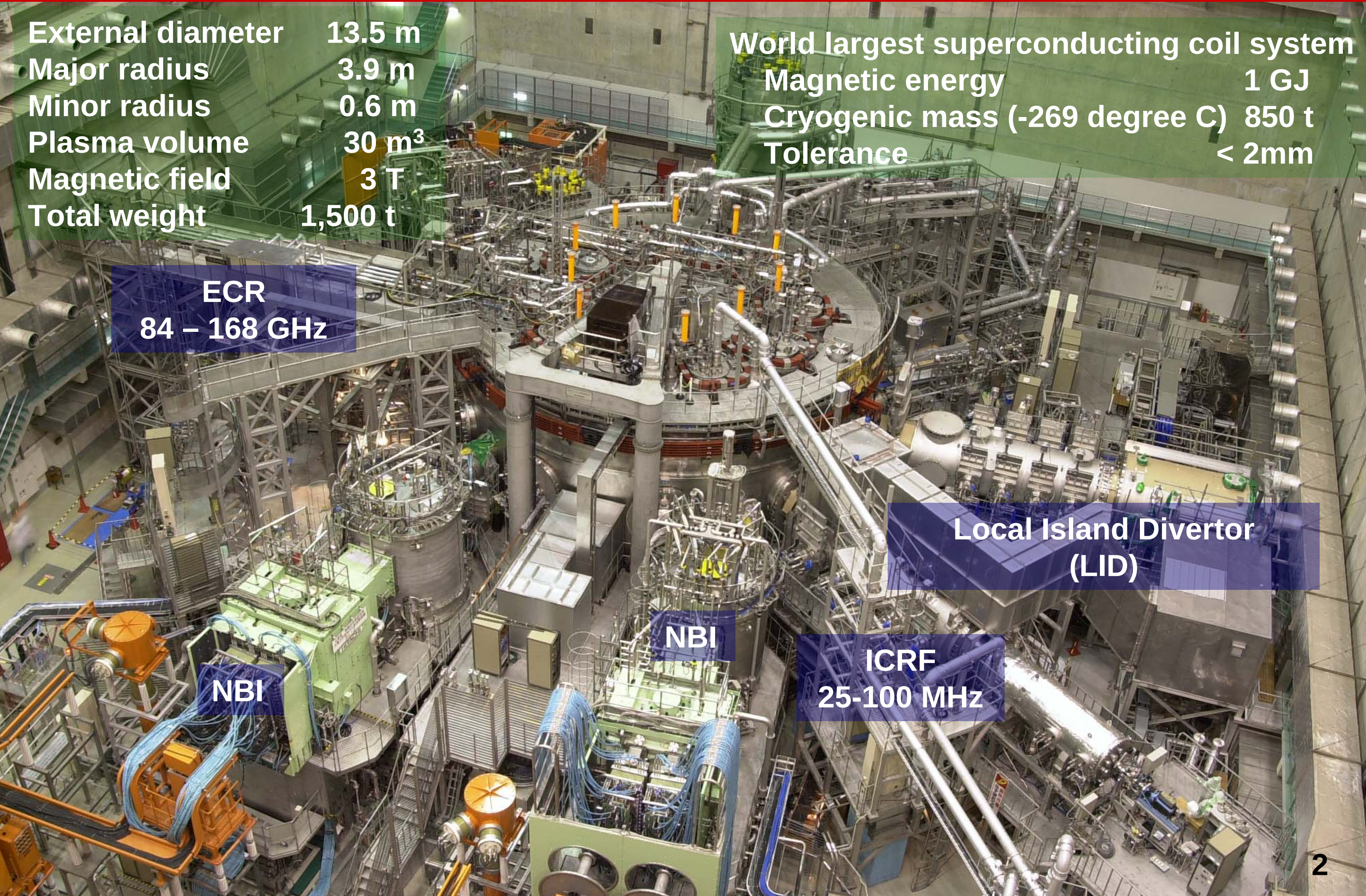
Plasma Control by Local Island Divertor in LHD

A. Komori, T. Morisaki, S. Masuzaki, M. Kobayashi, M. Shoji, N. Ohyabu, Y. Feng1), F. Sardei1), D. Reiter2), K. Ida, K. Tanaka, K. Kawahata, K. Narihara, S. Morita, B. J. Peterson, R. Sakamoto, S. Sakakibara, H. Yamada, K. Ikeda, O. Kaneko, S. Kubo, J. Miyazawa, K. Nagaoka, H. Nakanishi, K. Ohkubo, Y. Oka, M. Osakabe, T. Shimozuma, Y. Takeiri, K. Tsumori, K. Y. Watababe, I. Yamada, Y. Yoshimura, M. Yoshinuma, O. Motojima and LHD Experimental Group

National Institute for Fusion Science,Toki 509-5292, Japan
1) Max-Planck-Institute fuer Plasmaphysik, Greifswald, Germany
2) Forschungszentrum Juelich, Germany

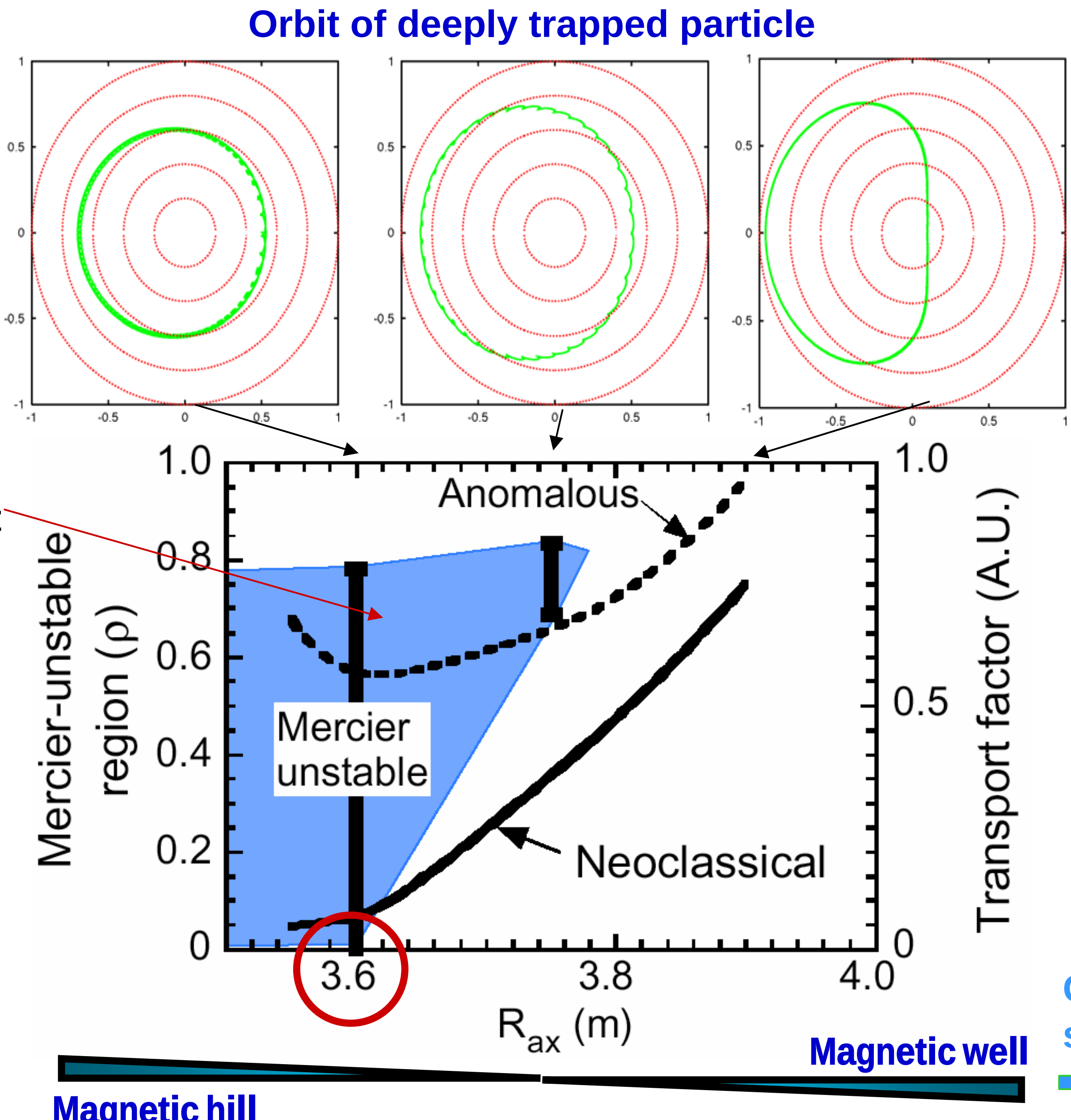
Inside view of V/V

Present View! Large Helical Device (LHD)



Performance of LHD plasma depends on magnetic axis position

Good particle orbit



Amplitudes of MHD instabilities were found to be small even in the unstable regime, so that almost no degradation of confinement was observed.

