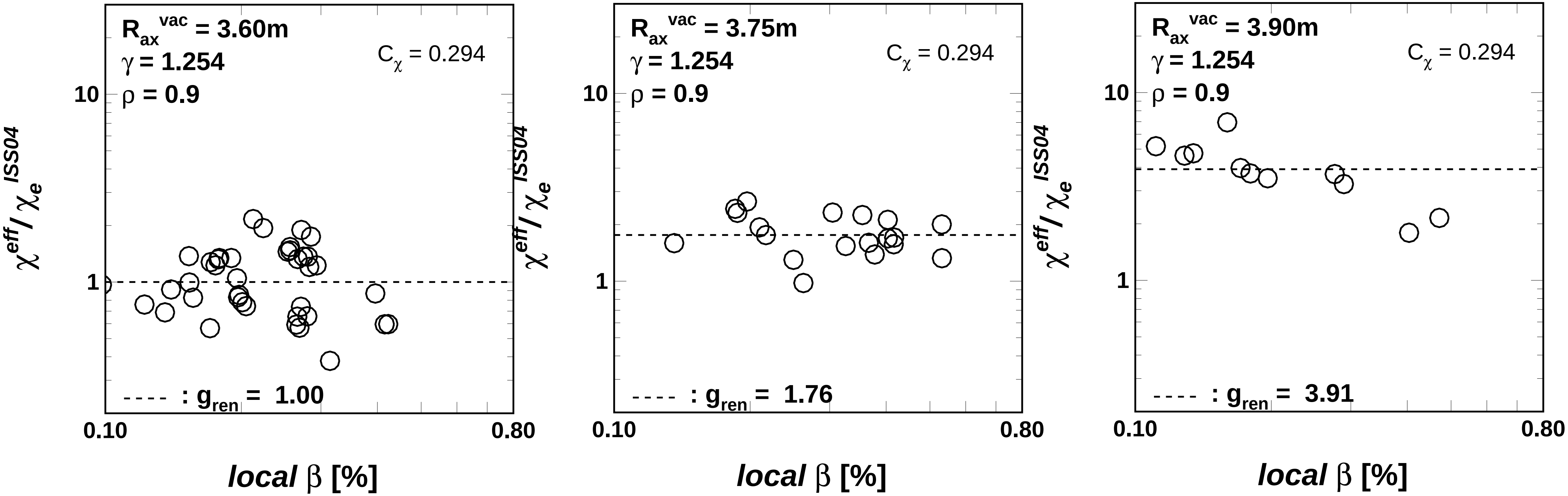
The modelded transport coefficients which has the same non-dimensional parameter dependence as τ_E^{ISS04}, χ^{ISS04} is introduced as the reference in this analysis.

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

C_χ is determined to make $\chi^{eff}/\chi^{ISS04} = 1$ for the $R_{ax}^{vac} = 3.6\,\mathrm{m}$ plasmas in the low β regime of $\beta(\rho) < 1\%$.

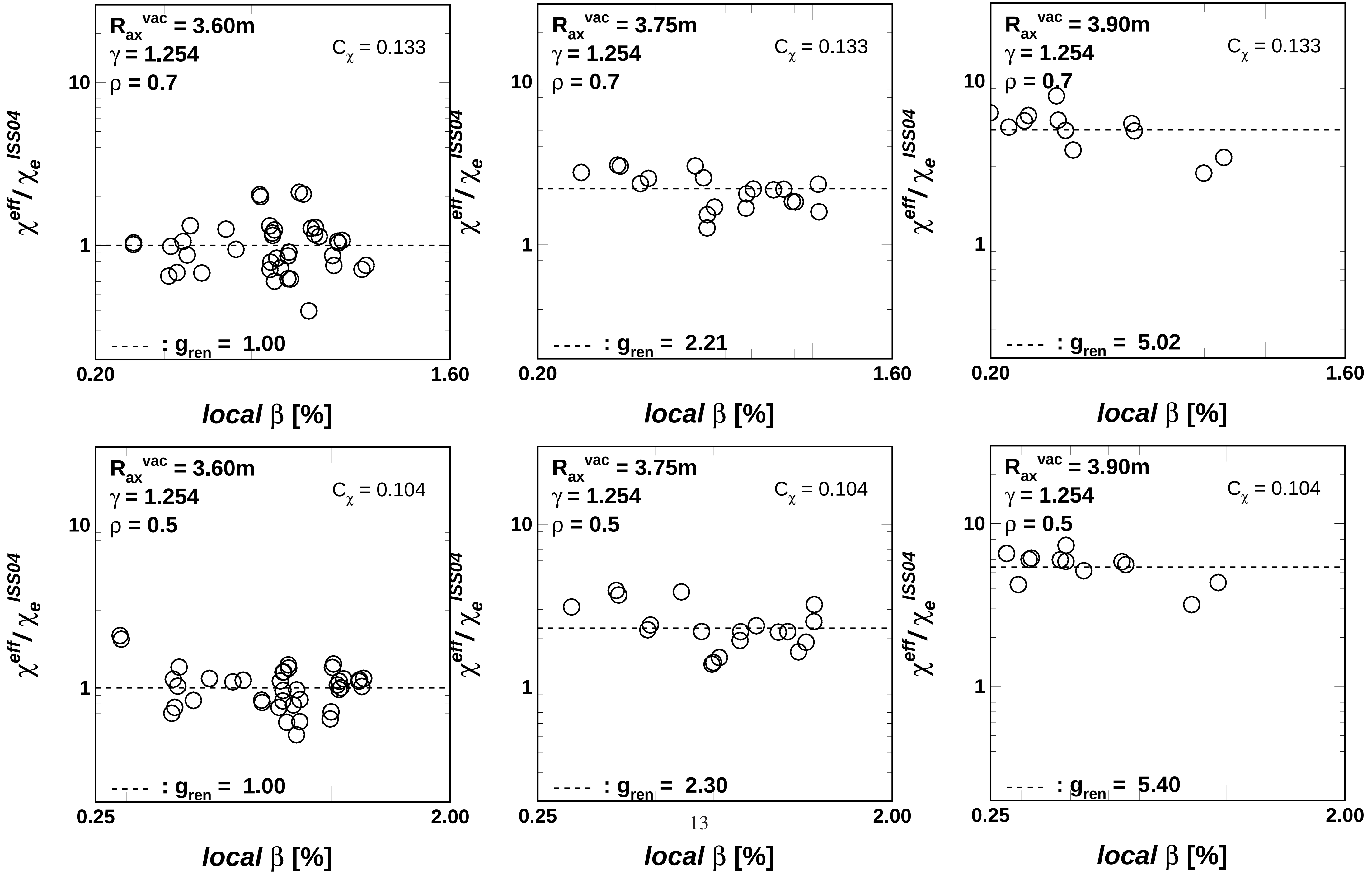
normalized average minor radius ρ	C_χ
0.5	0.104
0.7	0.133
0.9	0.294

Dependence of χ^{eff}/χ^{ISS04} on the magnetic configuration at $\rho = 0.9$ ($\langle\beta\rangle \leq 1$ %).

