I-8

# Local Island Divertor Experiments on LHD

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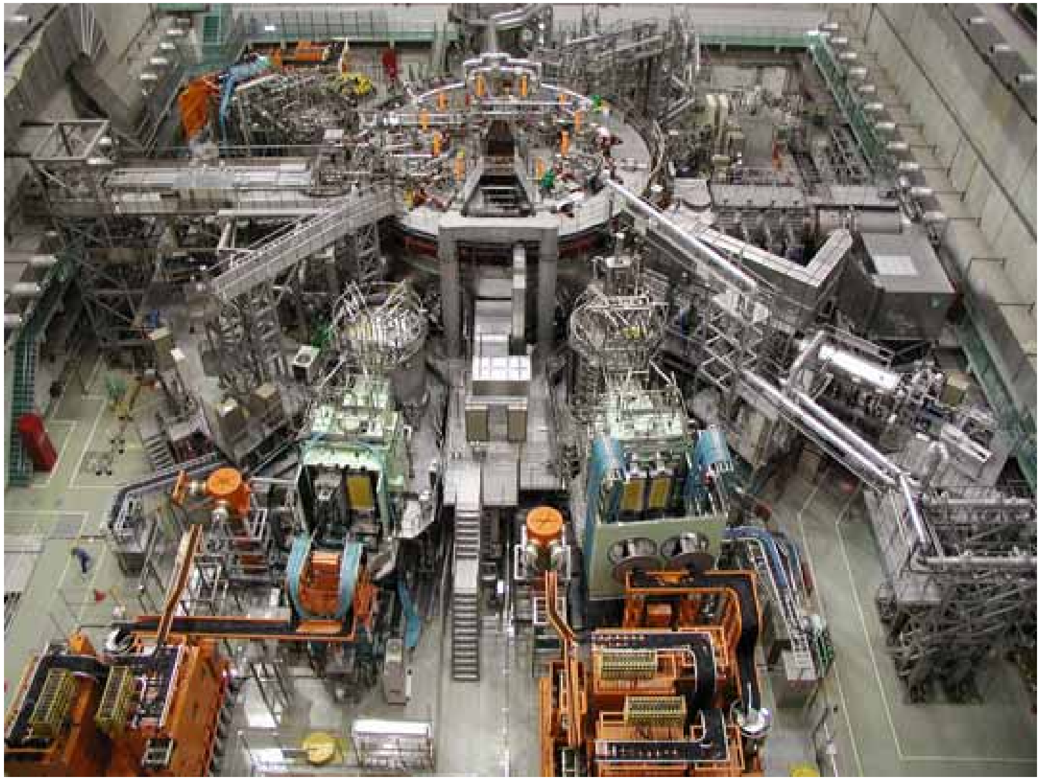
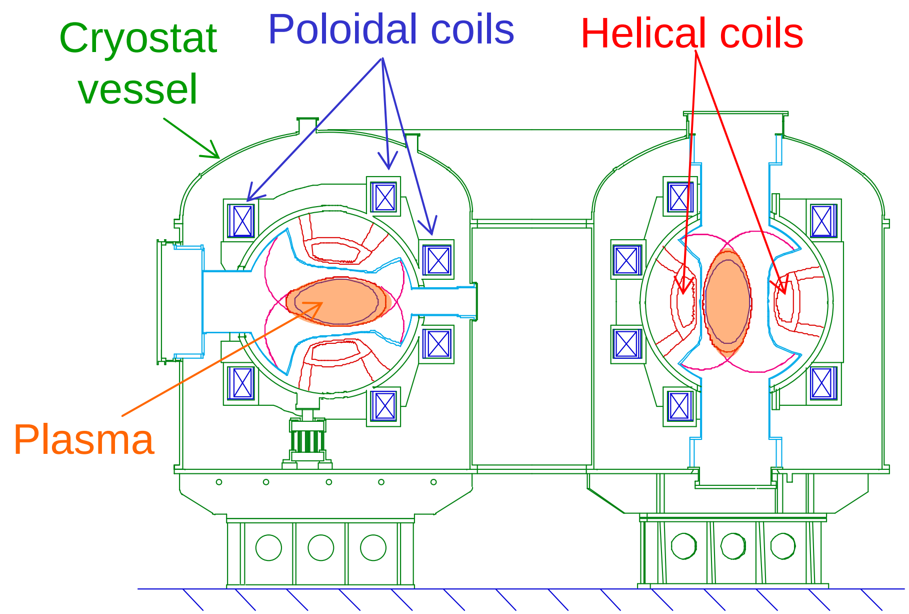
# LHD (Large Helical System)

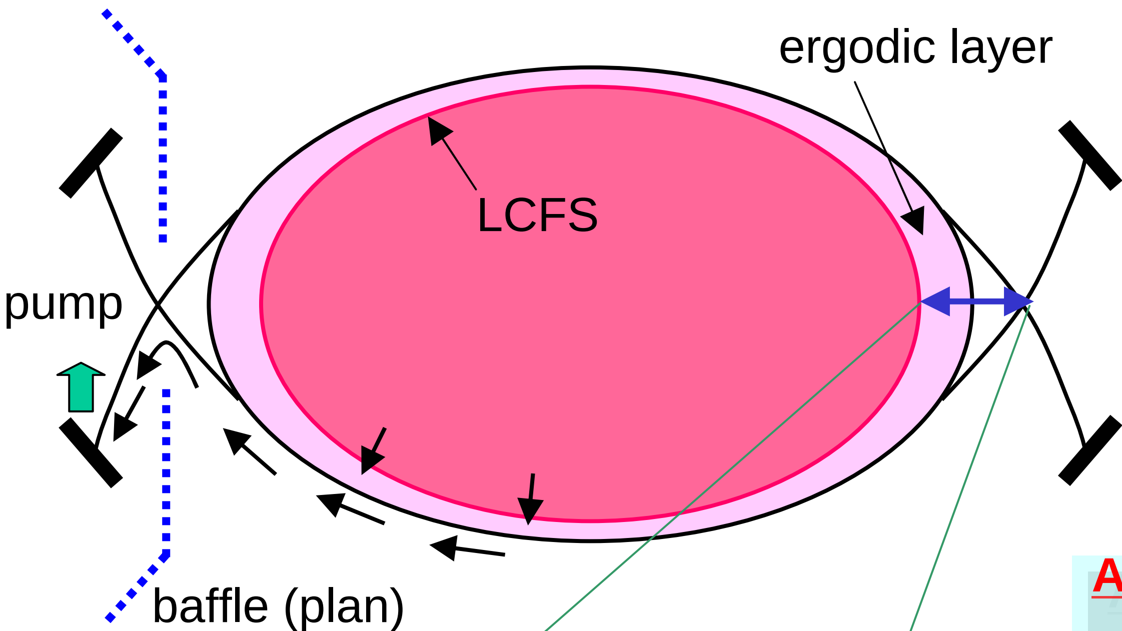


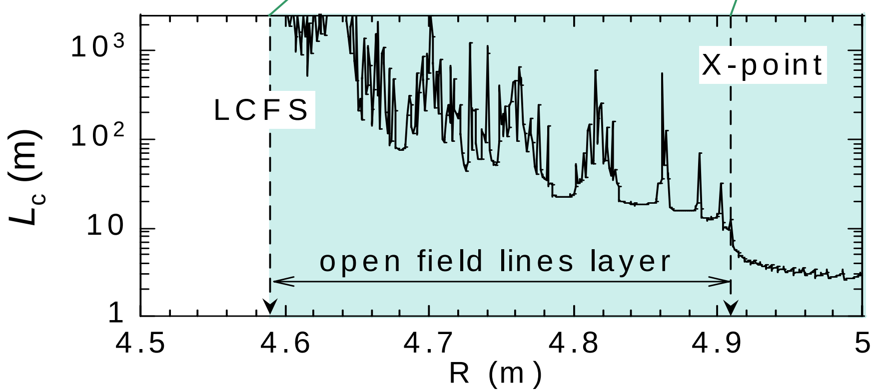
May 14, 2004




| | |
|---|---|
| Plasma Major radius | 3.5 - 4.0 m |
| Plasma Minor radius | ~ 0.6 m (average) |
| Plasma Volume | ~ 30 $m^3$ |
| | |
| Coil minor radius | 0.975 m |
| Magnetic field | 2.893 T (at $R_{ax}$=3.6m) |
| | |
| Heating power | |
| ECH | 1.2 MW |
| N-NBI | 10 MW |
| ICRF | 3.0 MW |

# Helical Divertor (HD)




## Feature

**Intrinsic double-null** type divertor
- * long legs.
- * short field lines (2-3m in LHD).

**Nonaxisymmetric** magnetic field
- * 3-d structure.

**Ergodic layer** surrounding core
- * thick (~ 30cm in LHD) .
- * no clear separatrix.
- * long $L_c$ (several 100m in LHD) .