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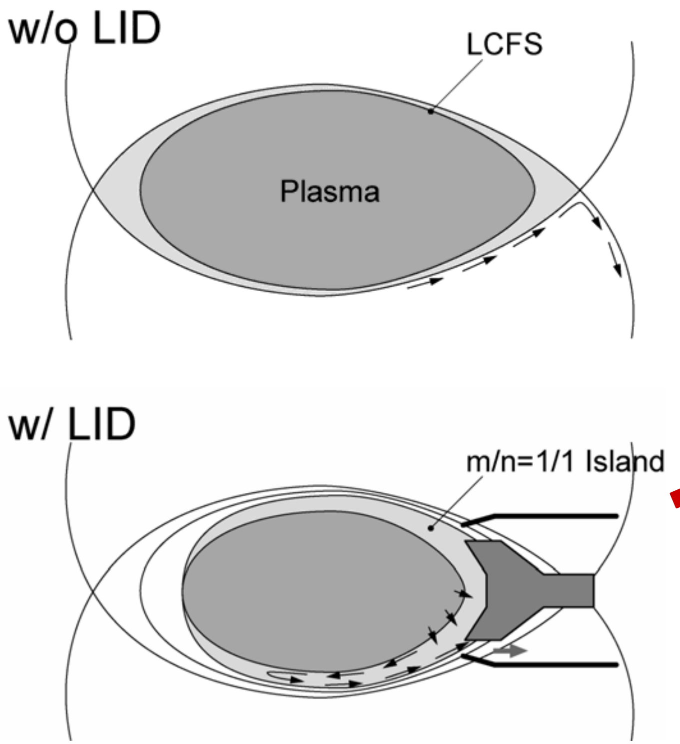
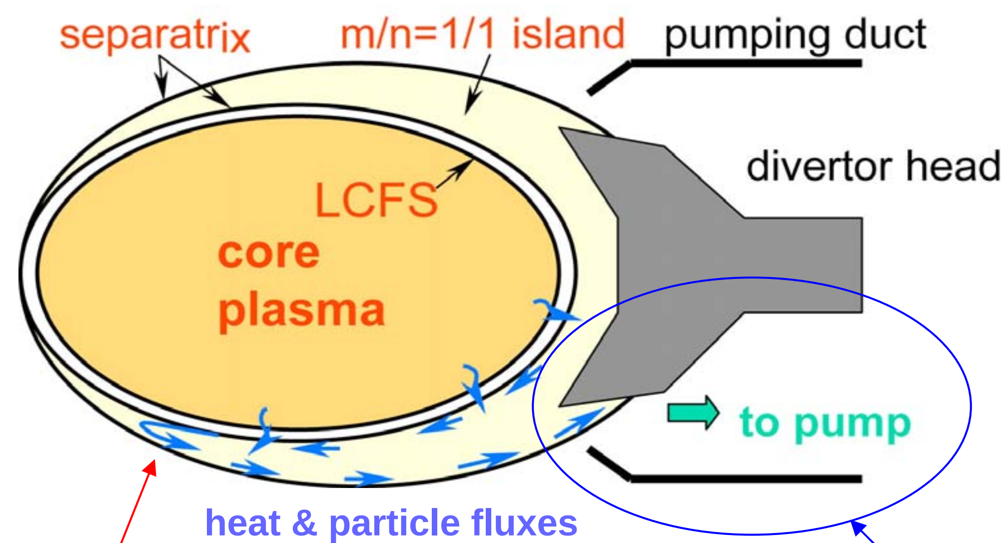
The potential conflict between stability and confinement was favorably resolved.

Good stability

Principle of LID

LID is a closed divertor that uses an m/n = 1/1 island.





Closed geometry

High pumping efficiency of ≥ 30%.

Outward heat and particle fluxes crossing island separatrix flow along field lines to backside of the island.

R_{ax} = 3.6 m

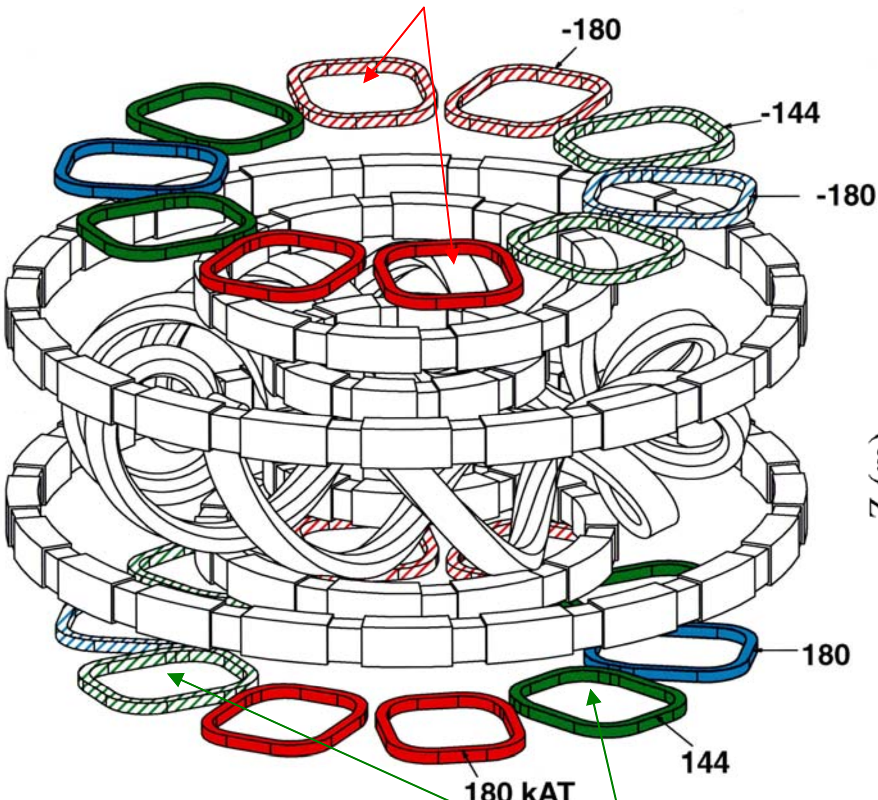
High efficient pumping, combined with core fueling, is the key to realizing a few keV edge plasma with steep temperature gradient, leading to a significant energy confinement improvement.

Technical ease of pumping is the advantage of LID over closed full helical divertor because recycling is toroidally localized.