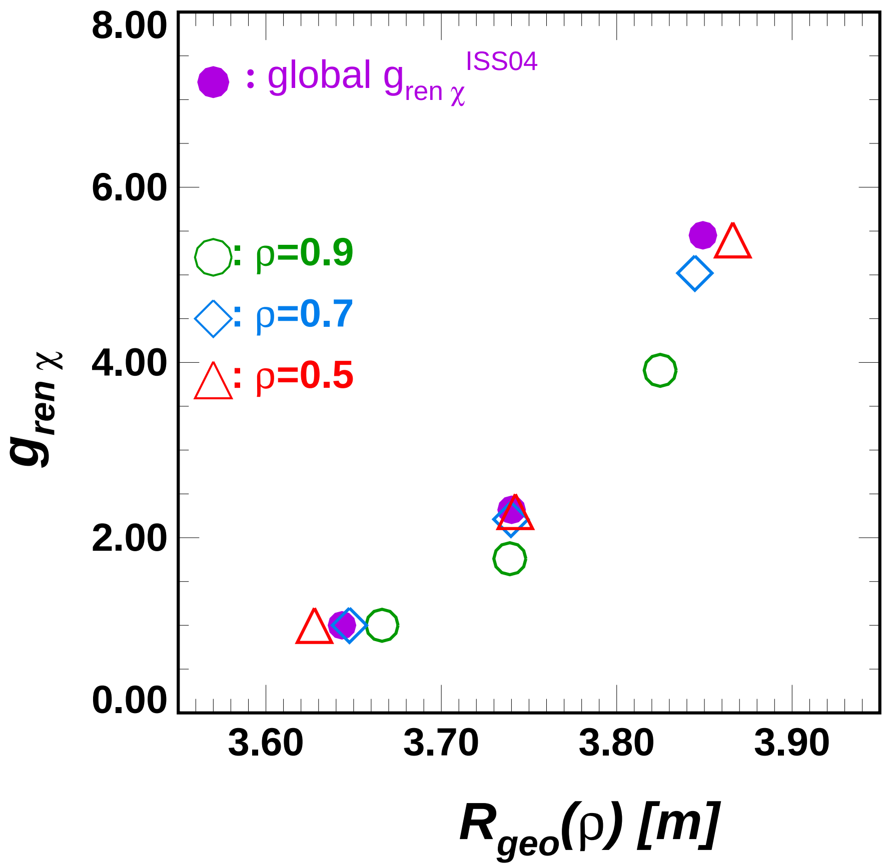


- $g_{ren\chi}$ is the average of χ^{eff}/χ^{ISS04} in the low β regime.
- Although the data are scattered, χ^{eff}/χ^{ISS04} increases as R^{vac}_{ax} moves torus-outward. This tendency seems to be the same as in the global confinement property.

Dependence of χ^{eff}/χ^{ISS04} on the magnetic configuration at $\rho = 0.7$ and $\rho = 0.5$



Renormalization factor for the local transport coefficients, $g_{ren\chi}$, is derived for various magnetic configurations and radial positions.



- As the geometric center of the magnetic flux surface is shifted torus outward, $g_{ren\chi}$ increases at any minor radius posisions.

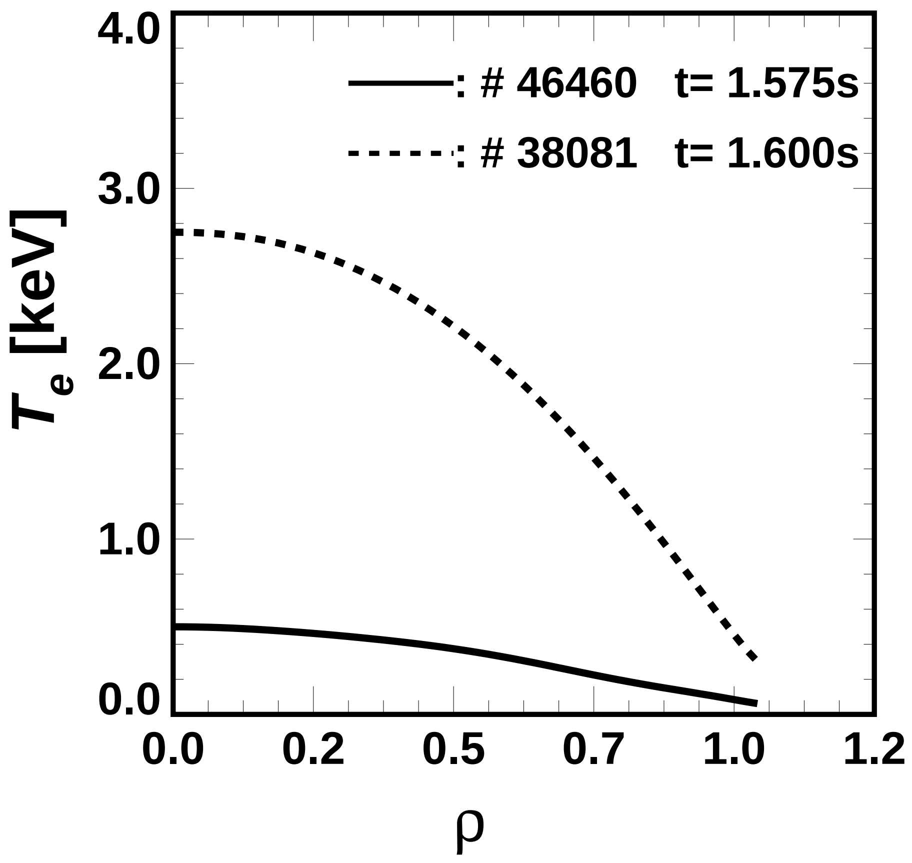
- $g_{ren\chi}^{ISS04}$ is derived from the global scaling ISS04 as follows.