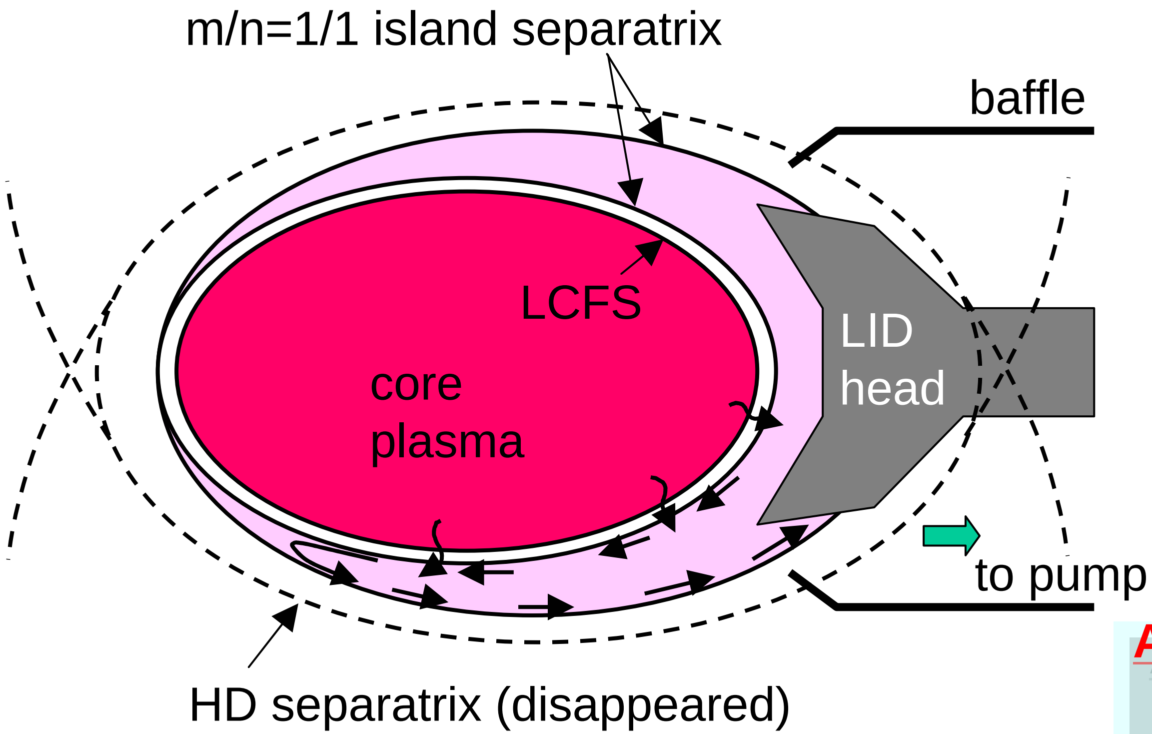
## Advantage

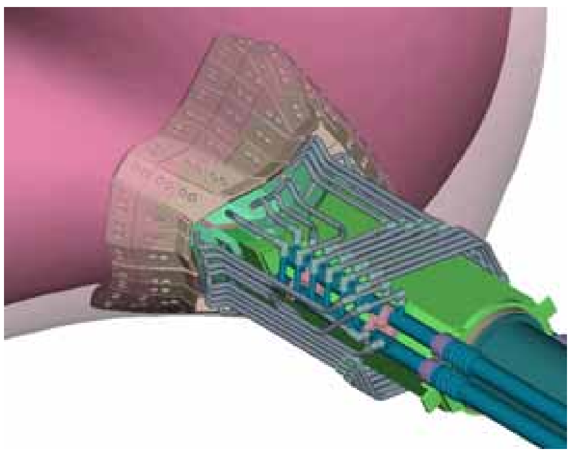
* relatively wide wetted area.
  --> *favorable for heat removal.*
* long distance from target to core.
  --> *favorable for impurity screening.*

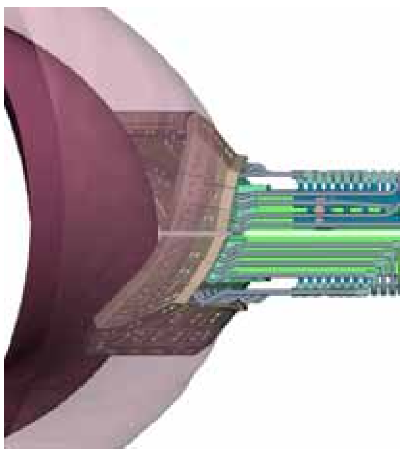
## Disadvantage

* complicated.
  --> *inadequate for diagnostics, blanket.*
* difficult to construct (3D).
  --> *high cost.*

# Local Island Divertor (LID)





**Features**

* Utilize m/n=1/1 island.
* Insert a divertor head locally.
* LCFS defined by island separatrix.
* No leading edge problem.
* Closed system.
* High efficient pumping.
* No ergodic layer.
* $L_c$=~250m.

**Advantage**

* high efficient pumping.
* easy to realize closed system.
  --> *superior cost performance.*
* compact and integrated
  --> *favorable for blanket, diagnostics.*

**Disadvantage**

* small wetted area.
  --> *high heat load.*

# LHD Divertor strategy

Active edge control by LID.

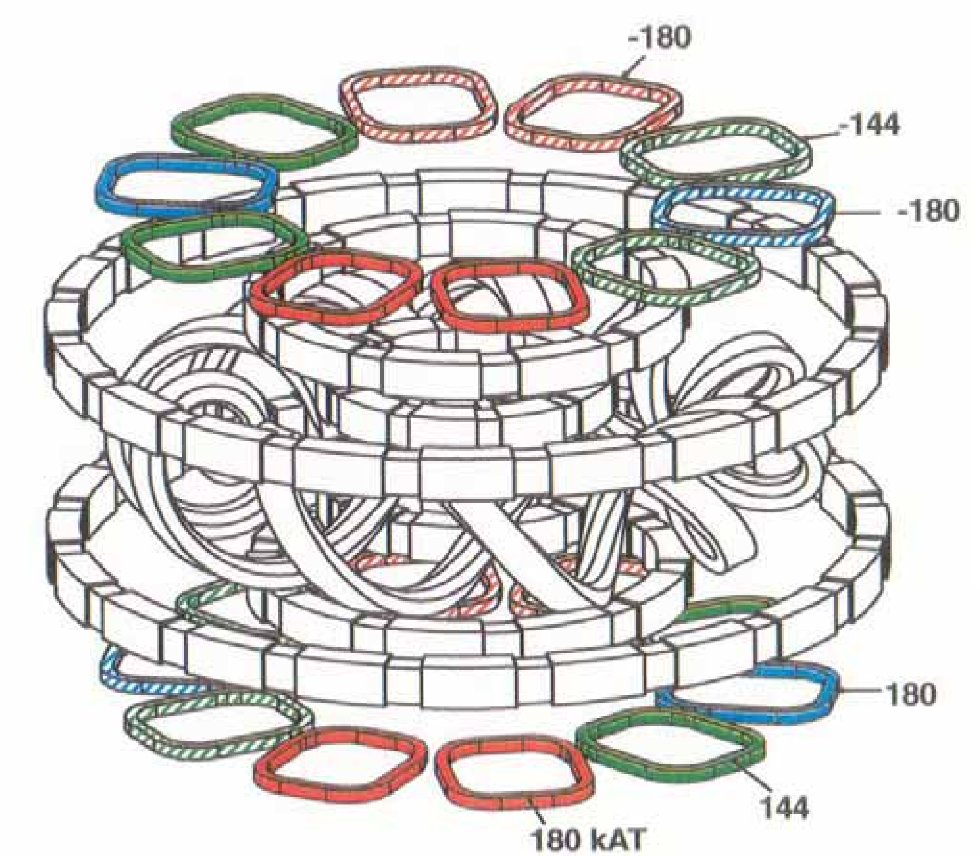
↓

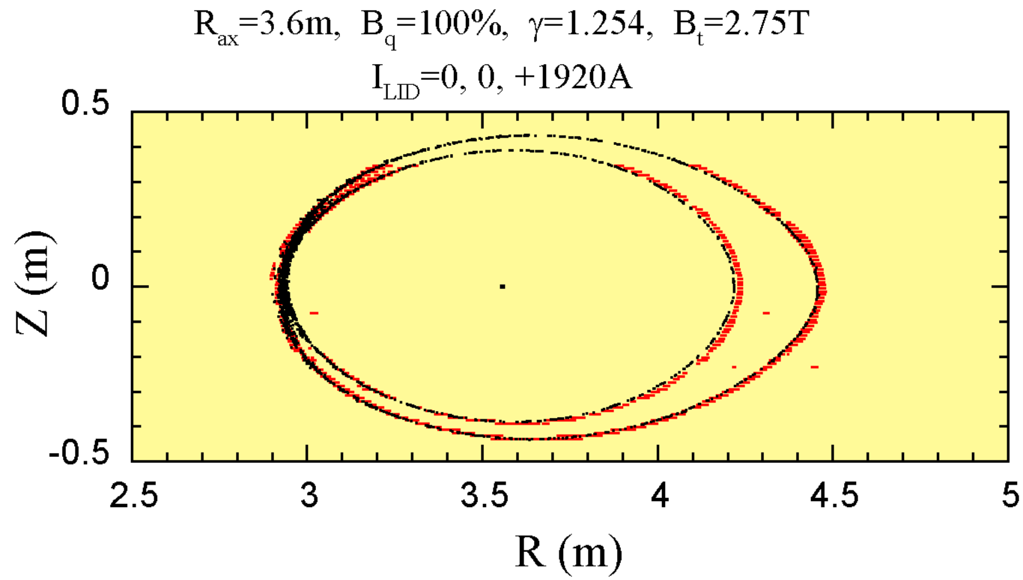
Steep $T_e$ and $n_e$ gradient.

↓

**Confinement improvement.**

# Perturbation coils




**m/n = 1/1 island**

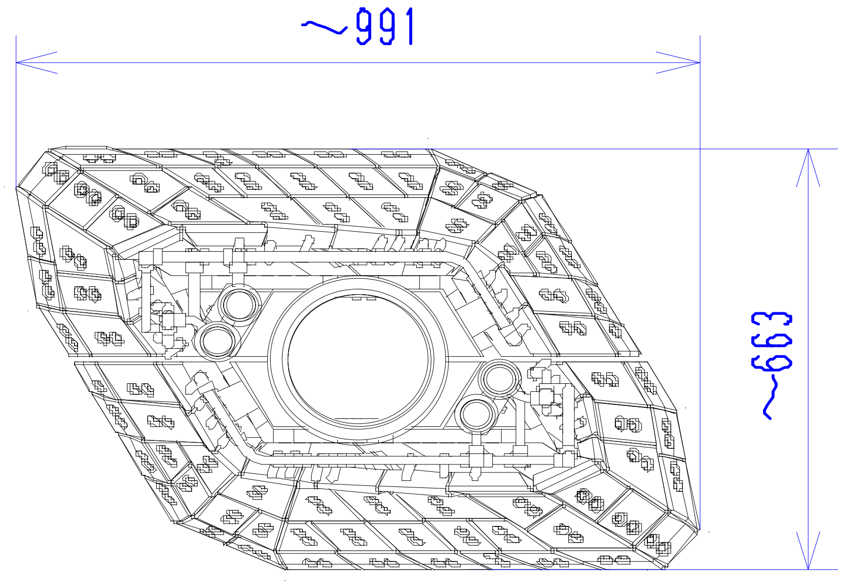
* surely exists as expected (calculation).

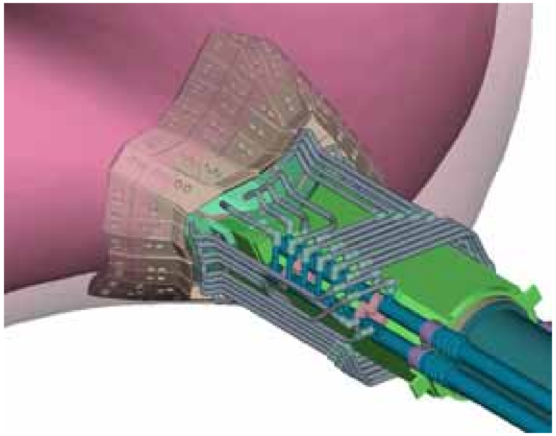
* confirmed by flux surface mapping with electron beam and probe.