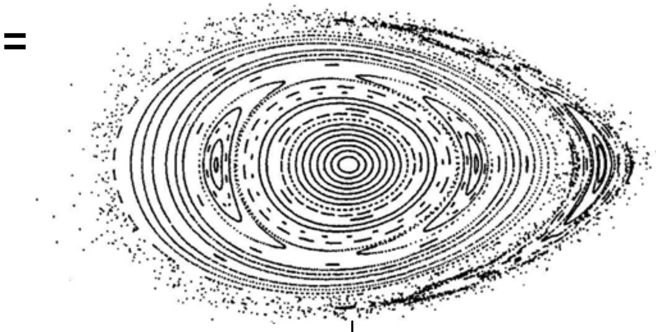
No leading edge problem.

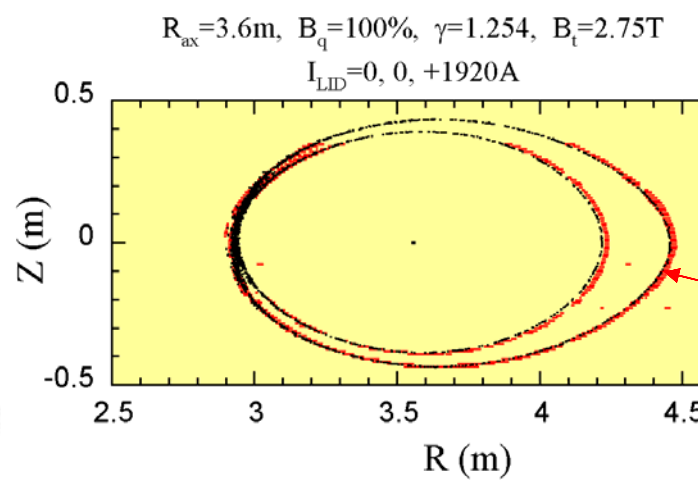
Perturbation coils form only 1/1 island

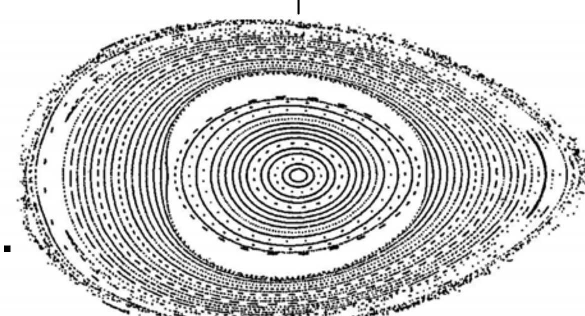
Red coils generate an *m*/*n* = 1/1 and 2/1 islands.



Green and blue coils generate *m*/*n* = 2/1 islands.





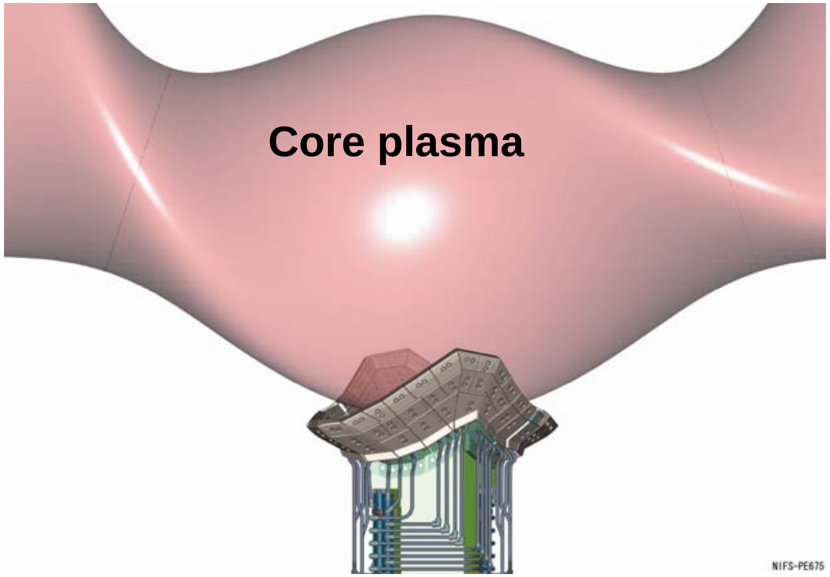


***m*/*n* = 1/1 islands, calculated (black line), and measured by flux surface mapping with electron beam and probe (red dots).**

Divertor head

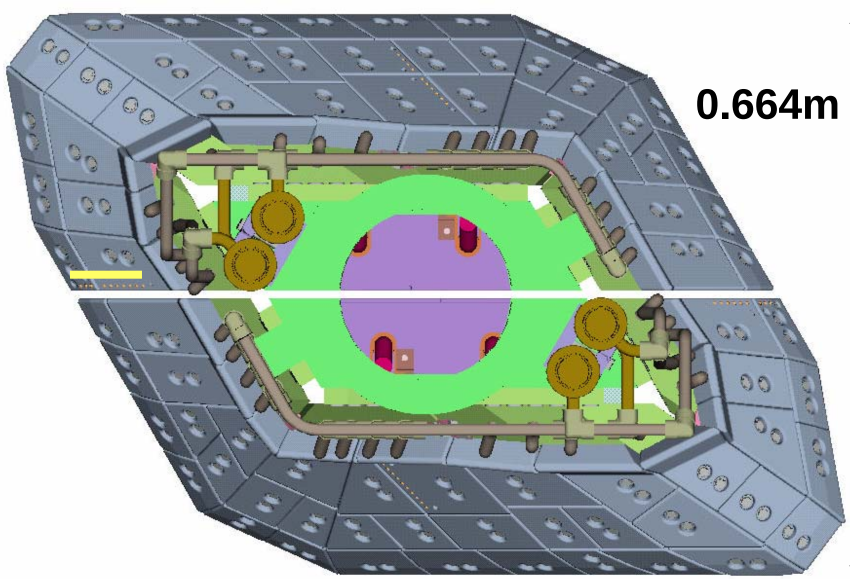
The size of divertor head is about 1 m × 0.7 m.

The area of divertor head, which receives the particle flux, is ~0.3 m^2, and the average heat flux onto carbon plates was designed ~5 MW/m^2 for 3 sec.

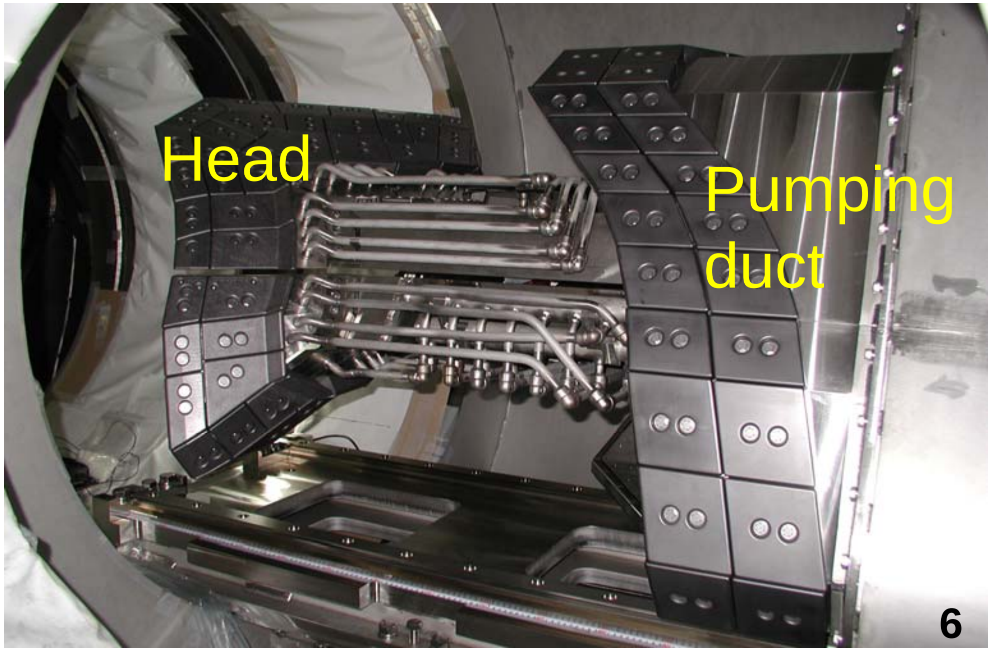


The core plasma is bounded on the inner island separatrix.