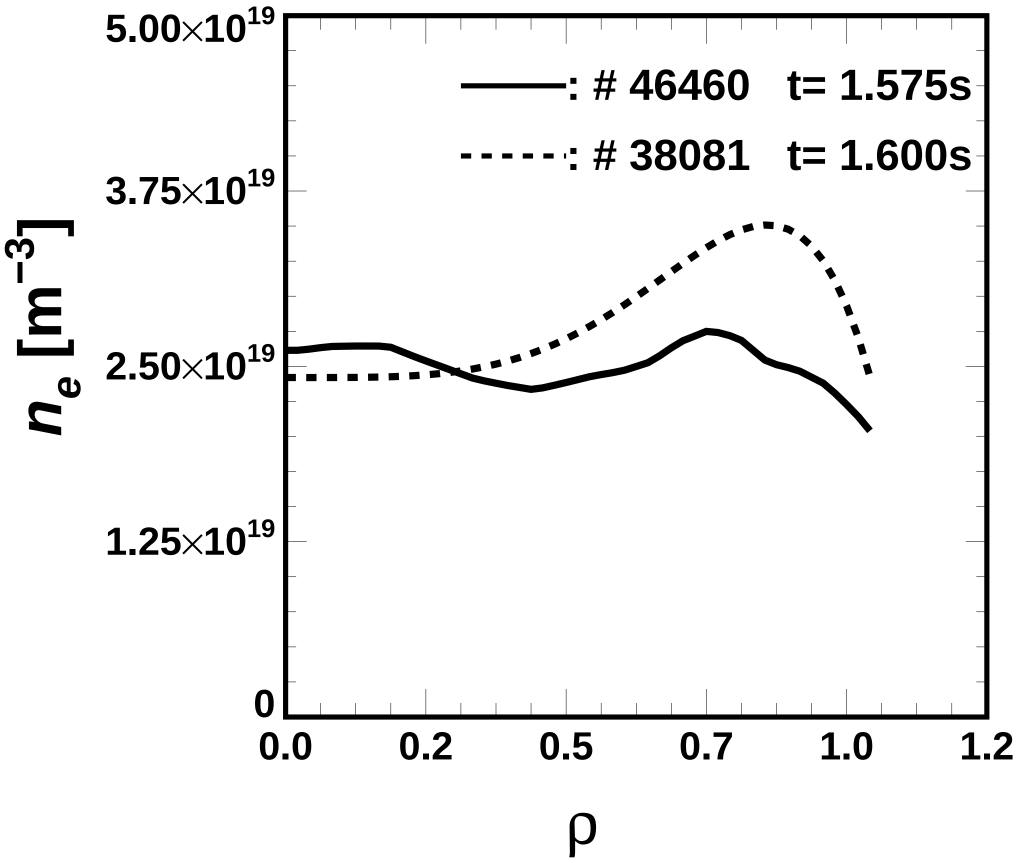
$$g_{ren\chi}^{ISS04} \equiv (f_{ren}/f_{ren}(R_{ax}^{vac} = 3.6))^{-1/(\alpha_P+1)} . \quad (4)$$

$(\alpha_P = -0.61)$

(3) Local transport property in the high β regime and its dependence on the magnetic configuration.

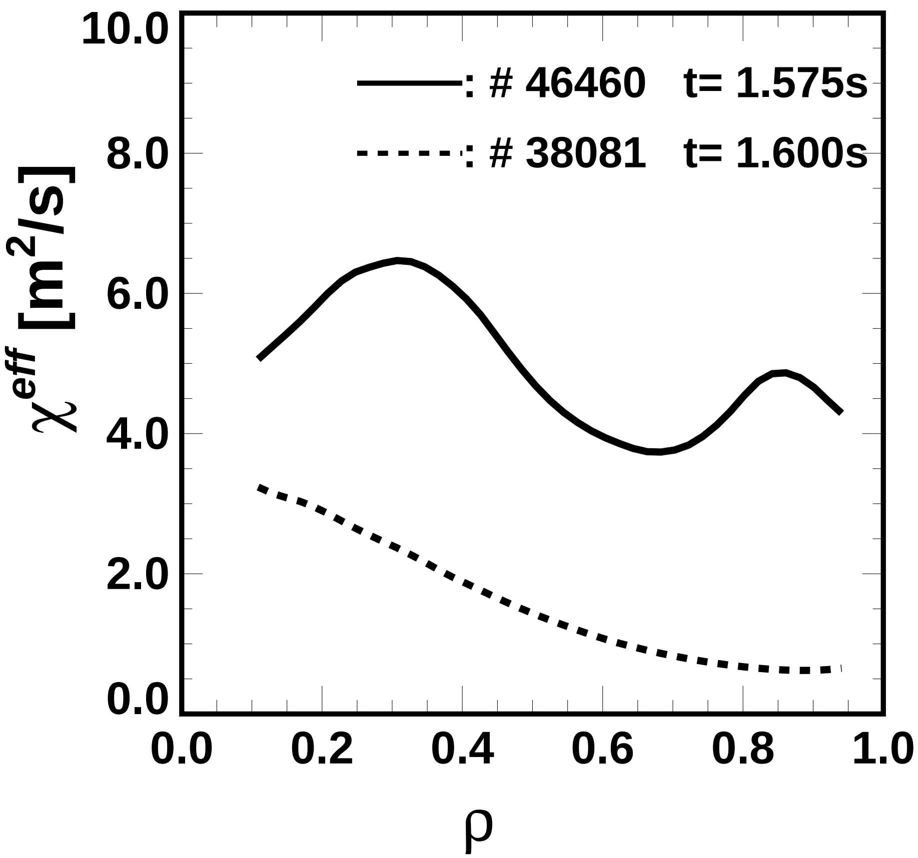
Examples of modeled T_e and n_e profiles.