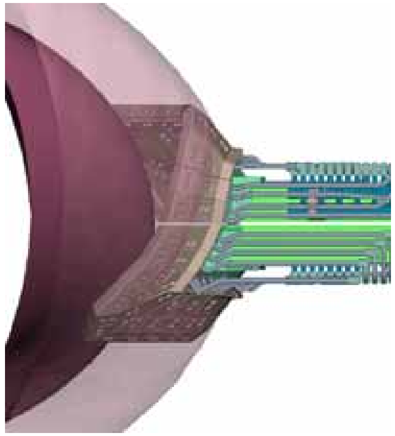
**10 pairs of normal conductor coils**

for m/n=1/1 island generation

# Divertor head





**Divertor head**

water cooled heat sink (stainless steel)

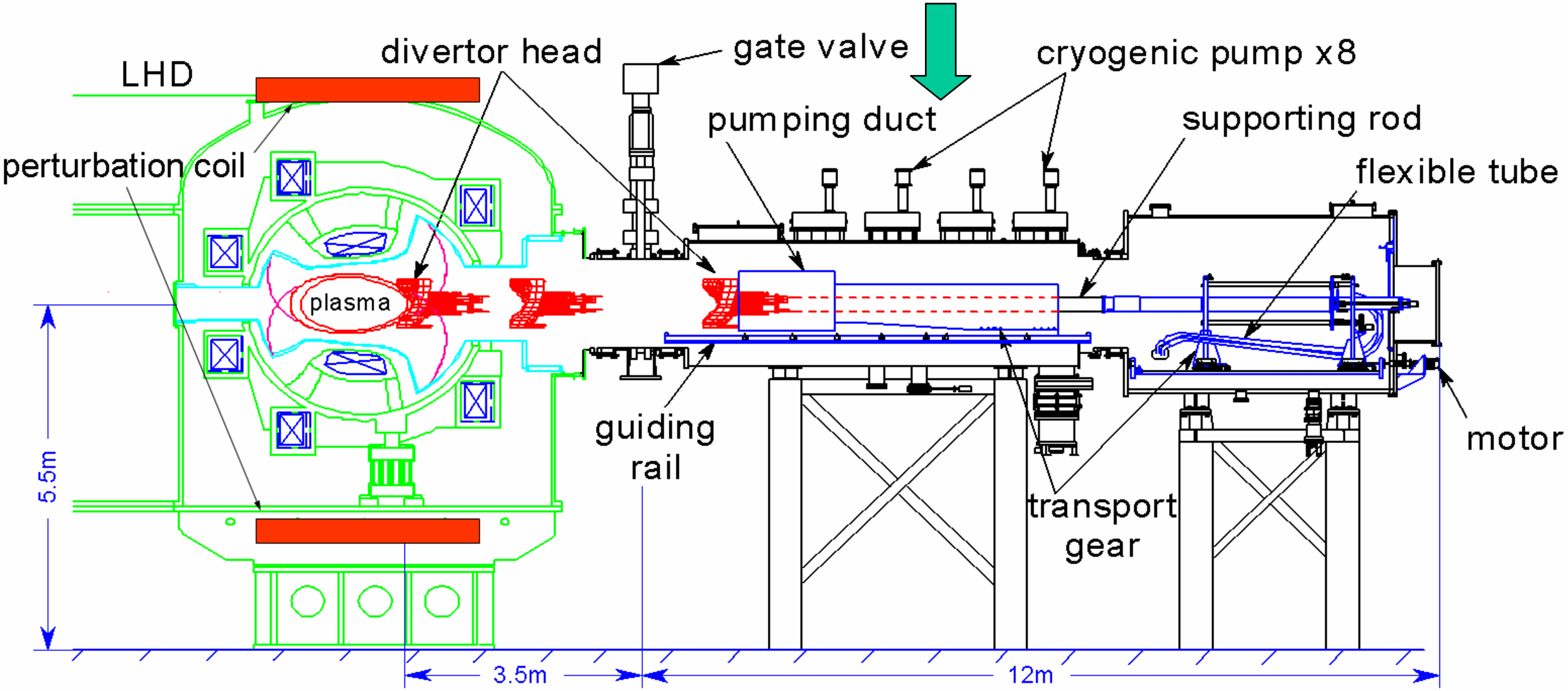
covered with carbon tiles.

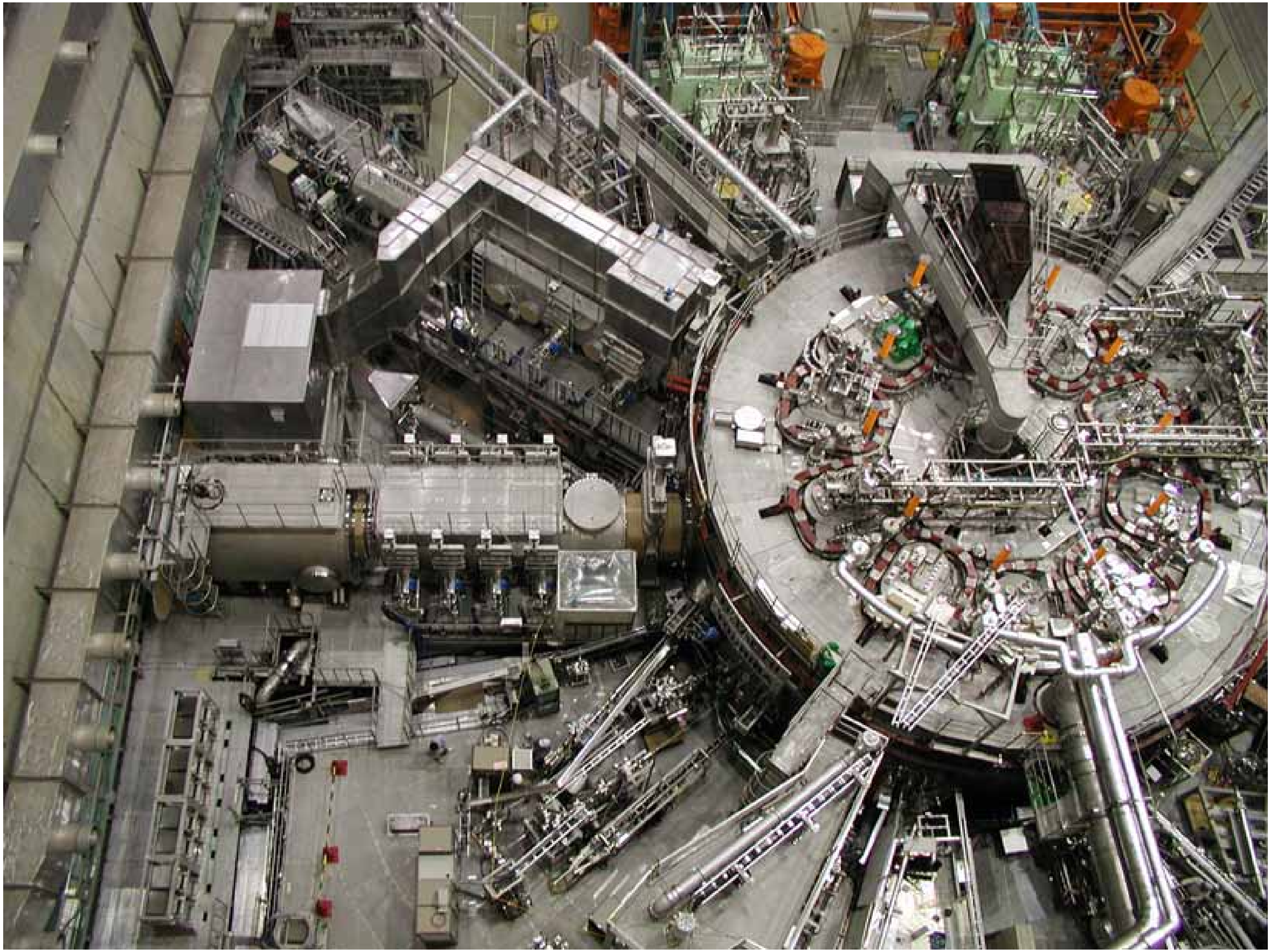
*P* < 7.5 MW/m2  (5s).

# Schematic of LID system

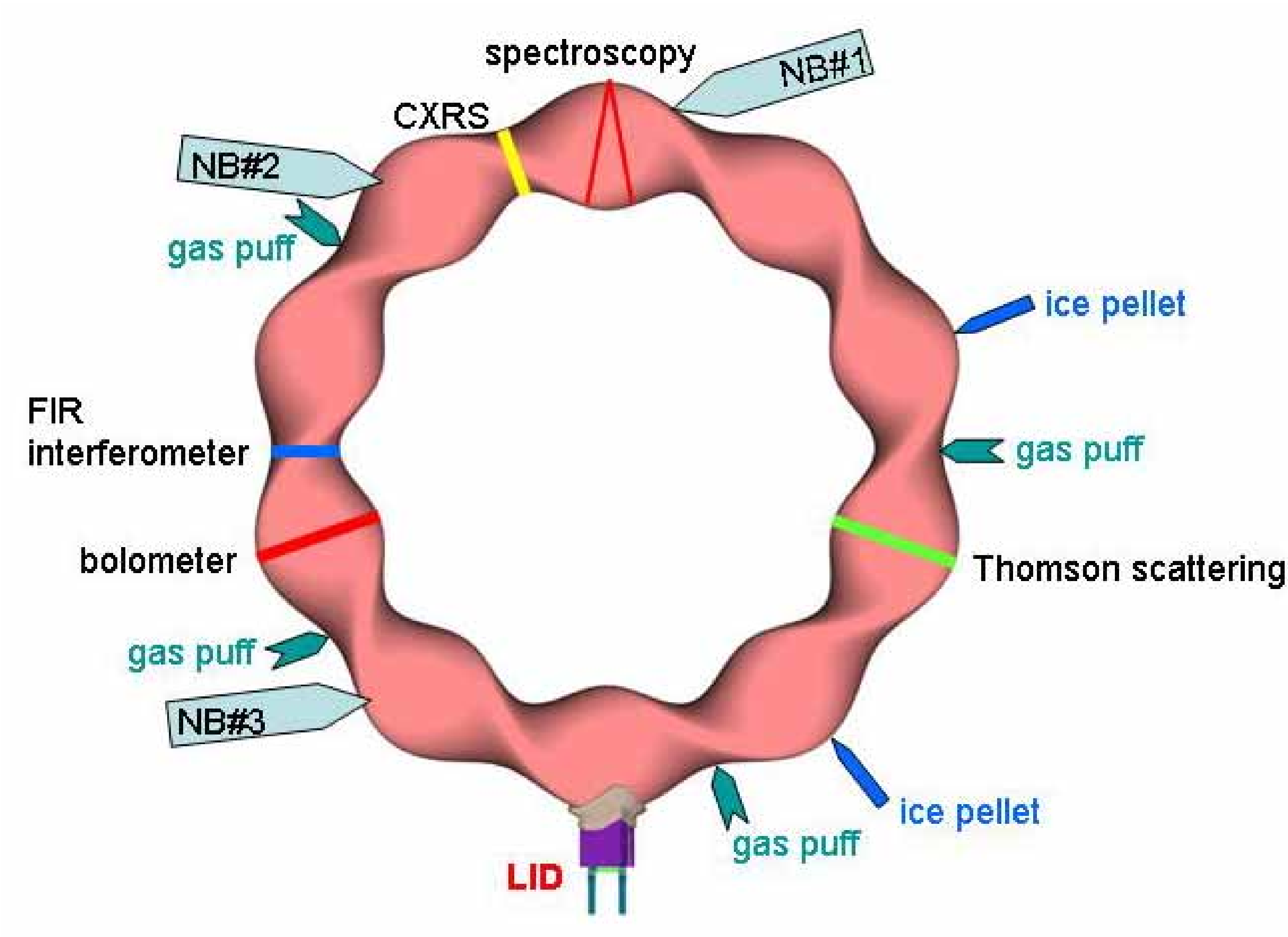
**Pumping system**

* 8 cryogenic pumps ($42 m^3/s$ each).
* effective pumping speed ~ $100 m^3/s$.