0.99m

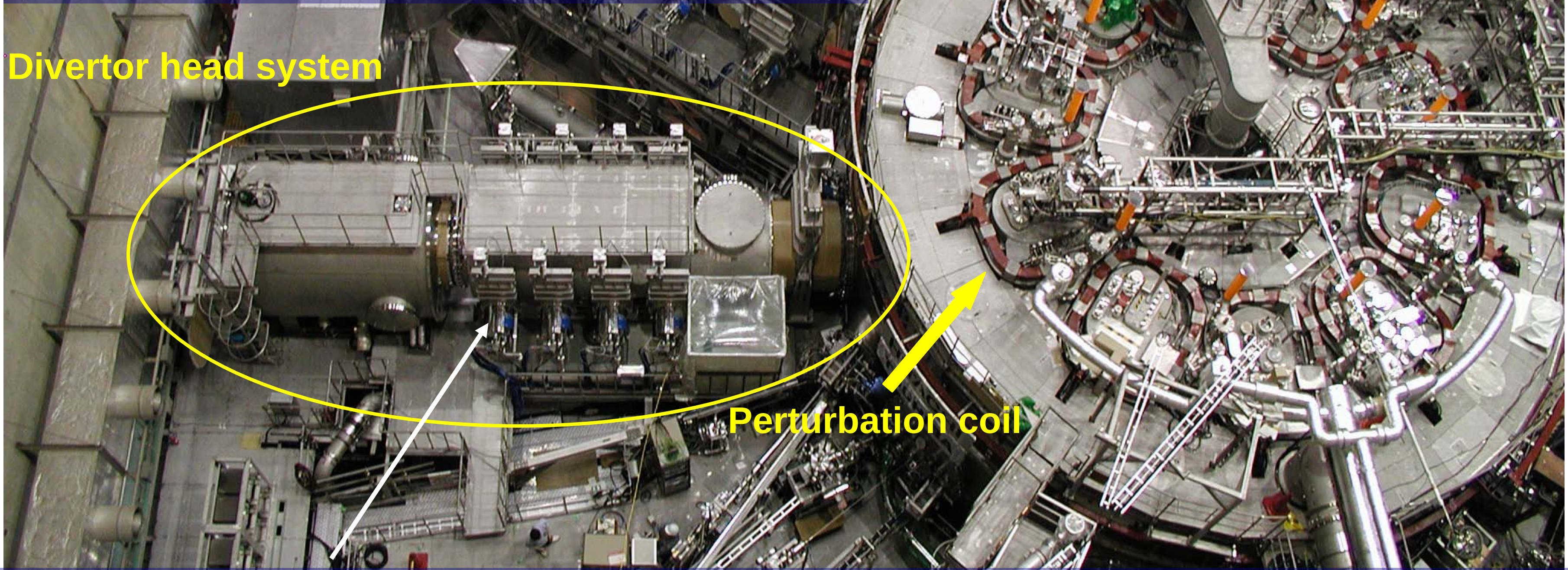


backside view



Divertor head system and perturbation coils installed in LHD

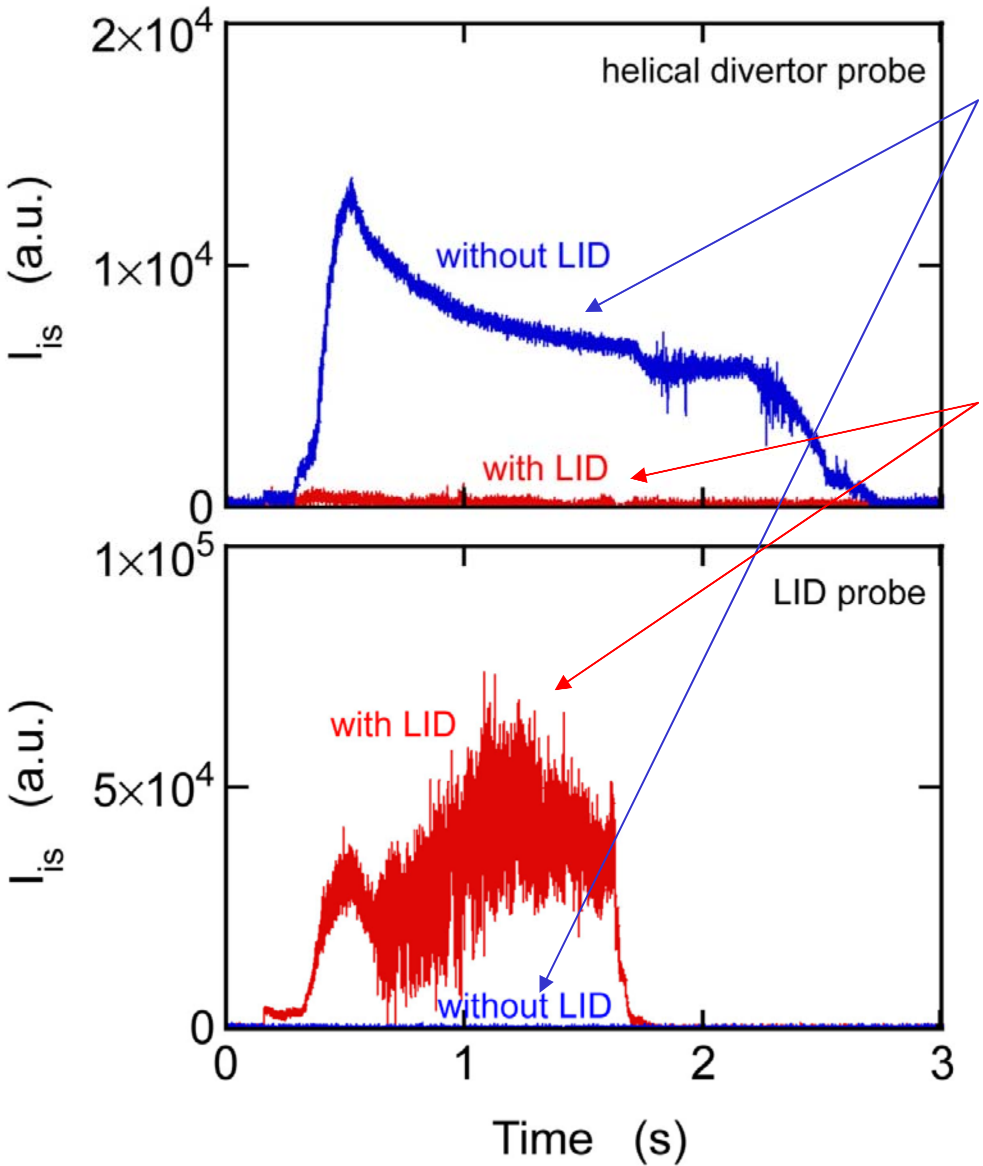
The divertor head system consists of a divertor head, its driving system, a pumping duct, an LID chamber, and so on.
The driving system and gate valve are necessary for maintaining the divertor head and performing experiments without LID.



Pumping system has 8 cryogenic pumps with a hydrogen pumping speed of 42,000 l/sec.

effective pumping speed; ~1×10^5 l/sec at the gate valve (realizing a molecular flow),
pumping capacity; 3×10^5 Torrl,
maximum pumping flux; 75 Torrl/sec.

Particle fluxes to helical divertor and LID



Without LID, particle flux flows, of course, to helical divertor and strikes upon its carbon plates.

With LID, I_{is} on the divertor head of the LID becomes large, while I_{is} on the carbon plate of the helical divertor is reduced to almost zero.