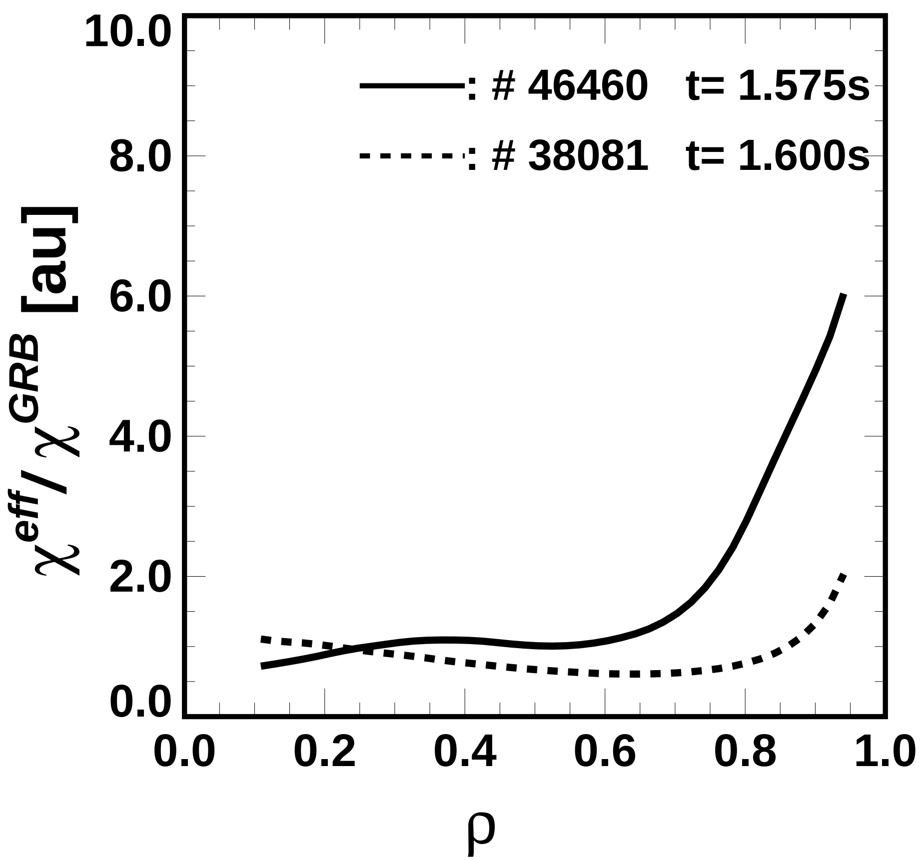




- # 46460, $t = 1.575\,\mathrm{s}$: $B = 0.5\,$T, $\langle\beta\rangle = 2.7\,\%$.
- # 38081, $t = 1.600\,\mathrm{s}$: $B = 2.8\,$T(CCW), $\langle\beta\rangle = 0.52\,\%$.

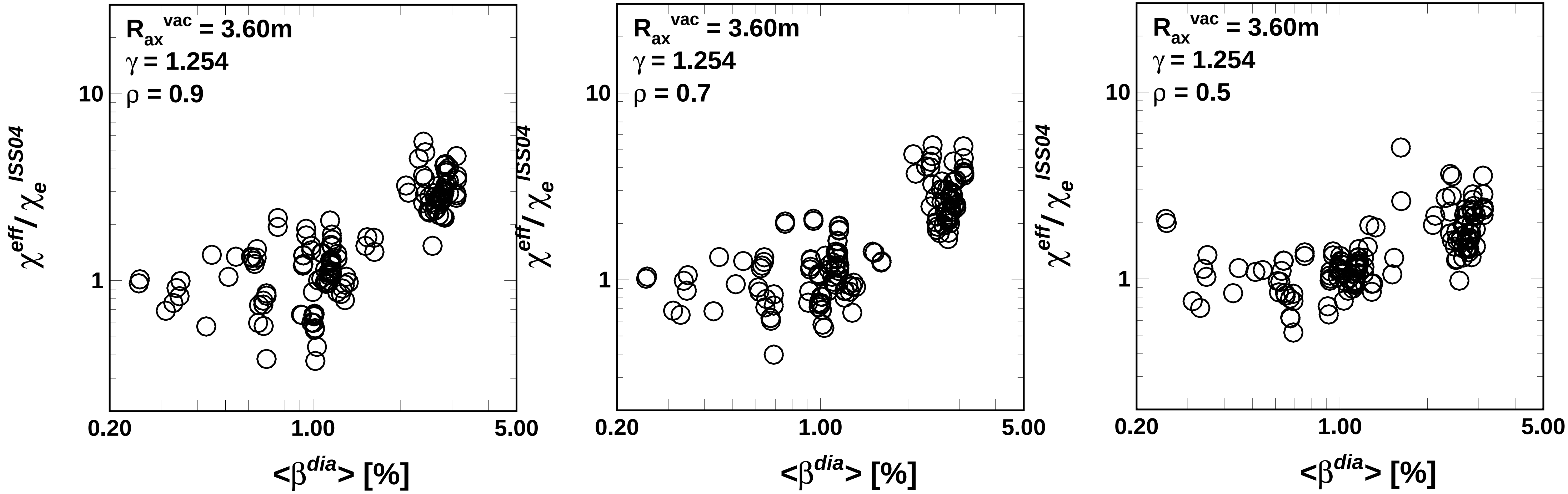
Examples of experimentally derived χ^{eff} and χ^{eff}/χ_e^{GRB} profiles.





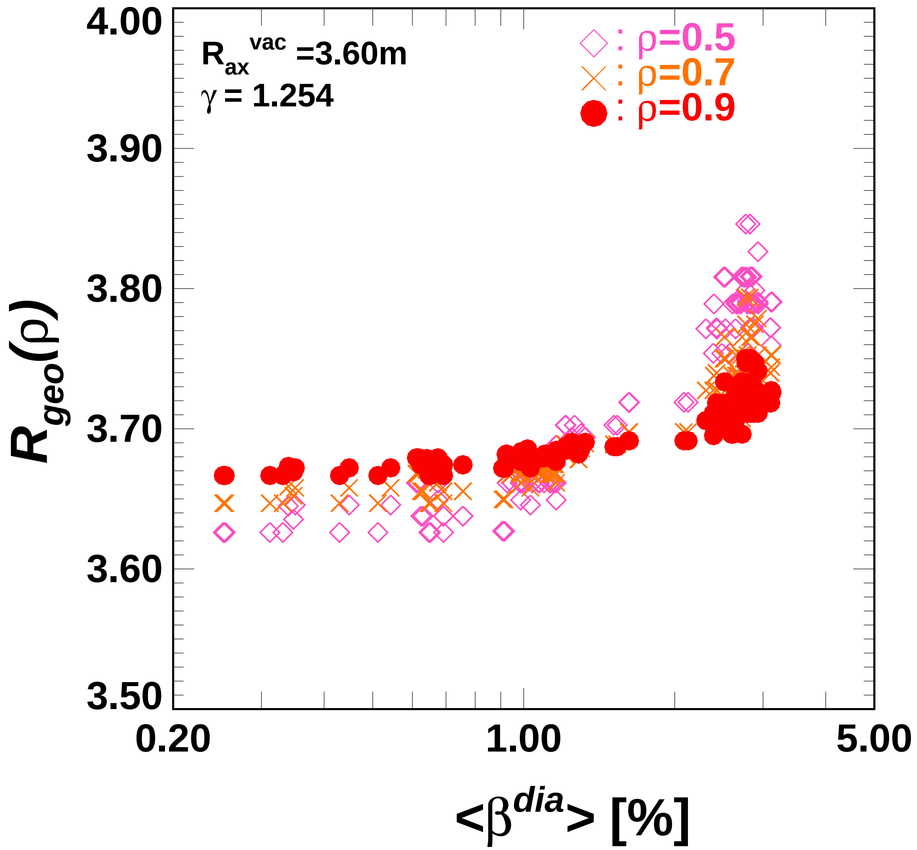
- # 46460, $t = 1.575\,\mathrm{s}$: $B = 0.5\,\mathrm{T}$, $\langle\beta\rangle = 2.7\,\%$.
- # 38081, $t = 1.600\,\mathrm{s}$: $B = 2.8\,\mathrm{T}$(CCW), $\langle\beta\rangle = 0.52\,\%$.
- $\chi^{GRB} = \frac{T_e}{eB}\frac{\rho_s}{a}$