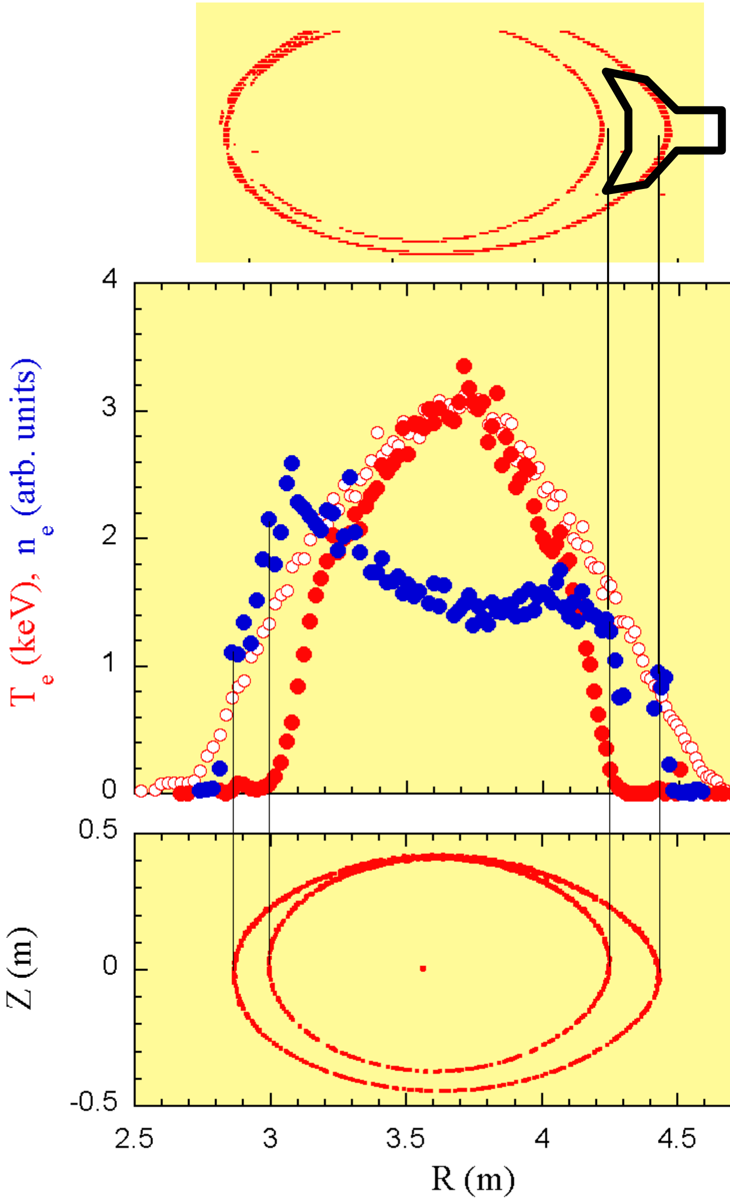




# Experimental setup



# $T_e$ profile and separatrix position




**In LID configuration,**

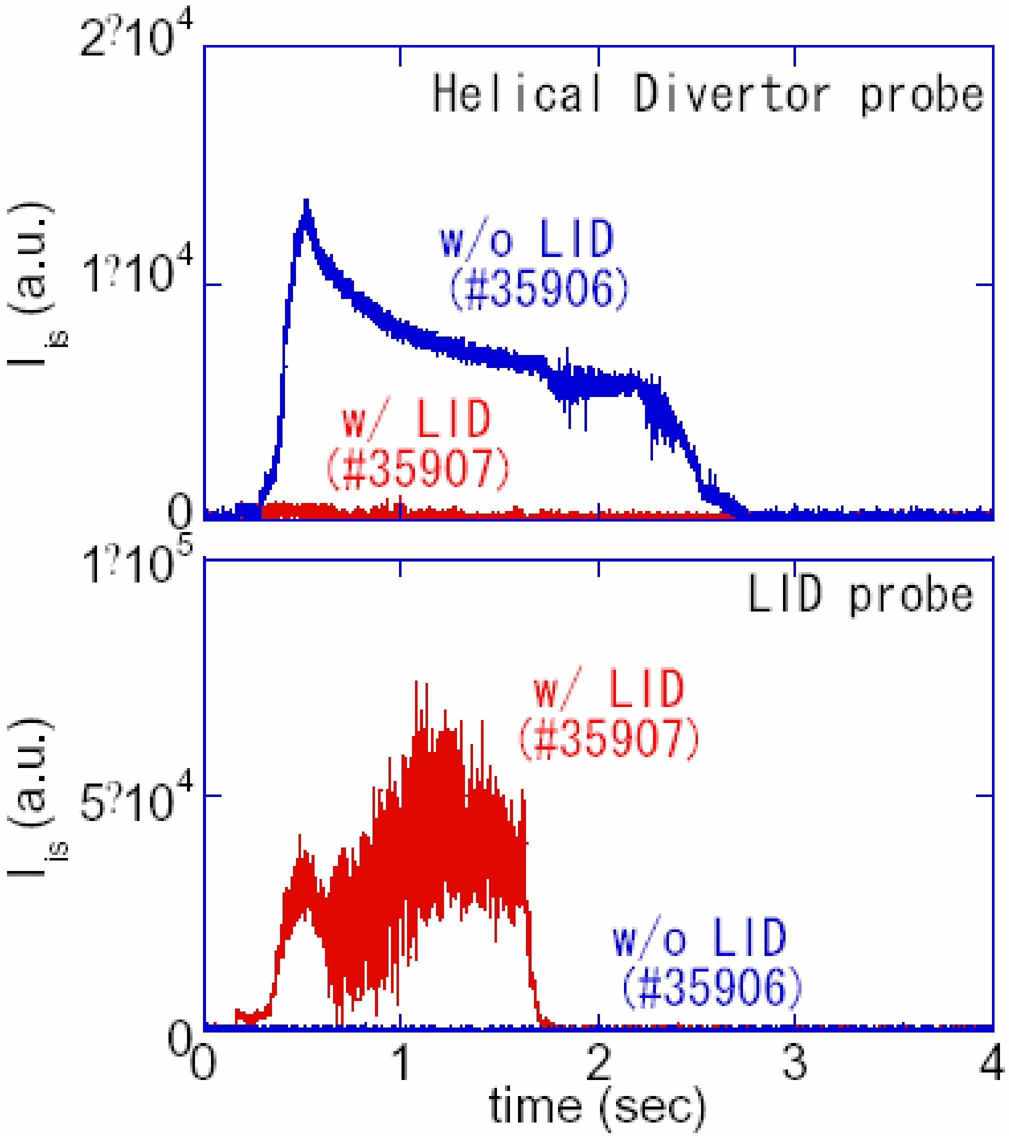
- no ergodic layer.
- volume is reduced at 60%.
- steep $T_e$ gradient.
- while $n_e$ bounary is unclear.

  ---> because of long $L_c$ ?

* LID functions as a divertor.

--> because divertor head does not touch the core plasma.

# Particle flux to the LID head and helical divertor




* **w/o** LID (open helical divertor)

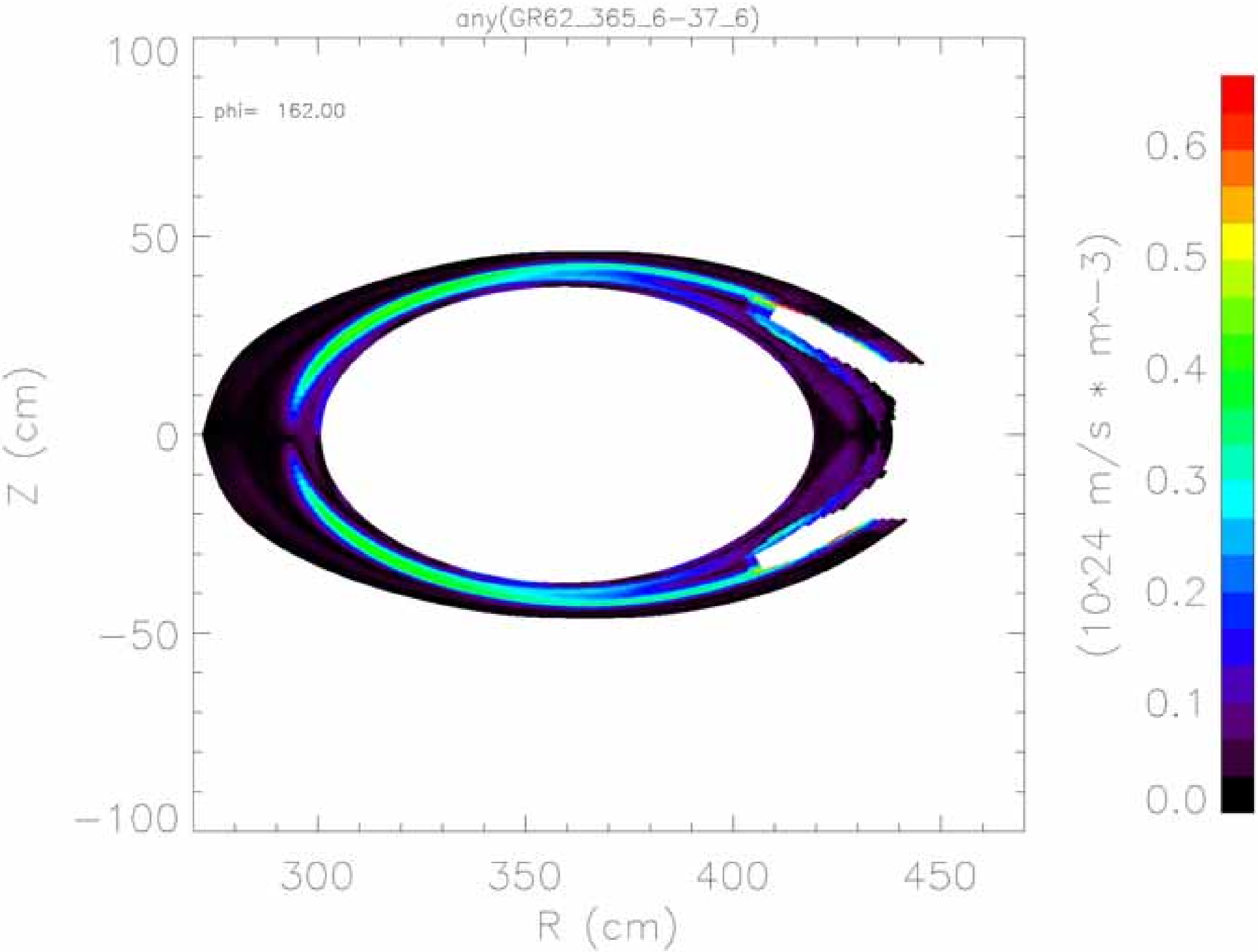
particle flux → helical divertor

* **w/** LID (closed island divertor)

particle flux → LID head

→ helical divertor ~0

# Plasma flow predicted by EMC3-EIRENE




Parallel flow established.