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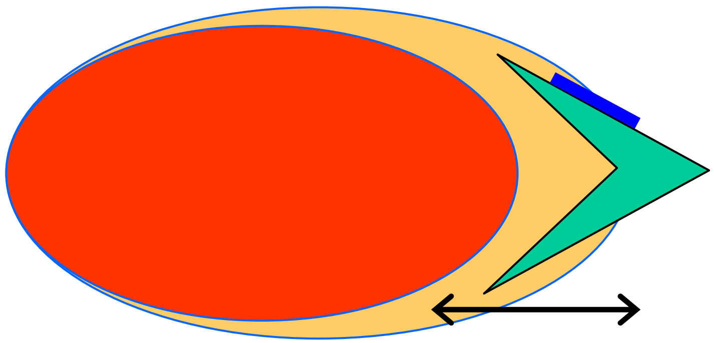
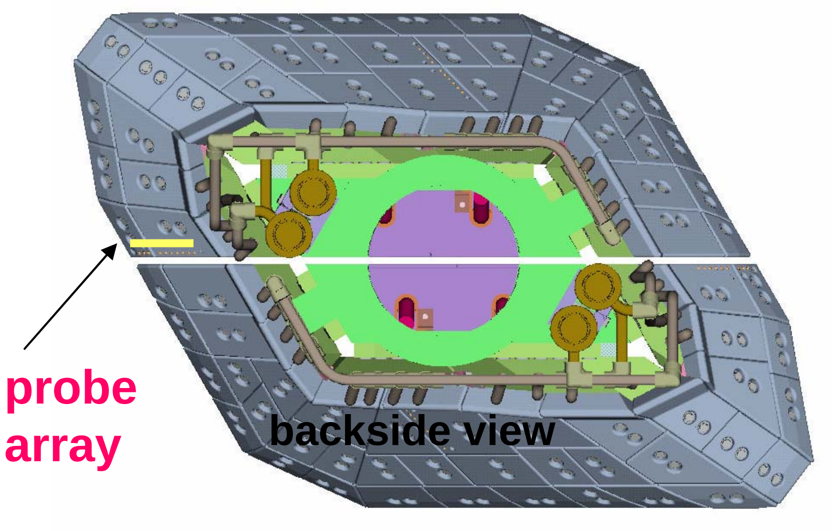
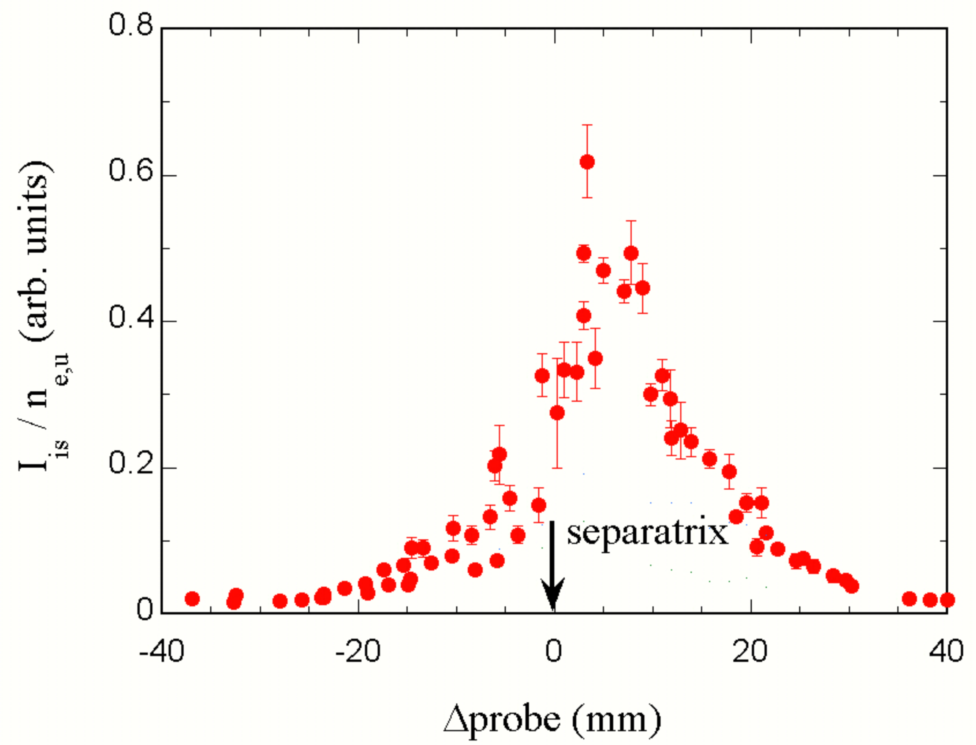
This indicates that LID collects almost all particles towards the helical divertor.

Particle flux profile on the divertor head





Head position scan (slit width = 8cm = const.)



The peak of the ion saturation current is located very near the outer island separatrix, indicating that particles flow along the island separatrix.

The particle flux to the blade is so small, that there is no leading edge problem, as expected.

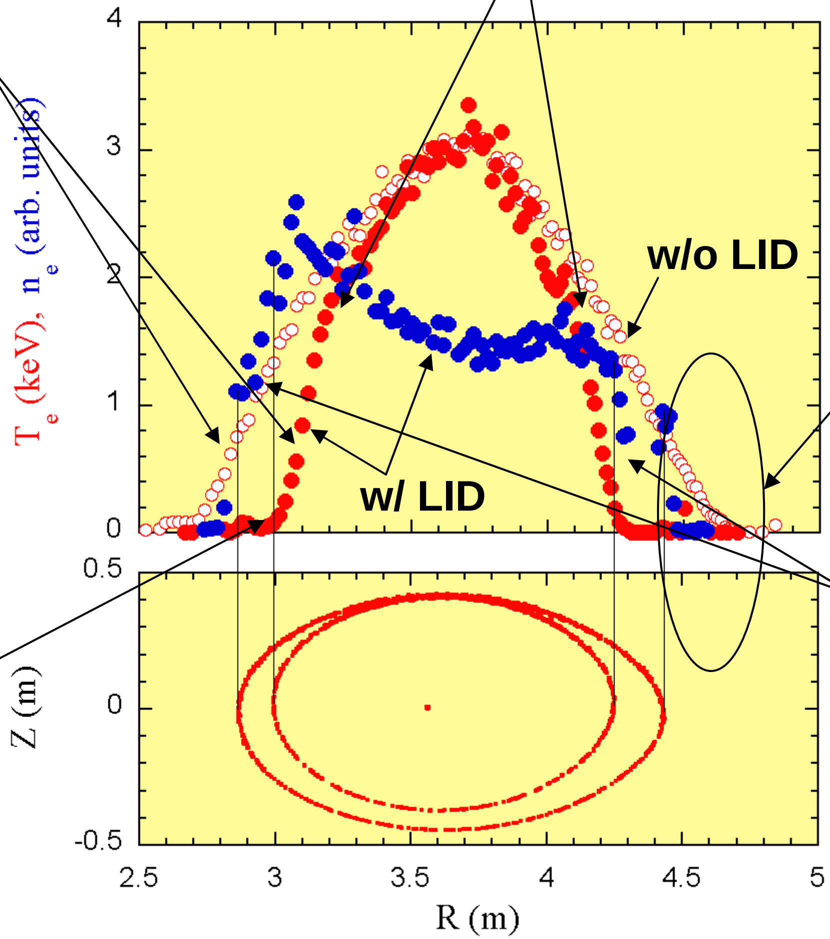
Radial T_e and n_e profiles with and without LID

R_{ax} = 3.6 m

These features with LID are consistent with those expected for plasmas, controlled by LID.

Bends in *Te* profile suggest a boundary of edge plasma, and therefore a high temperature edge plasma, in this case, of about 1.5 keV.

The steep temperature gradient in the edge region is realized, compared with that without LID.