χ^{eff}/χ^{ISS04} dependence on $\langle\beta\rangle$ at $\rho = 0.5, 0.7$ and 0.9 of the $R_{ax}^{vac} = 3.6$ m plasmas.



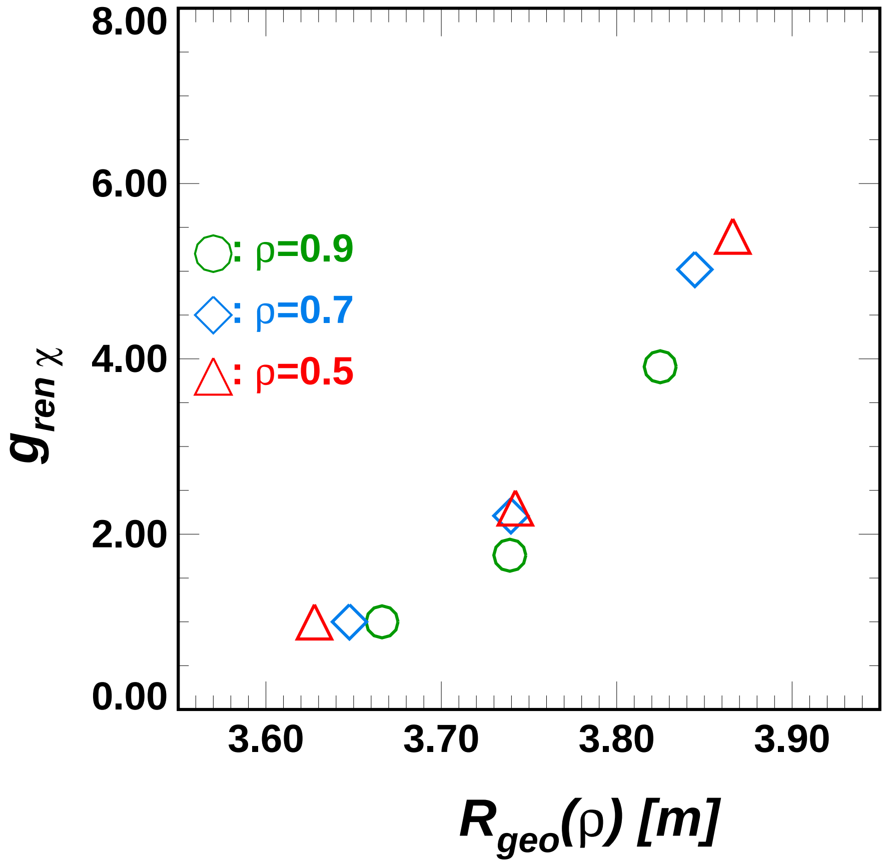
- χ^{eff}/χ^{ISS04} increases in the $\langle\beta\rangle > 1$ % region at $\rho = 0.5, 0.7$ and 0.9 positions.
- As the causes of this degradation, the effects of (1) the change of the magnetic configuration and (2) the increment in β or $\nabla\beta$ will be evaluated.
- The magnitude of χ^{eff}/χ^{ISS04} is set to become unity in the low β regime.

Dependence of the geometric center position of the magnetic flux surfaces, $R_{geo}(\rho)$, of $\rho = 0.5, 0.7$ and 0.9 on $\langle\beta\rangle$.



- $R_{geo}(\rho)$ is shifted torus outward in the $\langle\beta\rangle > 1$ % region at $\rho = 0.5, 0.7$ and 0.9 positions.

$g_{ren\chi}$ for various magnetic configurations and radial positions (again).



- These $g_{ren\chi}$ values are derived from the local transport analysis at each ρ.

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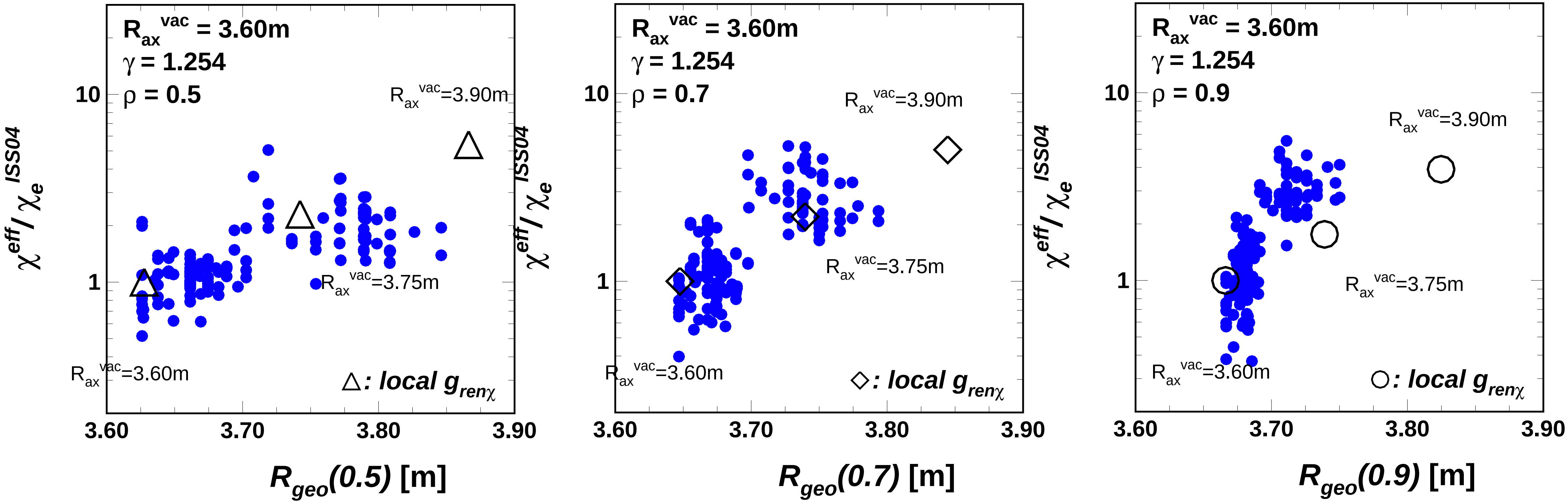
Comparison of β effects and geomrtrical effects on χ

The dependence of χ^{eff}/χ^{ISS04} on $R_{geo}(\rho)$ in the high β regime are compared with the dependence of χ^{eff}/χ^{ISS04} on $R_{geo}(\rho)$ in the low β regime with various magnetic axis positions.