(as expected)

- along separatrix of island
- to LID head (back side)

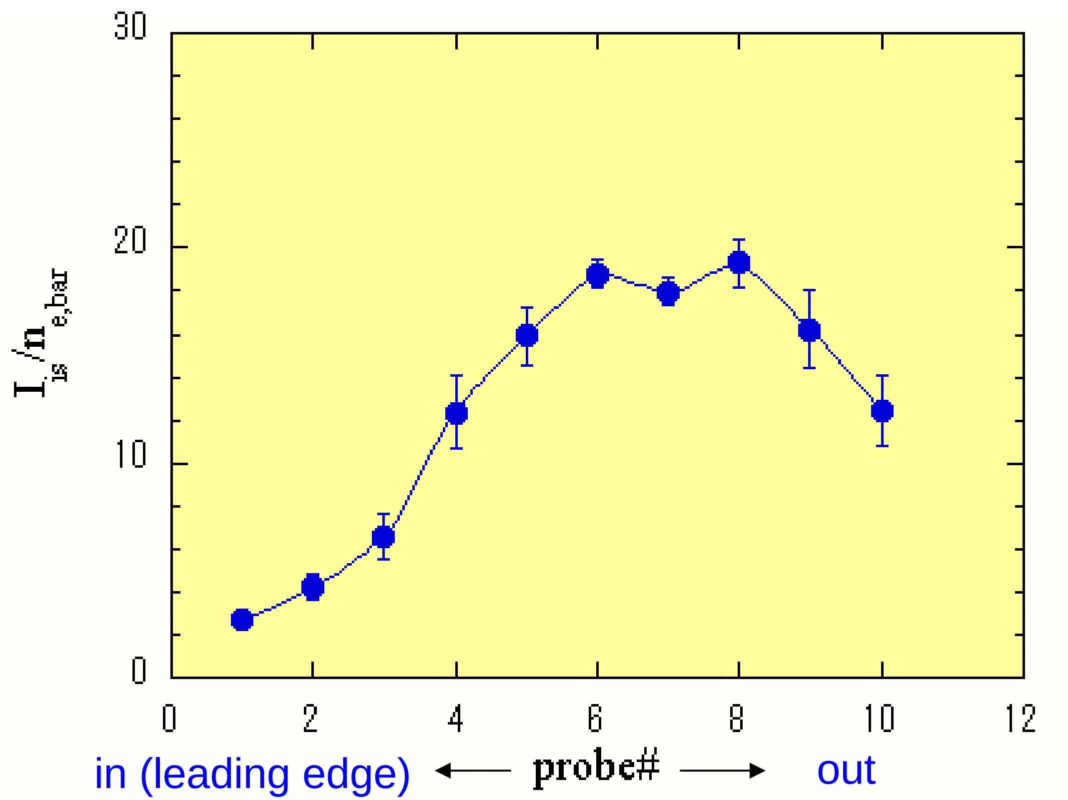
Unfavorable flow

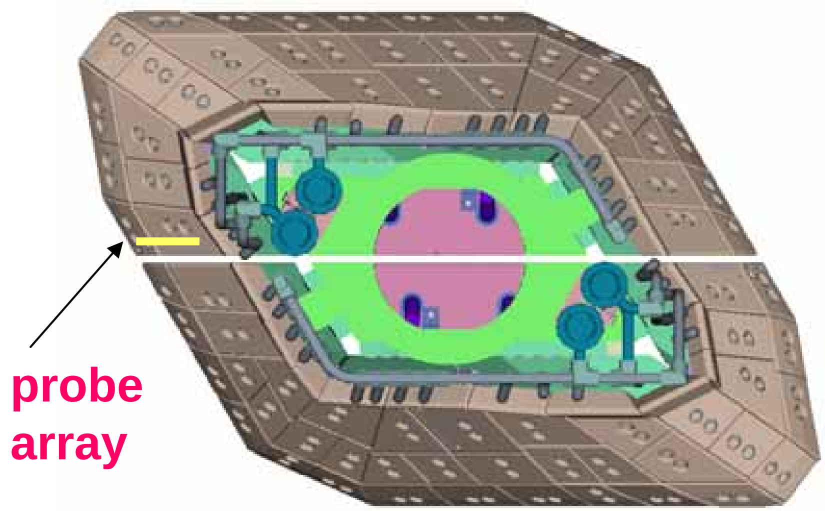
- to leading edge
- to front side of LID head.

--> hot spot

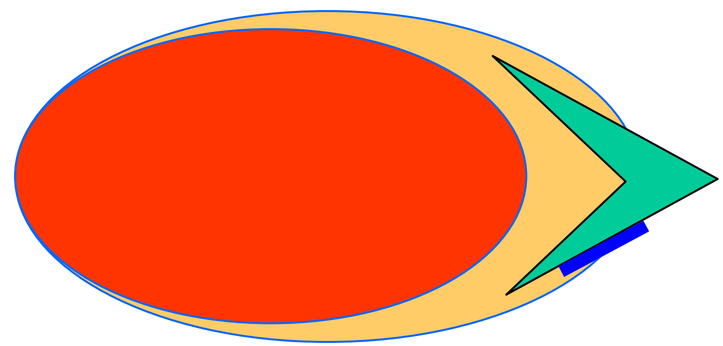
# Particle flux profile on the LID head

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



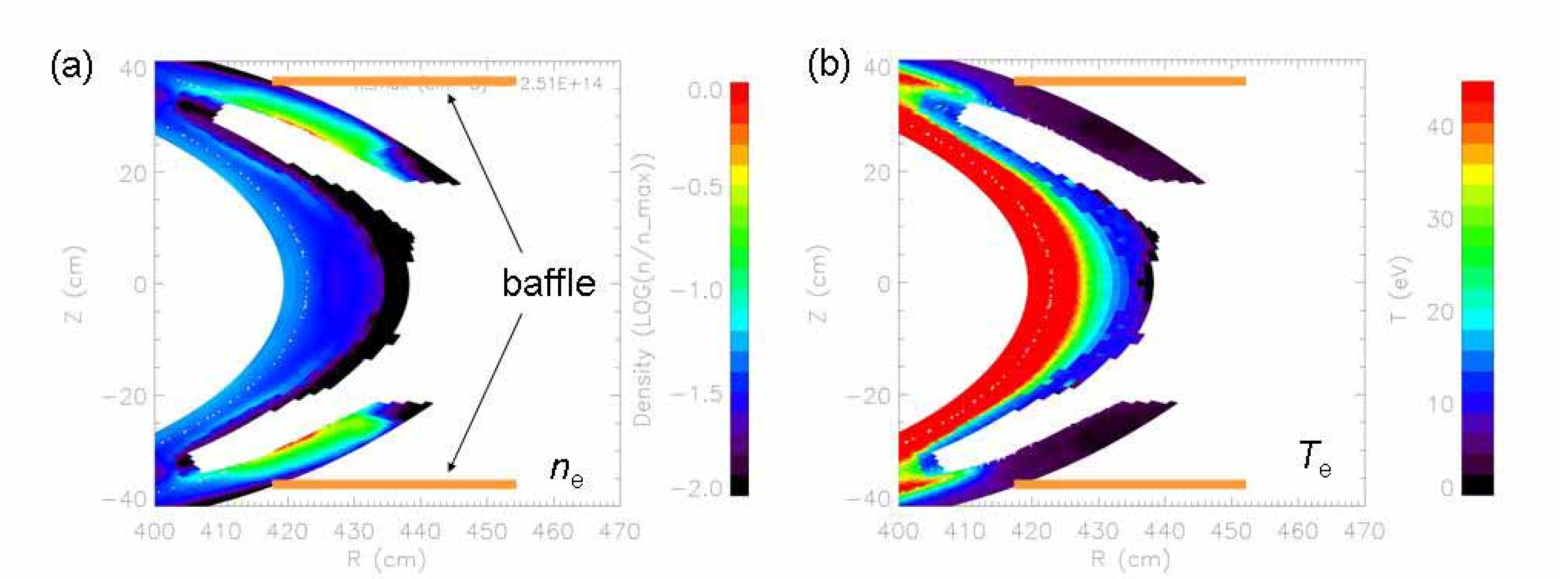

backside view



* At the appropriate position,

particle flux has its peak avoiding the leading edge.

# $T_e$ and $n_e$ profile predicted by EMC3-EIRENE



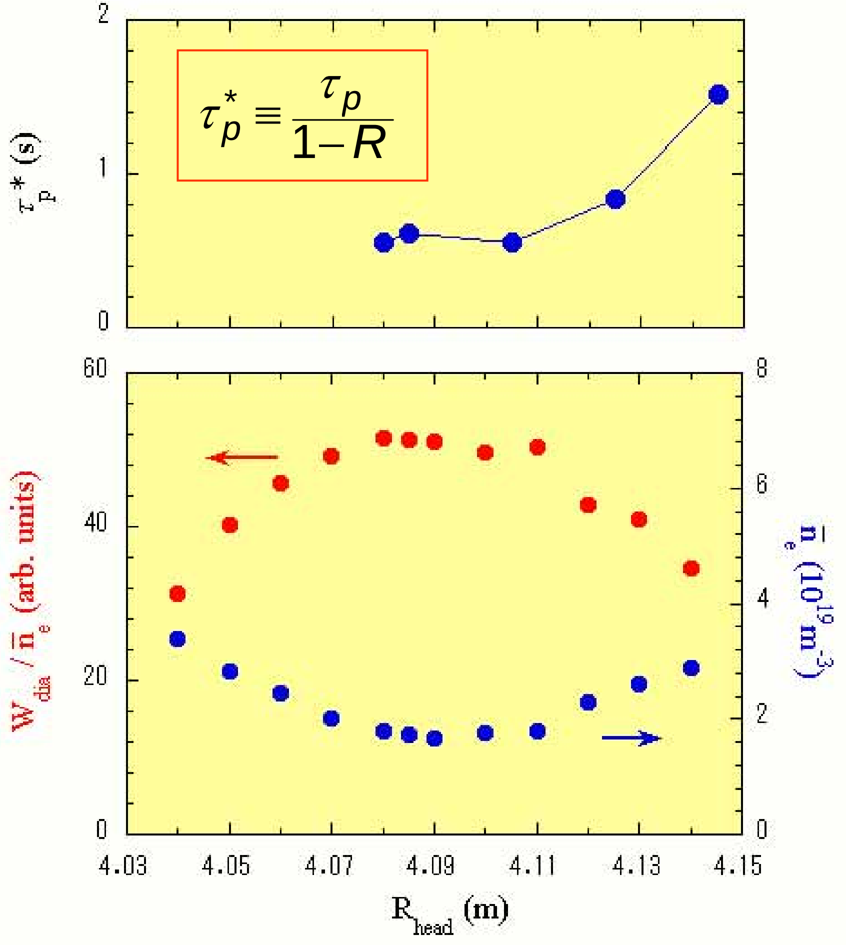

* Prallel flow along the island separatrix.