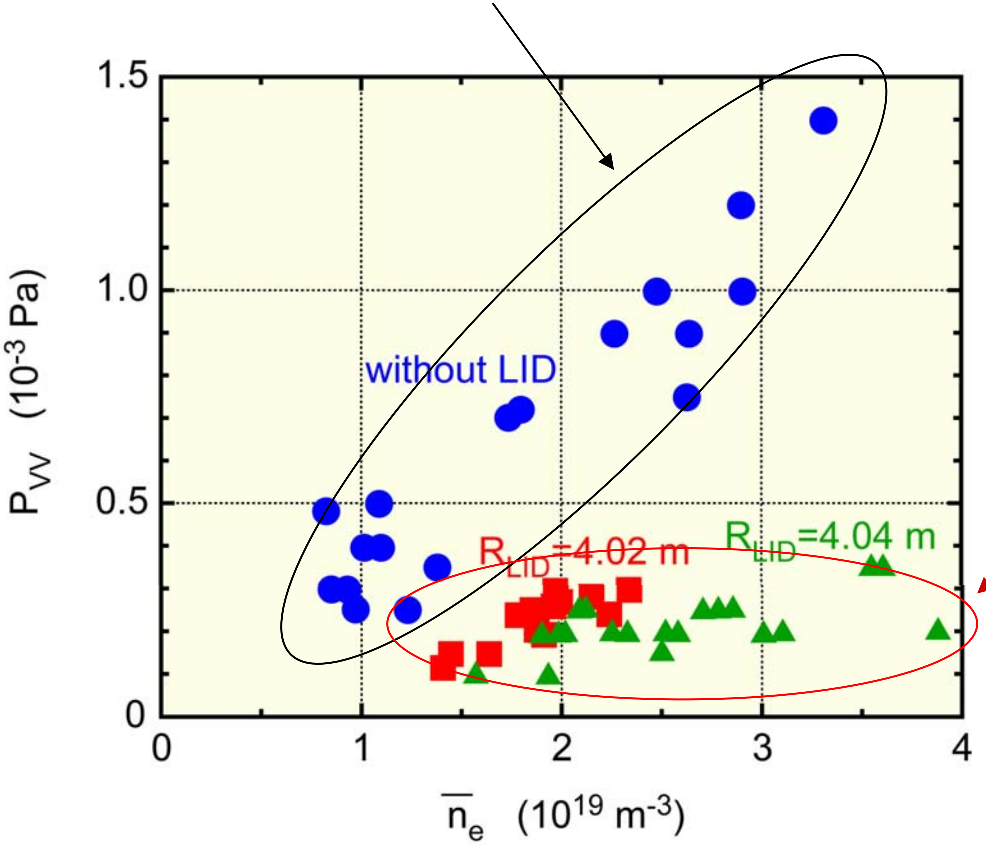
Low-temperature plasmas outside the outer island separatrix are scrapped off with LID.

***T_e* is bounded on the inner island separatrix with LID.**

***n_e* is bounded on the outer island separatrix, indicating the low-temperature particle flow along the island separatrix to the divertor head.**

Neutral particle pressure, p_{vv}, between the plasma and wall is independent of $\bar{n}_e$ when LID was turned on.

Without LID,
p_{vv} increases monotonically with $\bar{n}_e$.



Much gas puffing is necessary for production of the higher $\bar{n}_e$, and there is a lot of recycled particles, under the condition that heating power is kept constant.

With LID,
p_{vv} is almost constant and kept low, independently of $\bar{n}_e$.

The number of recycled particles from the wall and helical divertor is small, because almost all divertor plasma strikes upon the divertor head, and there are almost no particles to the wall and helical divertor.

LID functions and edge plasma control

LID functions have been clearly demonstrated, and active control of the LHD edge plasma was performed for the first time in the LHD project.

Particle flow is indeed guided to the backside of the divertor head by the island structure, and a high pumping efficiency was suggested.

Accordingly, almost no plasma exists between the last closed magnetic surface (LCFS) and wall,

and hence, a recycling rate of particles becomes low when LID is turned on.

A high temperature edge plasma with steep temperature gradient is formed.

Heat load to the leading edge is smaller than that along the island separatrix.

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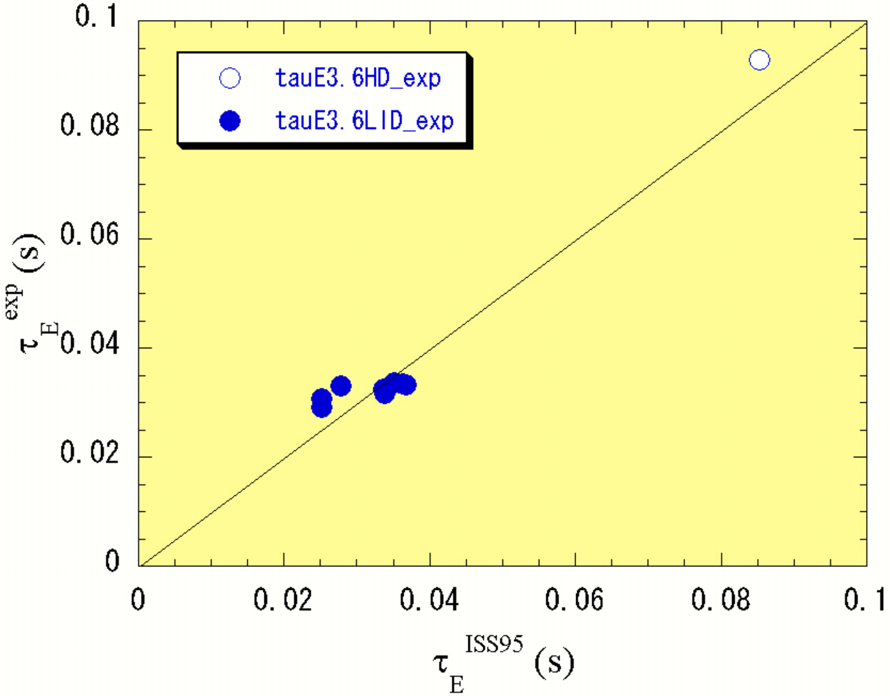
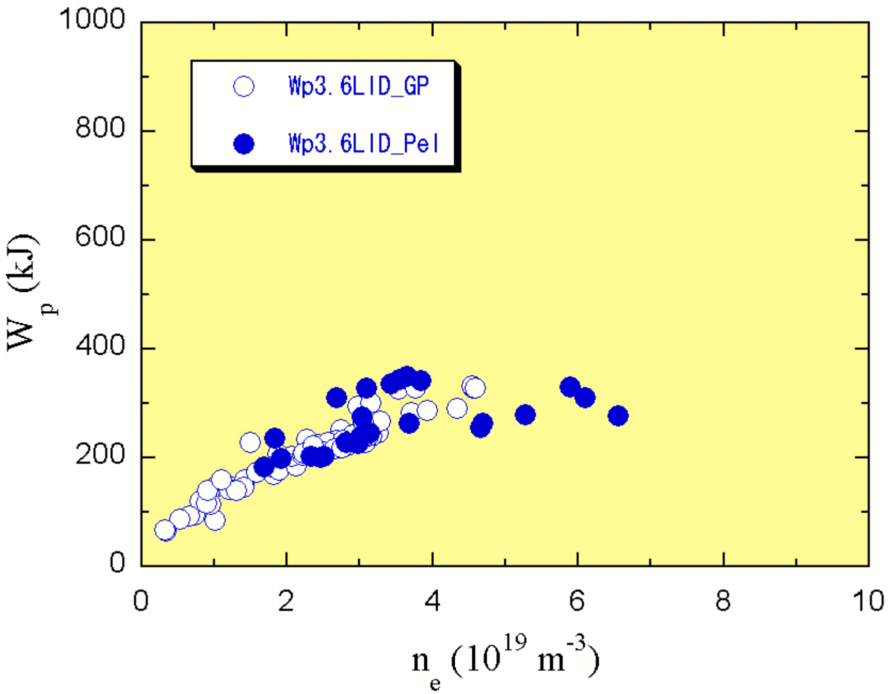
In the next step, we aim at remarkable improvement of plasma confinement like H-mode in tokamaks.