- The degradation of the local transport with the increment in $\langle\beta\rangle$ seems to be comparable with or slightly smaller than the degradation by the torus outward shift of the magnetic flux surface at $\rho = 0.7$ or 0.5.
- On the other hand, at the peripheral region of $\rho = 0.9$, it is found that some effects other than the change of the magnetic flux surface may exist.

Comparison of β effects and geomrtrical effects on χ (continued).

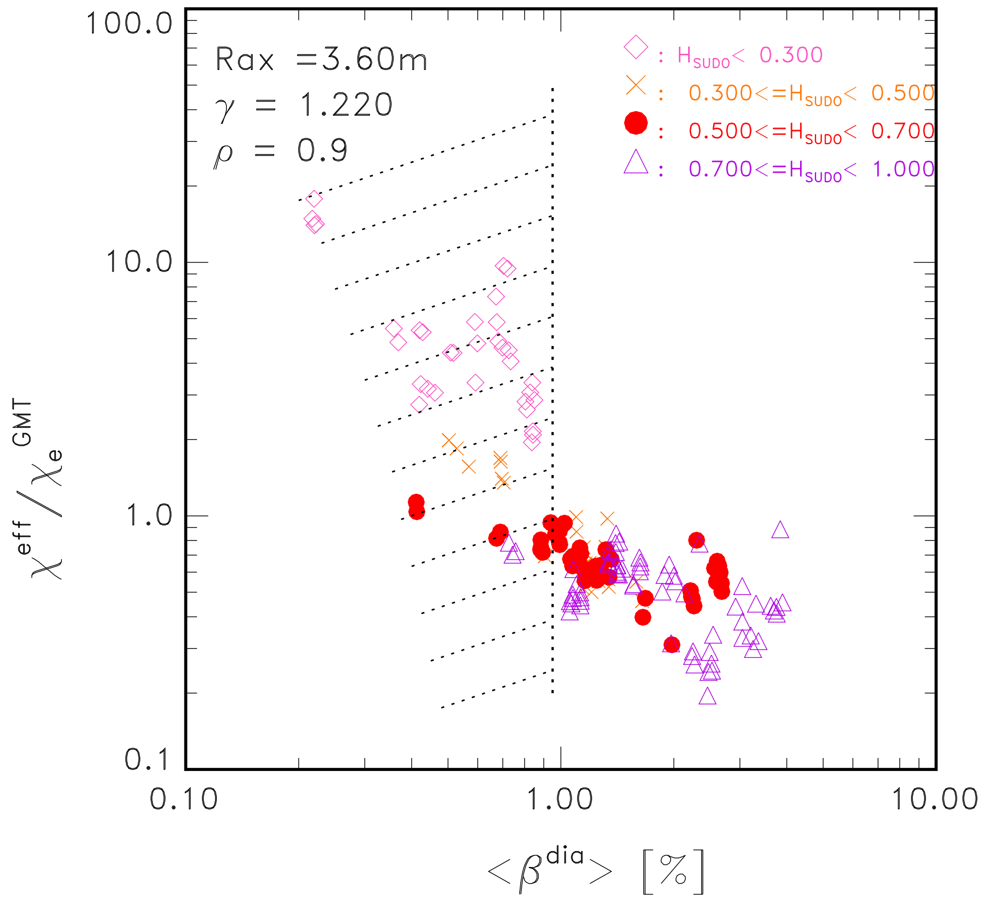
Although the the degradation with $\langle\beta\rangle$ seems to be explained by the change of the magnetic configuration from the global confinement analysis, transport degradation by some effects which are directly causaed by β or $\nabla\beta$ may exist in the peripheral region from the results of the local transport analysis.

As the causes of this difference, following reasons may be considered.

(1) In the peripheral region near $\rho = 0.9$, effects other than the change of the magnetic configuration may dominate. On the other hand, in the inner reagion near $\rho = 0.5$, the transport degradation is smaller than that by the configuration effect. The degradation of global confinement property by $\langle\beta\rangle$ seems to be similar with the configuration effect since these effects are balanced. (The registive g-mode turbulence can be considered as one of the causes of the transport degradation at the peripheral region.)

(2) In this analysis, the geometic center of the magnetic flux surface ($R_{geo}(\rho)$) is assumed to represent the property of that magnetic flux surface. It is needed to check the validity of this assumption.

$\langle\beta\rangle$ Dependence of the Ratio of the Experimental results to the Resistive g-mode Type Transport Coefficients, χ^{eff}/χ_e^{GMT} at $\rho = 0.9$