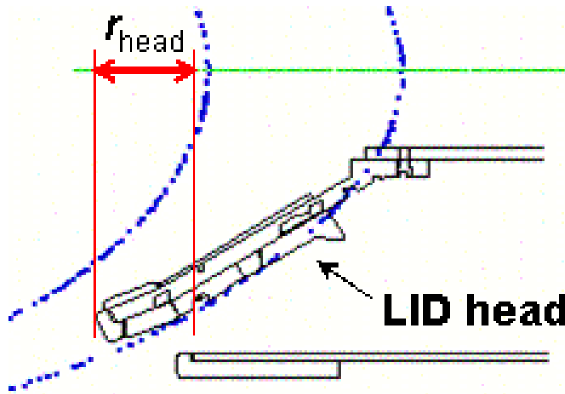
* Highest density at outer island separatrix.

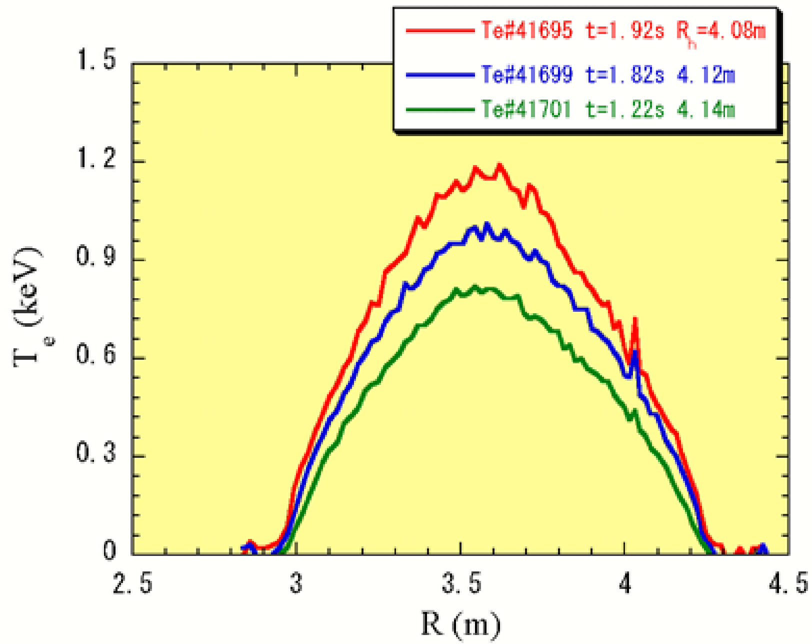
* High $n_e$ low $T_e$ plasma around LID head.

  ---> high recycling

# Pumping efficiency (head position dependence)

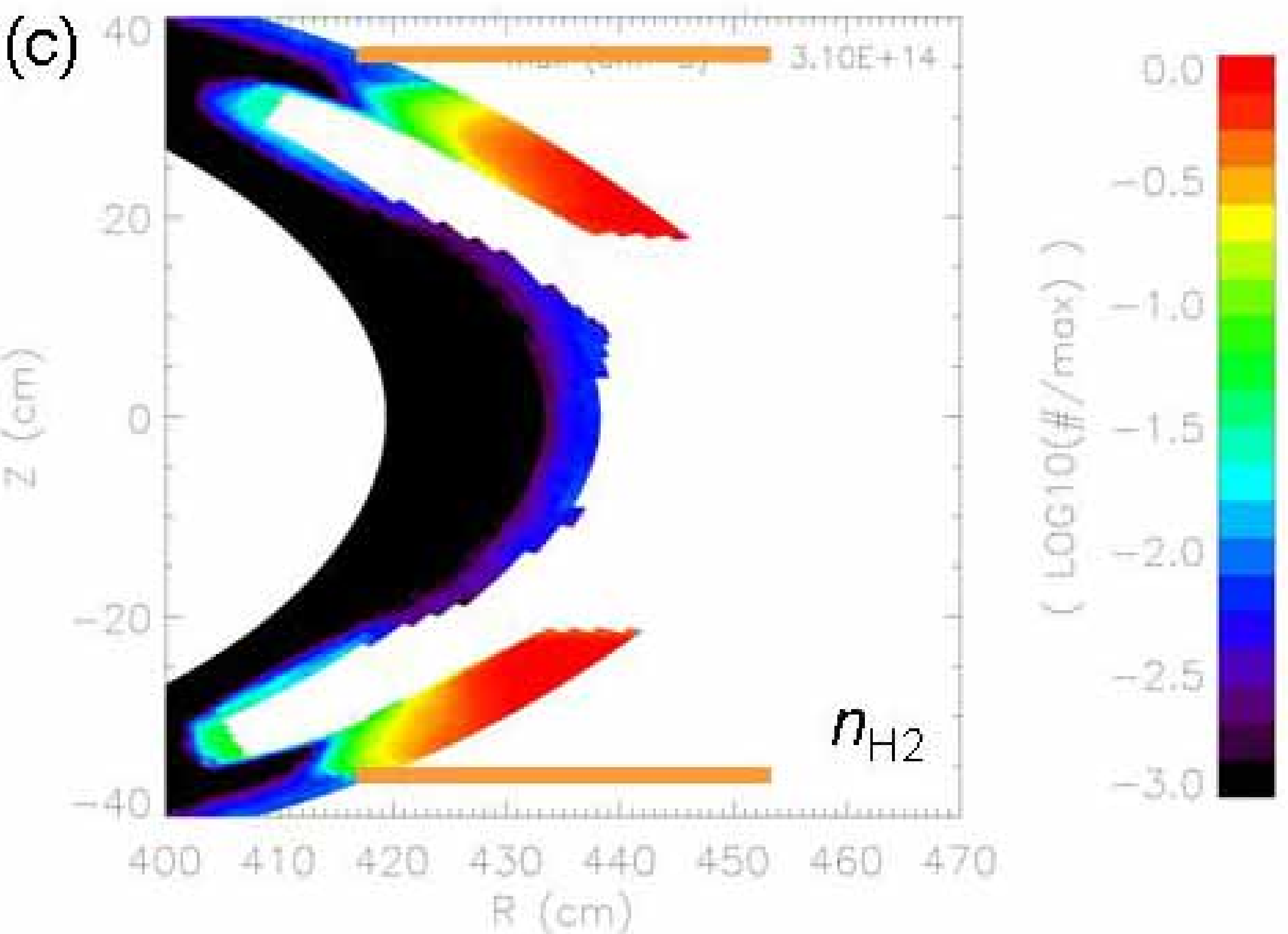



* gas puffing rate=const.,
* slit size=8cm (const.).
* $n_e$_bar is minimum at $R$_head=4.08〜4.09m
--> Max. pumping efficiency

# $H_2$ density predicted by EMC3-EIRENE




* High particle flux.

* Closed system.

↓

High neutral confinement property ($3 \times 10^{21}\ m^{-3}$)

↓

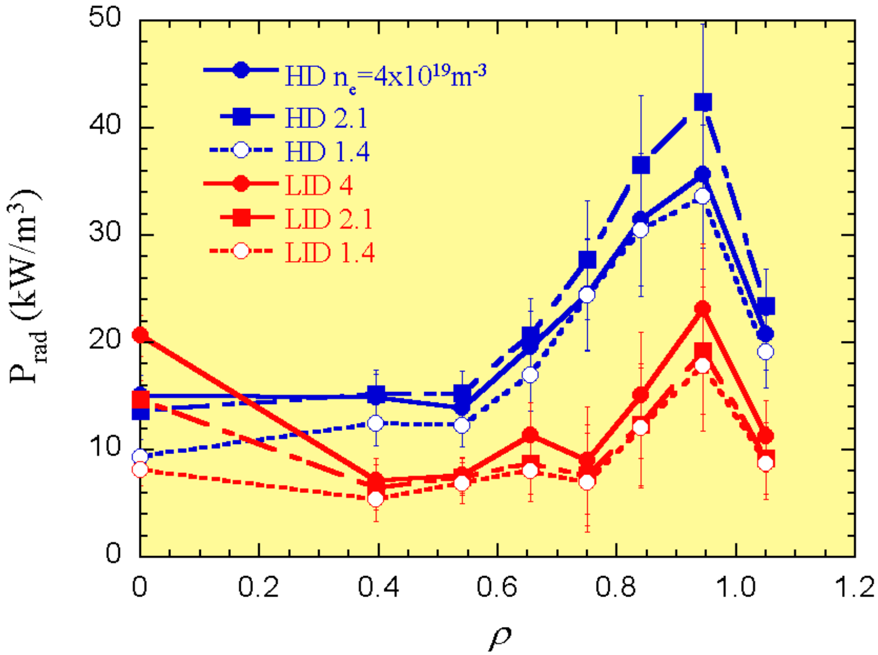
* High recycling.

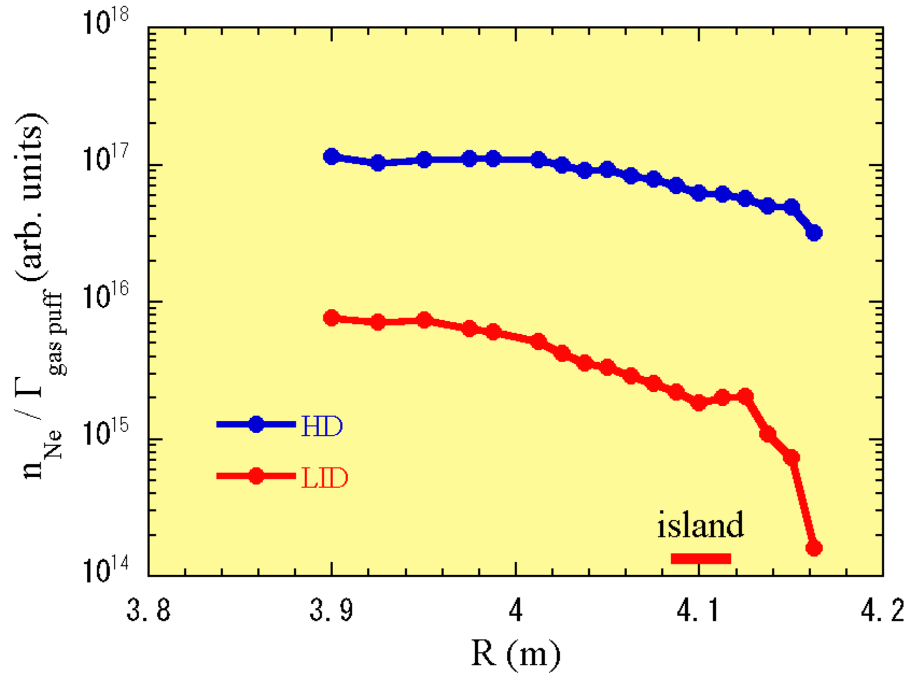
* High density.