Comparison of τ_E with ISS95 scaling law

R_{ax} = 3.6 m





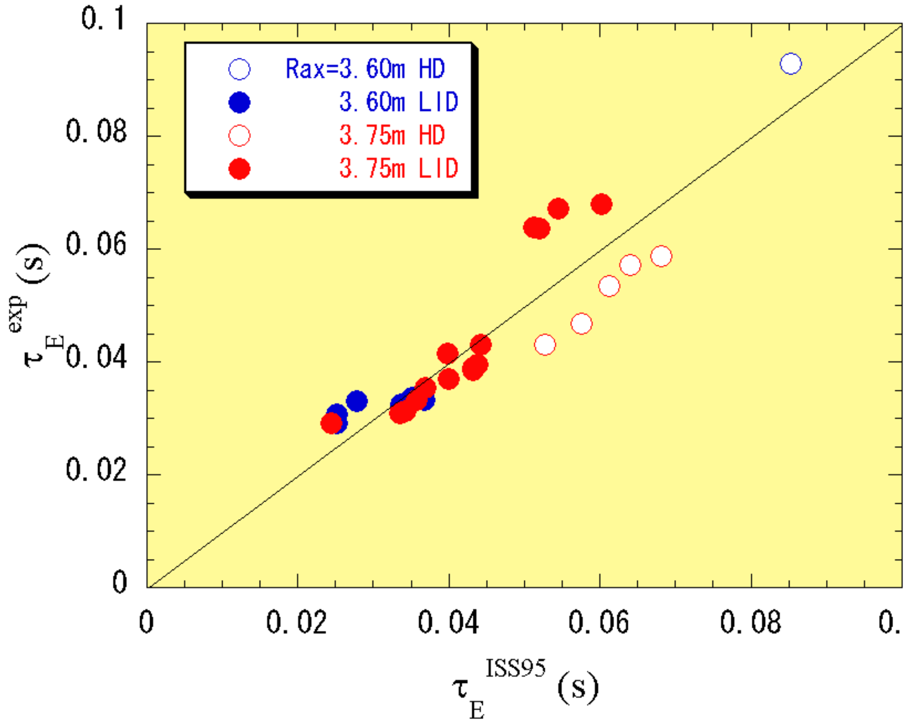
Without LID, the energy confinement time is better than that of the ISS95 scaling law by about 1.5 times.
Thus, it is shorter than that without LID.

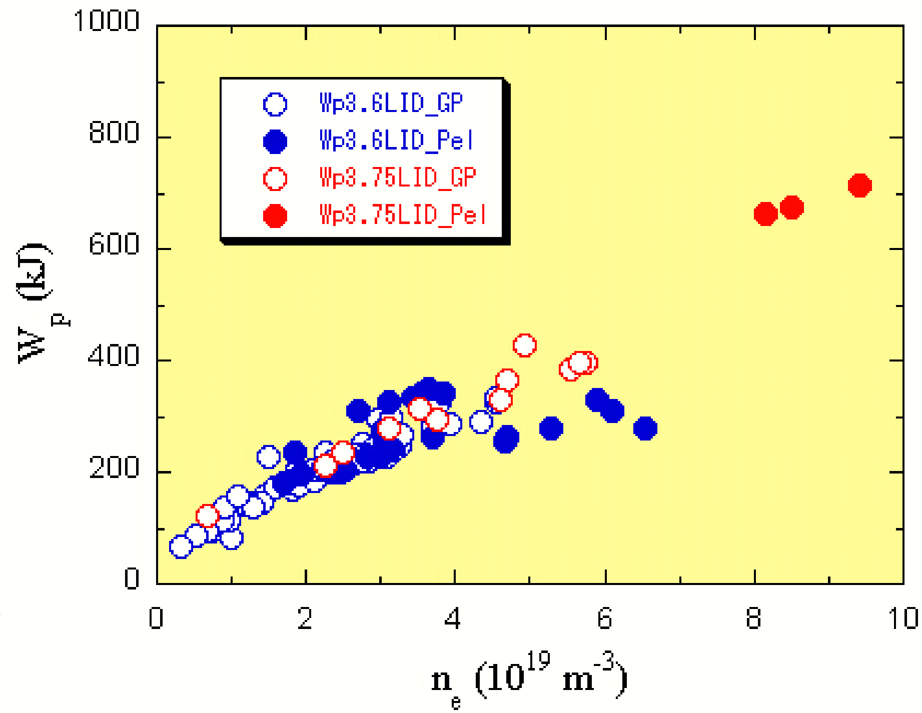
Pumping ability is too high, so that n_e and W_p cannot increase, even if strong gas-puffing or pellet injection is applied.

Large number of particles, ionized around the island separatrix, is scraped off.