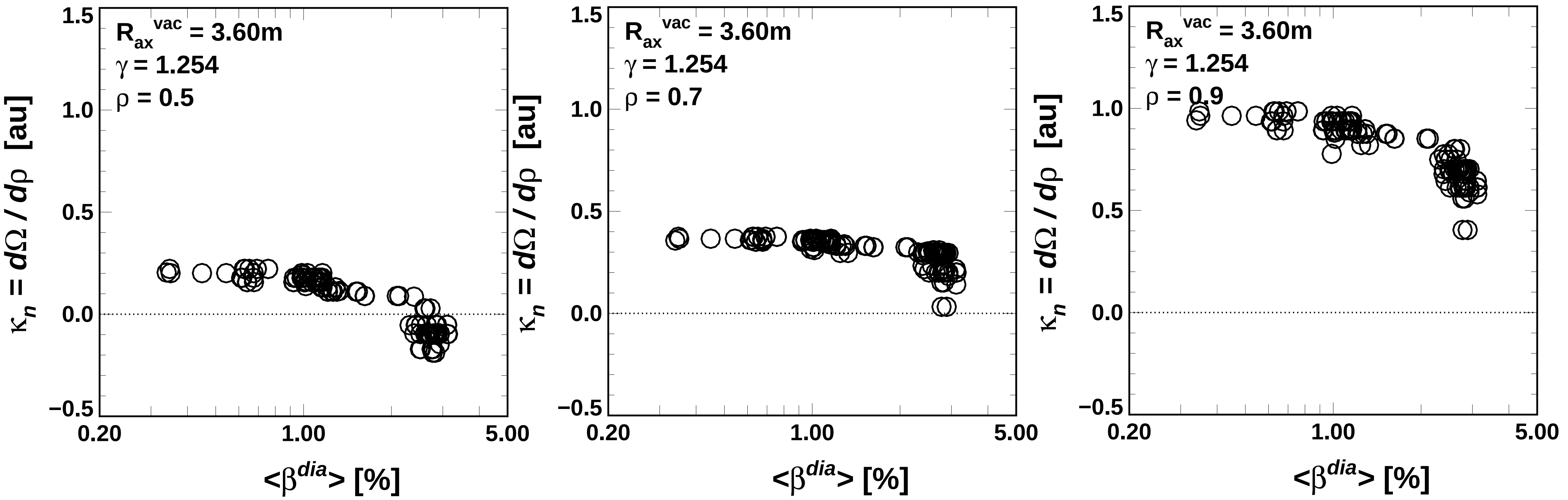


- The ratio of χ^{eff}/χ_e^{GMT} at $\rho = 0.9$ become more than 1 in the range of $\langle\beta\rangle < 1.0\,\%$, This result shows that the effect of the resistive g-mode is small in this regime.

- When $\langle\beta\rangle$ exceeds $1\,\%$, the dependence of χ^{eff}/χ_e^{GMT} on β becomes about $\beta^{-0.3}$. Although the β dependence of the resistive g-mode model seems to be stronger than that of the experimental results, the resistive g-mode has a possibility for one of the causes of the degradation at the peripheral region.

- $A_p = 6.3$

$\langle\beta\rangle$ dependence of κ_n, which denotes the magnetic well or hill structure.



- Dependence of $\kappa_n = \frac{\mathrm{d}\Omega}{\mathrm{d}\rho}$ on $\langle\beta\rangle$.
- $\kappa_n < 0$ denotes the magnetic well region.

Summary 1

(1) The change of the magnetic flux surface structure by the increment in β and its effect on the global confinement characteristics.

- The global confinement analysis is carried out including the change of the magnetic configuration with the increment in $\langle\beta\rangle$. If f_{ren} is assumed to depend on $R_{geo}(2/3)$, the degradation in the high β regime become unclear.

(2) The dependence of the local transport on the magnetic configuration in the low β regime.

- In order to evaluate the dependence of local transport coefficients on the magnetic configuration, the renormalization factor for the transport coefficients, $g_{ren\chi}$ is introduced. Then χ^{ISS04} is used as the reference in this analysis. As the geometric center of the magnetic flux surface is shifted torus outward, $g_{ren\chi}$ increases at any minor radius positions.

Summary 2

(3) Local transport property in the high β regime and its dependence on the magnetic configuration.

The main purpose of this study is to distinguish the causes of the gradual confinement degradation with β from following two effects: (1) the change of magnetic configuration by the increment inβ, (2) β value or the gradient of β.

- The degradation of the local transport with the increment in $\langle\beta\rangle$ seems to be comparable with or slightly smaller than the degradation by the torus outward shift of the magnetic flux surface at $\rho = 0.7$ or 0.5.
- On the other hand, at the peripheral region of $\rho = 0.9$, it is found that some effects other than the change of the magnetic flux surface may exist.
- From the global confinement analysis, it seems that the global confinement degradation with $\langle\beta\rangle$ may be explained by the change of the magnetic configuration. However, from the results of the local transport analysis, it is considered that degradation by β value or the gradient of β appears at the peripheral region.

References

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[2] K.Y.Watanabe et al., Nucl. Fusion **45** 1247 (2005).