↓

* Detachment ?

# Screening / pump out effect of LID on impurities




In LID configuration,

* $P_{rad}$ is localized in island.
  --> accumulation at island ?
* $P_{rad}$ is low in confinement region.
  --> lead to steep $T_e$ ?
* $P_{rad}$ at center increases as $n_e$.
  --> due to metallic impurity from LHD head.
  --> lead to degradation in $T_e$ gradient.

* Ne is injected by gas puffing.

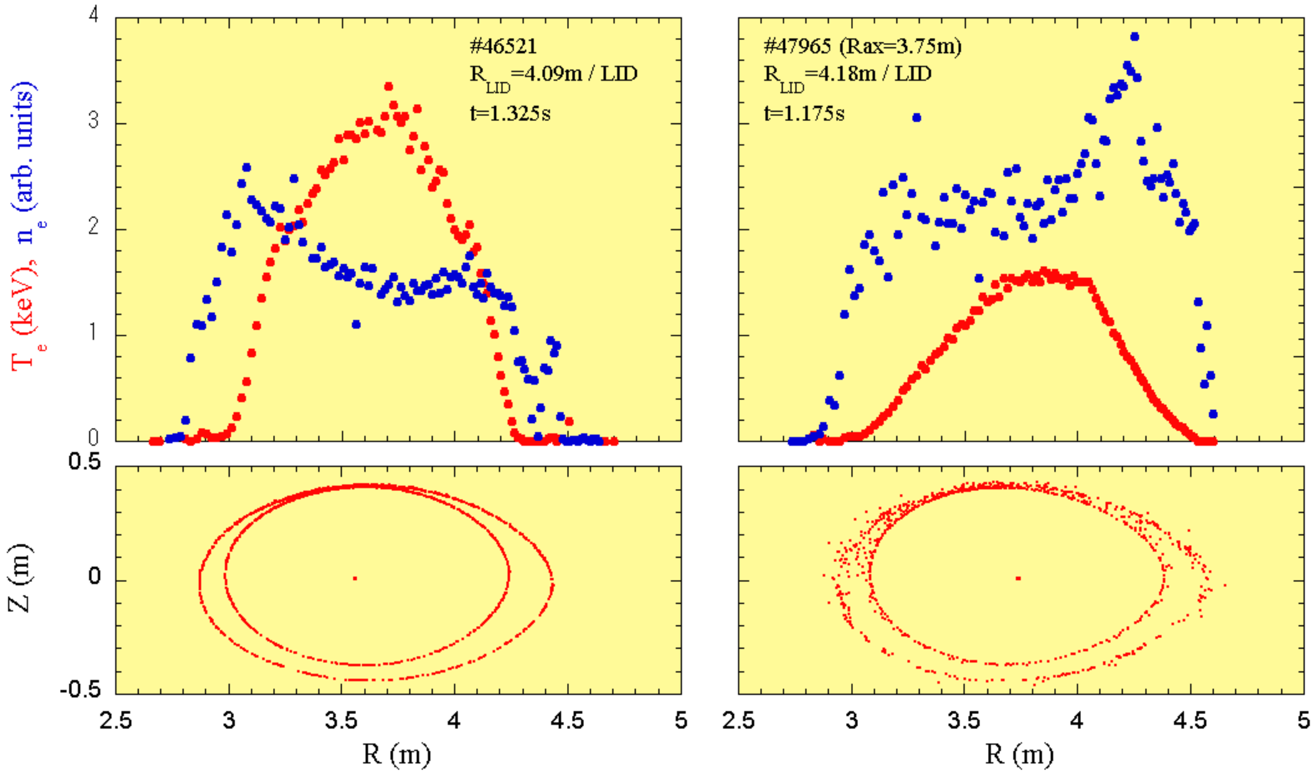
$\Gamma_{gas\ puff}$ = 3.26 Pa m$^3$/s (HD)
= 34.7 Pa m$^3$/s (LID)

* $n_{Ne}$ profiles are measured with CXRS.

Low Impurity density in LID

--> impurity screenig

# New outward shifted magnetic configuration ($R_{ax}$=3.75m)




**In $R_{ax}$=3.75m configuration,**

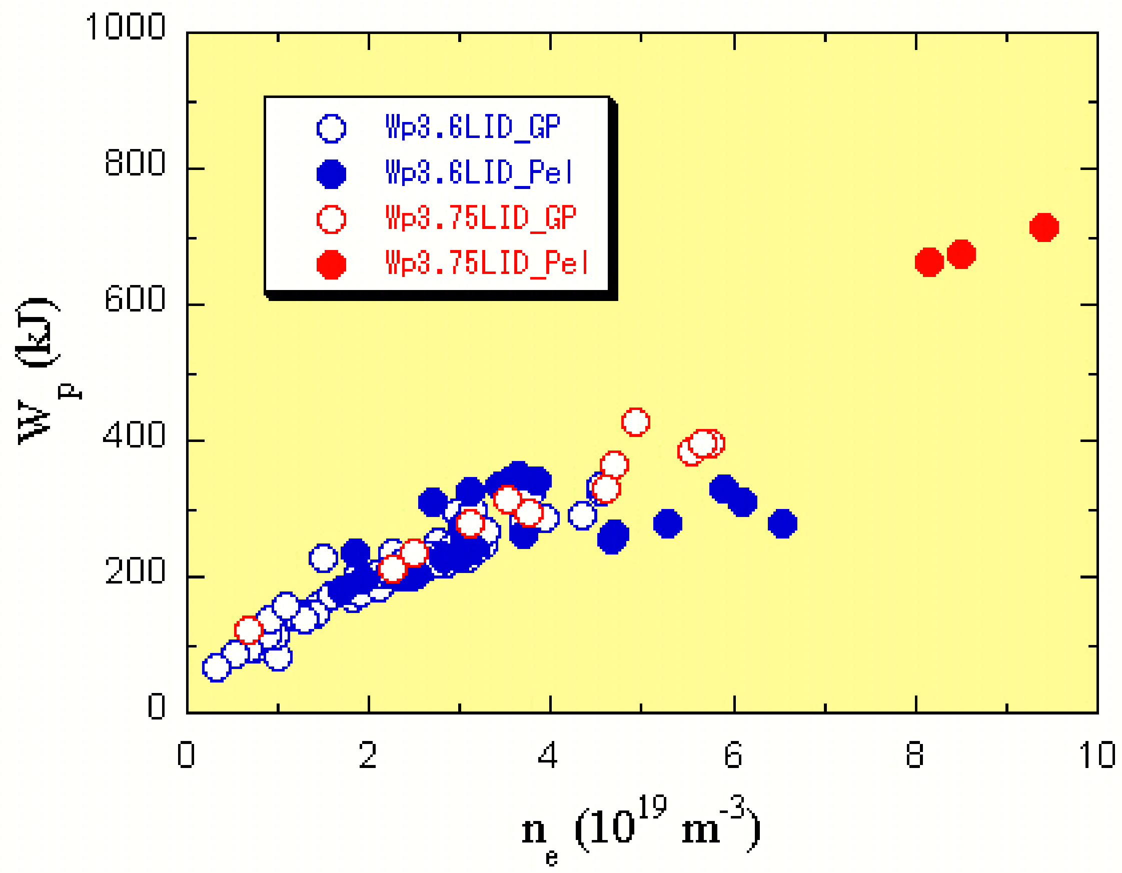
* Confinement volume is almost the same as $R_{ax}$=3.60m.

* Foot positions of $T_e$ and $n_e$ are close (--> SOL is wide).

--> *due to* the stronger ergodicity around the island ?

--> *due to* the different $L_c$ ?

# Parameter regime is extended



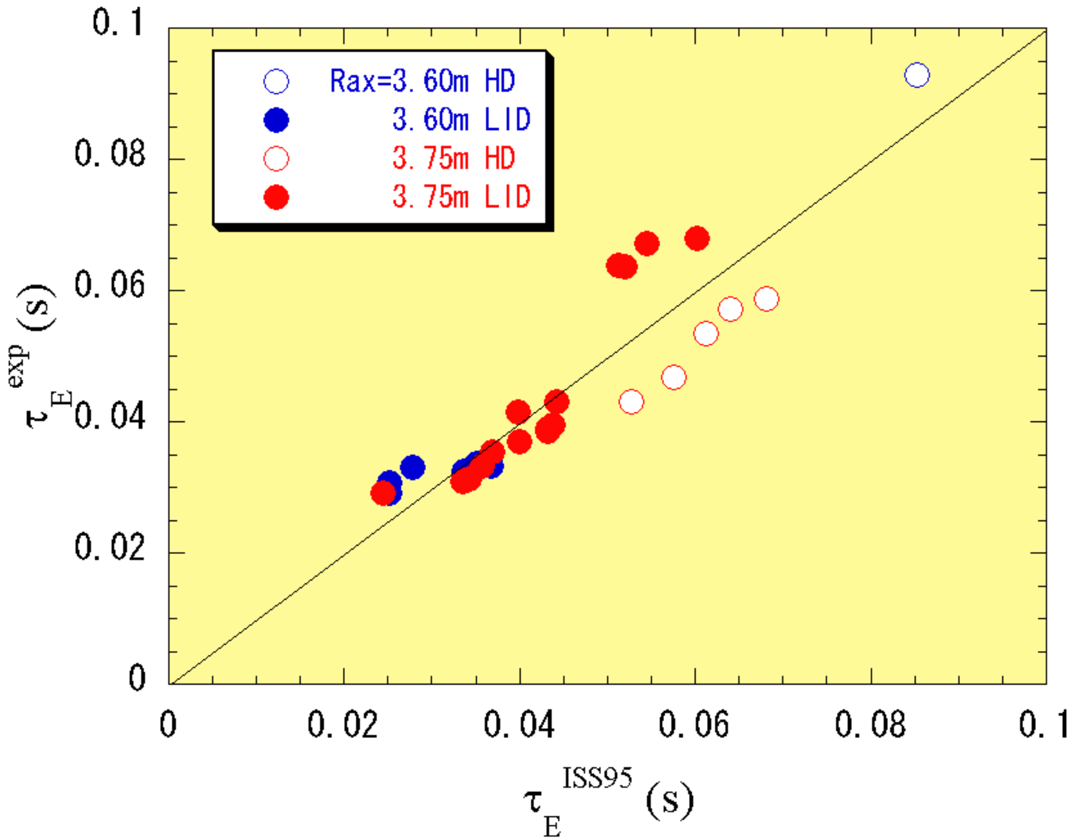

**In $R_{ax}$=3.75m configuration,**

* higher $n_e$ is achieved.