A hint of improved confinement was in the experiment at R_{ax} = 3.75 m

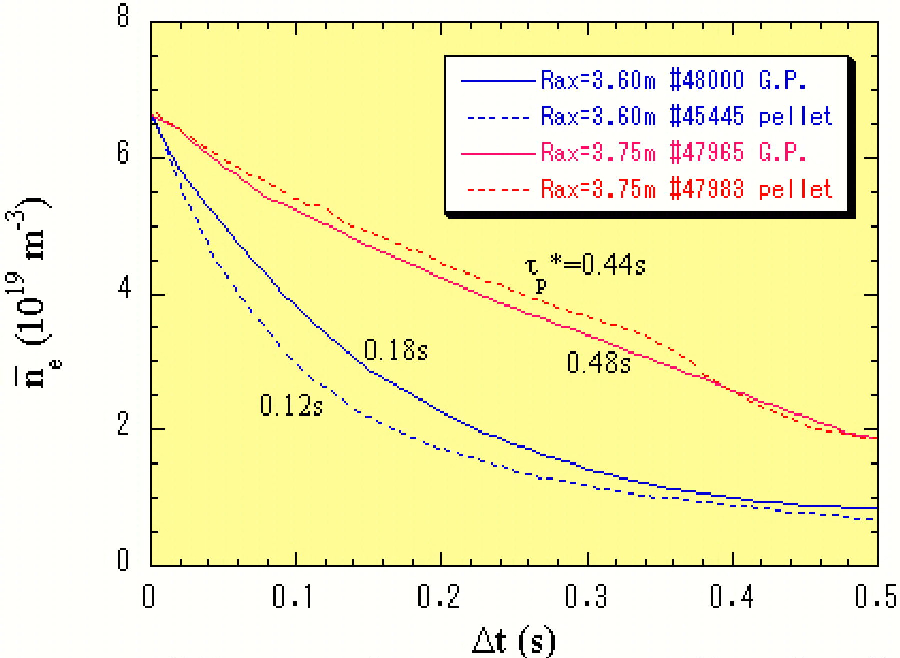
R_{ax} = 3.75 m



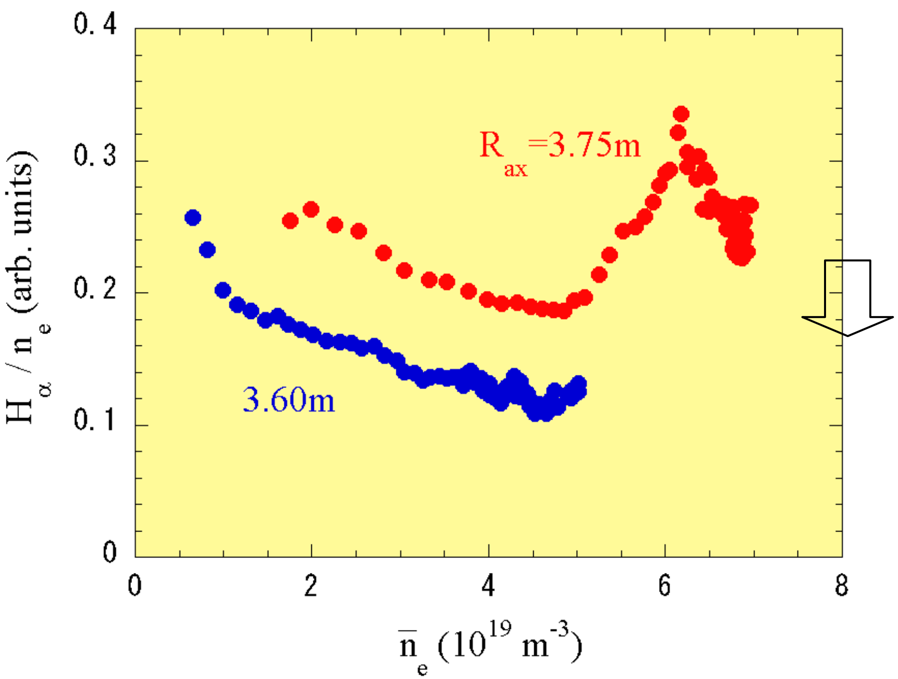


The energy confinement time with LID is better than that of the ISS95 scaling law by about 1.2 times.
Without LID, it is comparable to or a little less than that of the ISS95 scaling law.
Thus, good confinement was obtained at 3.75 m.

Higher n_e and W_p are achieved by both gas puffing and pellet injection, compared with those at 3.6 m.



No difference between gas puff and pellet



Experiments at R_{ax} = 3.75 m

Recycling is enhanced and pumping efficiency is degraded.

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Fueling efficiency is increased and high density is achieved.

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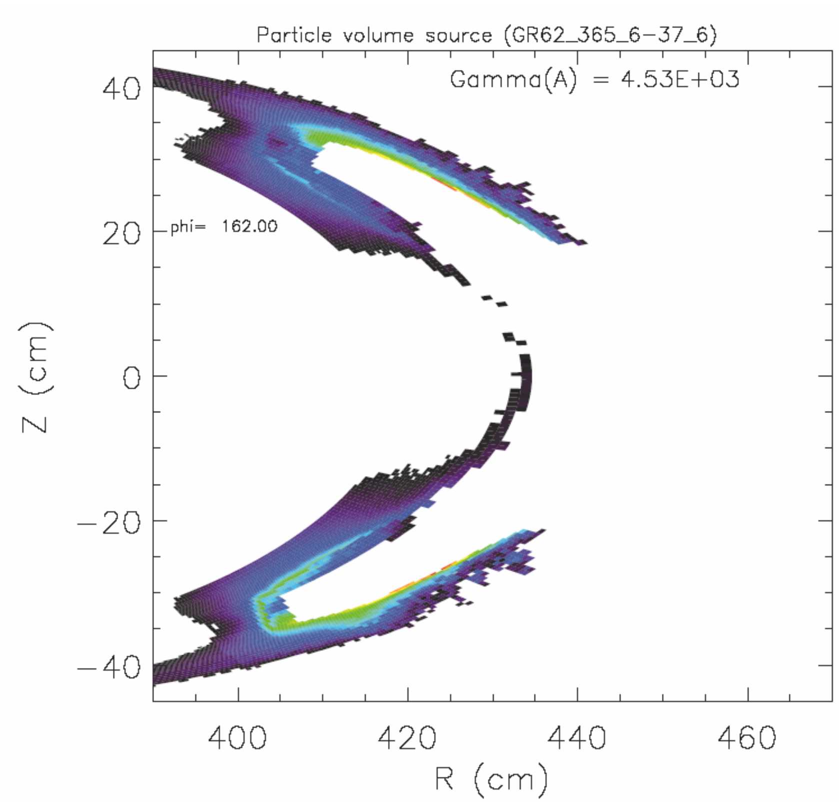
Good plasma performance

At the magnetic axis position of 3.75 m, the island touches the ergodic layer;
some field lines reach the carbon plates of the helical divertor,
and the divertor head shape is not fitted for the configuration,
because it was designed for the configuration with the magnetic axis position of 3.6 m.

3-D profiles of plasma density, neutral particles, and so on were simulated around the divertor head, using EMC3-EIRENE code

R_{ax}=3.60m



Particles are recycled mainly at the back side of the divertor head, that is, inside the pumping duct.

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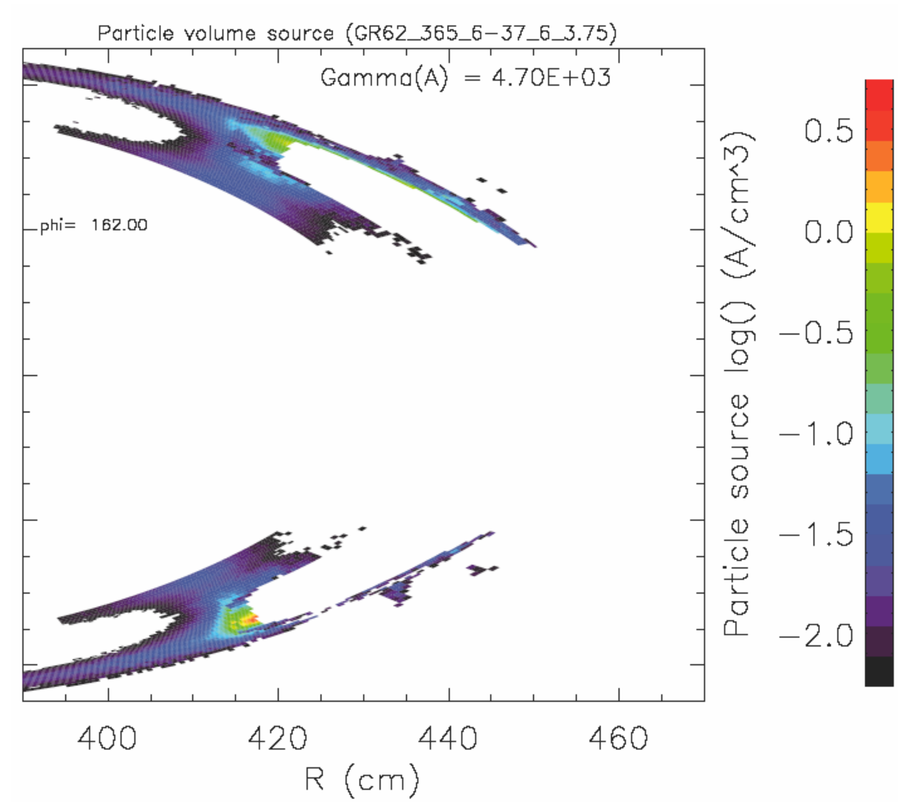
Pumped out
High pumping efficiency

R_{ax}=3.75m



Many particles are recycled at the blades of the divertor head, that is, outside the pumping duct.

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Penetrating into the core region
Degradation of pumping efficiency

Summary

Functions of a local island divertor (LID) were demonstrated experimentally, which is a closed divertor, utilizing an $m/n = 1/1$ island generated externally by 20 small perturbation coils, and the edge plasma control was performed for the first time in the LHD program.

It was found that the outward heat and particle fluxes crossing the island separatrix flow along the field lines to the backside of the divertor head, where carbon plates are placed to receive the heat and particle loads.

Accordingly high efficient pumping was demonstrated, which is considered to be the key in realizing high temperature divertor operation, resulting in an improvement of energy confinement.

In the present experiment, the plasma confinement with LID follows the International Stellarator Scaling 95 at a magnetic axis position of 3.6 m. However, there is a possibility of realizing improved plasma confinement after realizing efficient center fueling or degrading the LID pumping ability.

Results of edge modelling were also presented, using the EMC3-EIRENE code.