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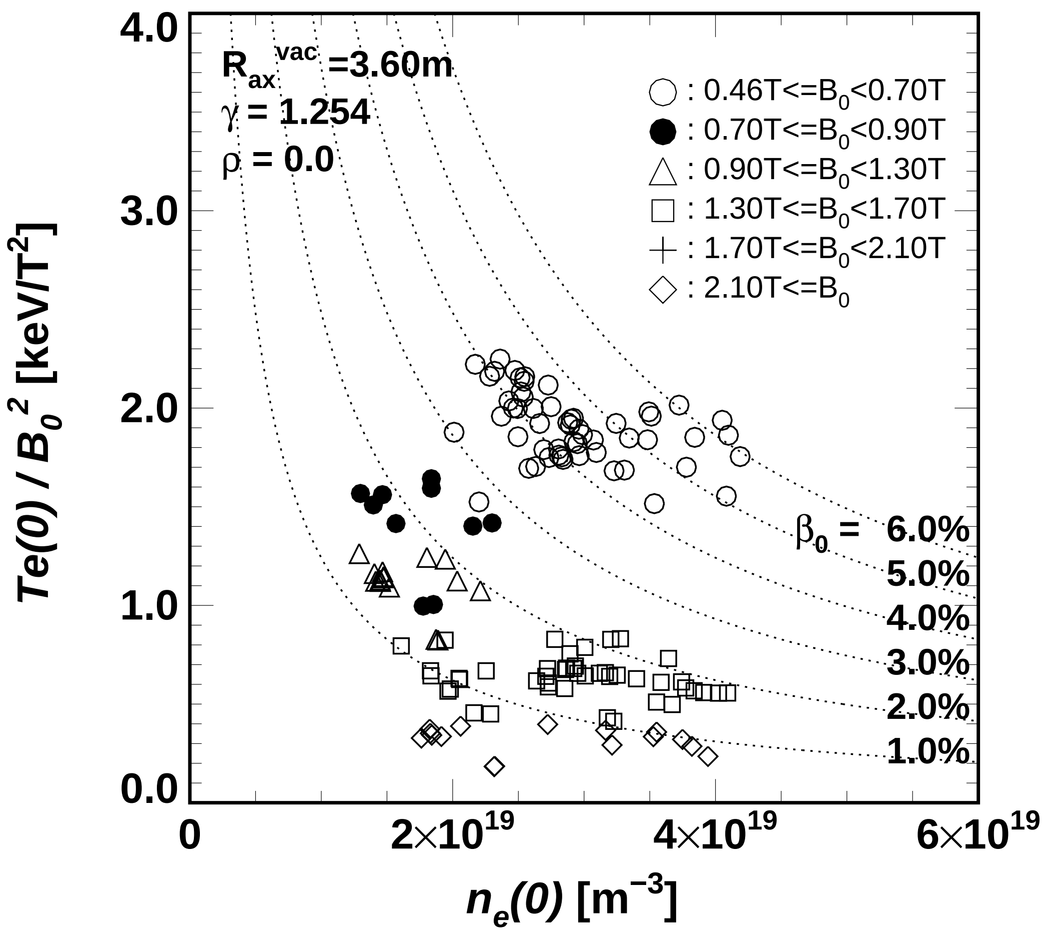
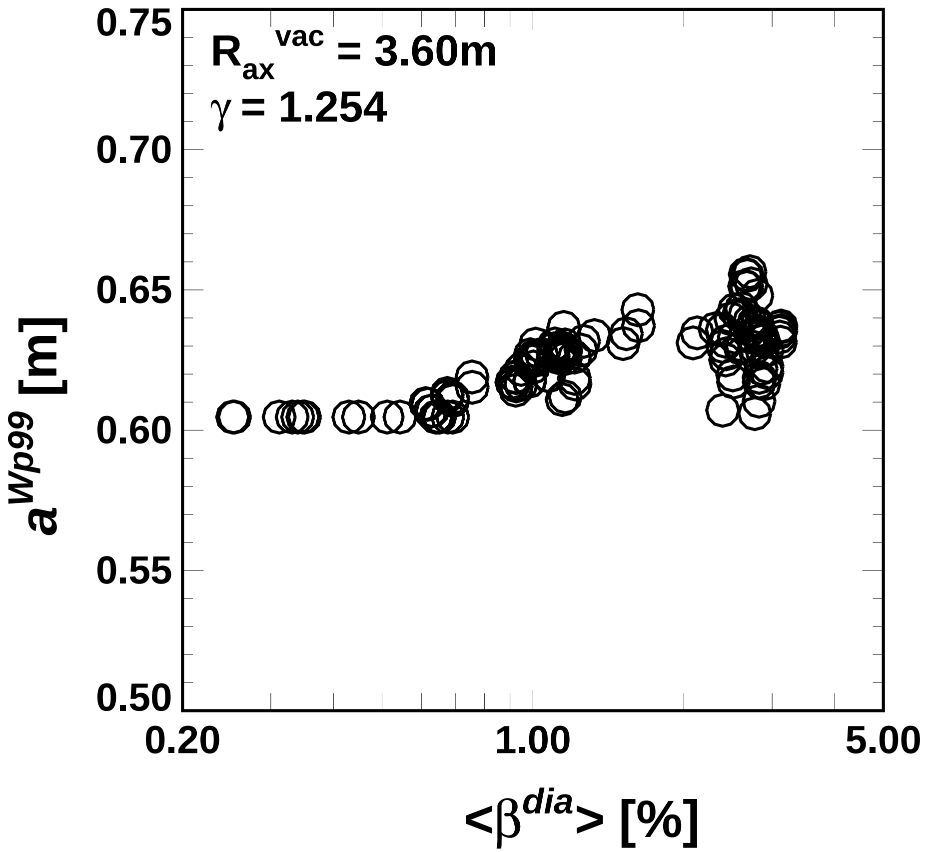
Parameter region of used data.



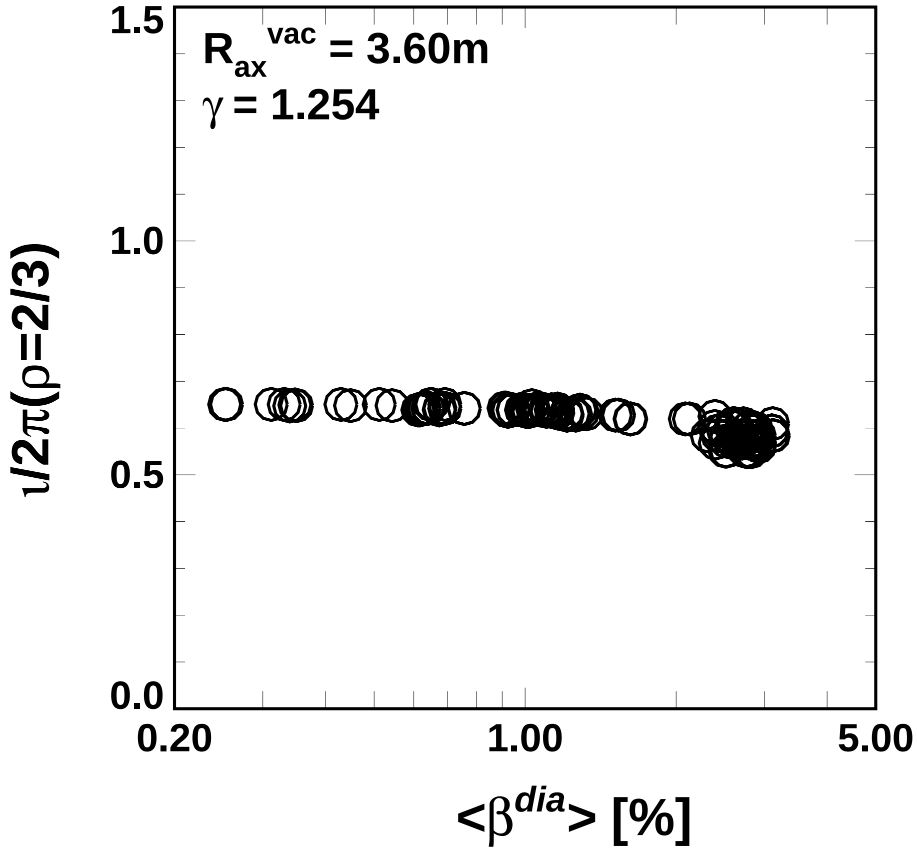
- The NBI heated plasmas with $B_q = 100\,\%$ 、 $A_p = 5.8$ are analyzed in this study.

- The data are limited in the parameter region of $1.5 \times 10^{19} \leq \overline{n_e} \leq 4.3 \times 10^{19}\,\mathrm{m}^{-3}$, $I_p/B \leq 30\,\mathrm{kA/T}$, $W_b/W_{kin} \leq 0.5$.

Change of a and $\iota(2/3)$ with increment in $\langle\beta\rangle$.



The minor radius of the LCFS derived from the volume which contains the 99% of W_p.



The $\langle\beta\rangle$ dependence of ι of the $\rho = 2/3$ magnetic flux surface.

- $\iota_{2/3}$ is one of the parameters of the ISS04 scaling.