* $W_p$ ~ 757kJ (LID),

-- comparable to HD ---

# Outward shifted configuration

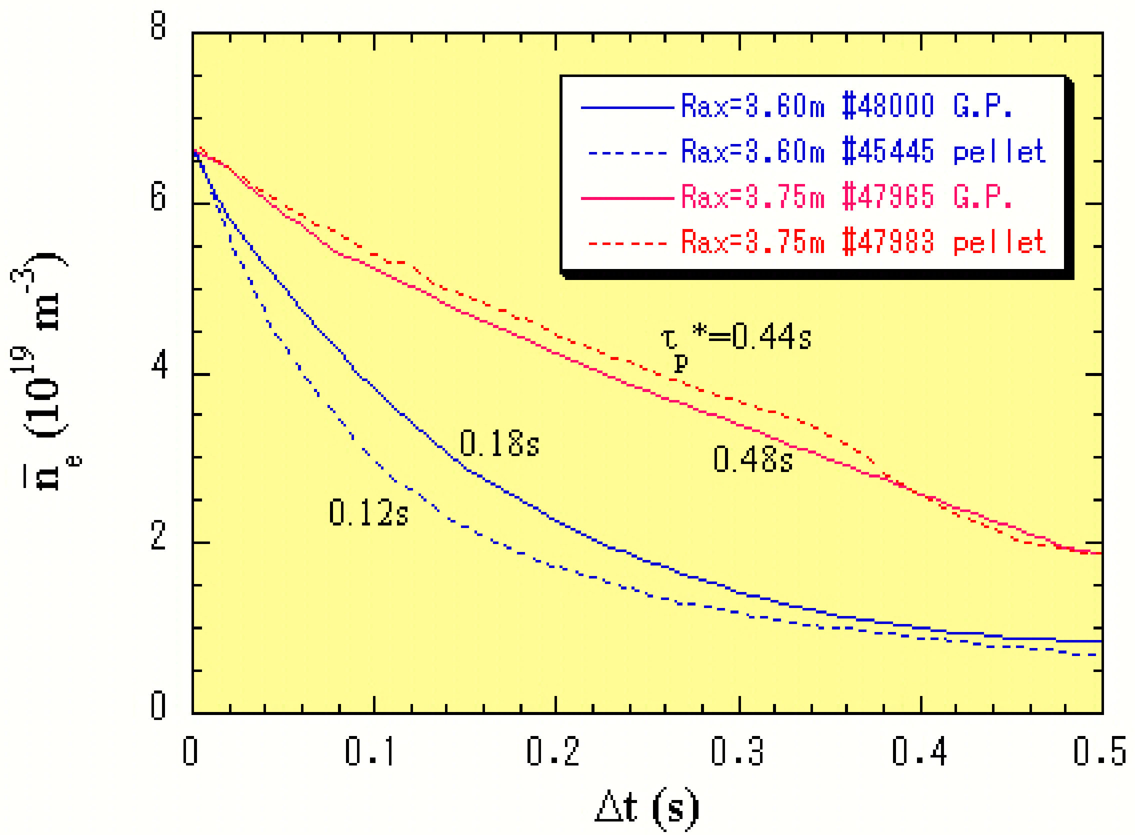



*** Energy confinement in LID**

confinement is improved in outward shifted configuration,

- which is superior to that in HD configuration.
- which is 1.2 times higher than that of ISS95 scaling.

# Density decay time in two configurations




In outward shifted configuration

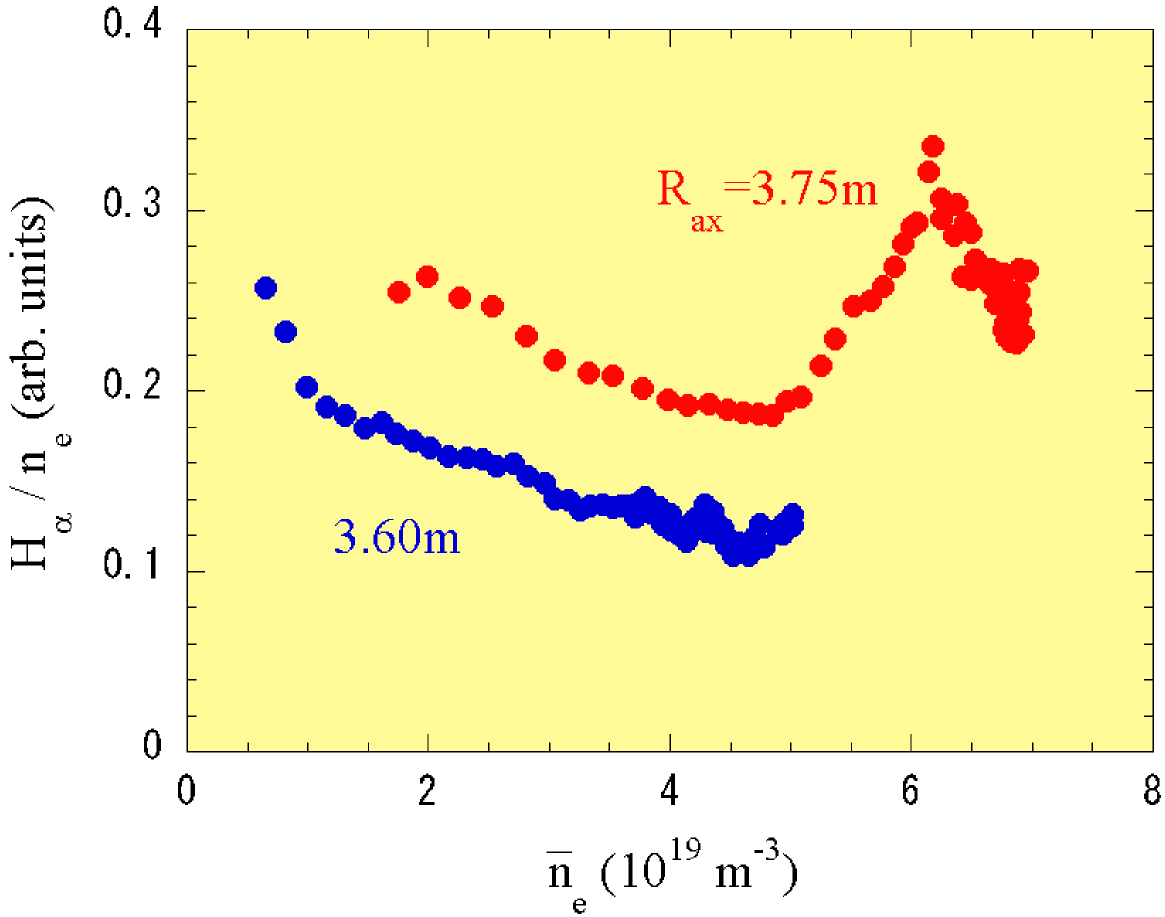
- ergodic
- unfitted LID head shape

* Degradation of collecting efficiency
* Unfavorable recycling is enhanced.

Long $\tau_p$*

No difference between gas puff and pellet

# Outward shifted configuration




In outward shifted configuration.

↓

High recycling.

↓

Fueling strongly increased.

↓

Good plasma performance

# Summary

1) Fundamental functions of LID were confirmed, that is,

* strong pumping effect,
* formation of the steep edge gradients,
* avoiding the leading edge problem.
* impurities (Ne) screening effect.

--> pump out effect ?

2) Confinement property in LID configuration

* follows the ISS95 scaling law.
* improves in the outward shifted configuration,

--> 1.2 times higher than that of ISS95.

--> due to the enhanced recycling particles ?

* ***efficient fueling leads to high confinement regime ?***

3) First results from EMC3-EIRENE

# Plans for next campaign

1) Control the $L_c$ to LID head.

   - by shifting $R_{ax}$.

   - by controlling the perturbation field strength.

2) Divertor gas puffing.

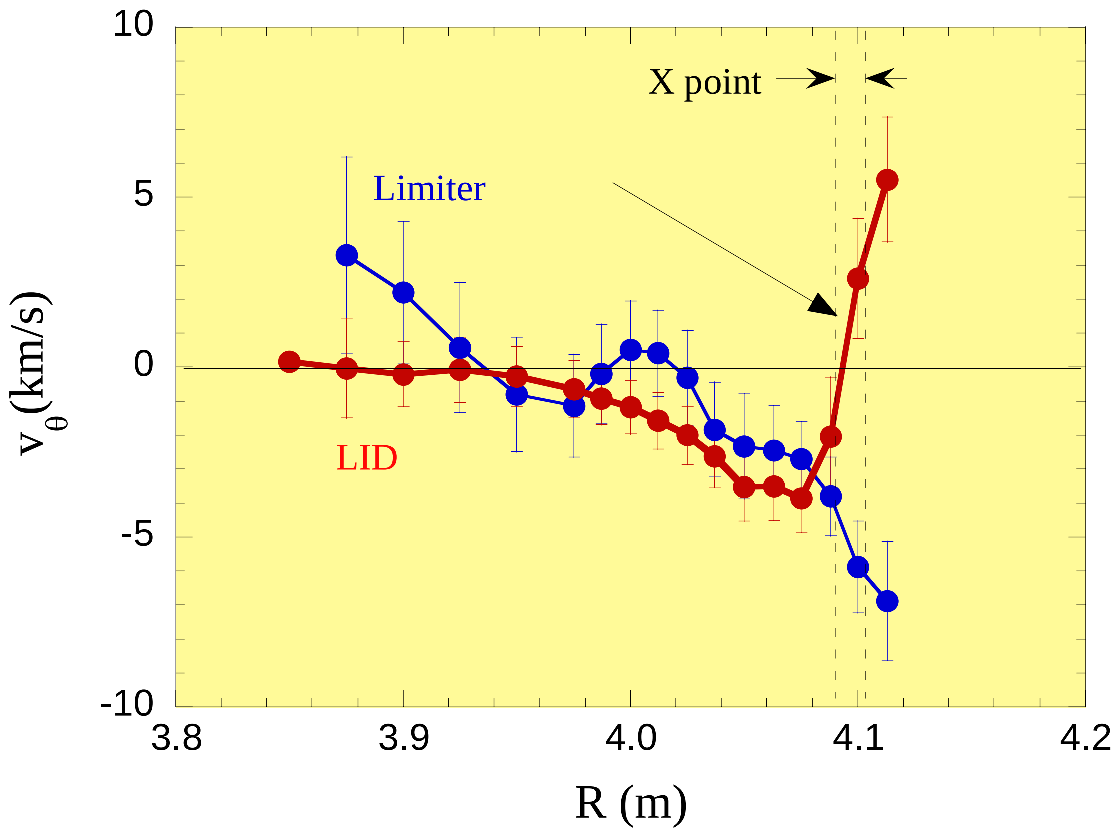
3) Potential control

4) Estimation of pumping efficiency

5) Analyses of impurity transport.

6) Edge modeling (EMC3-EIRENE)

# Radial electric field



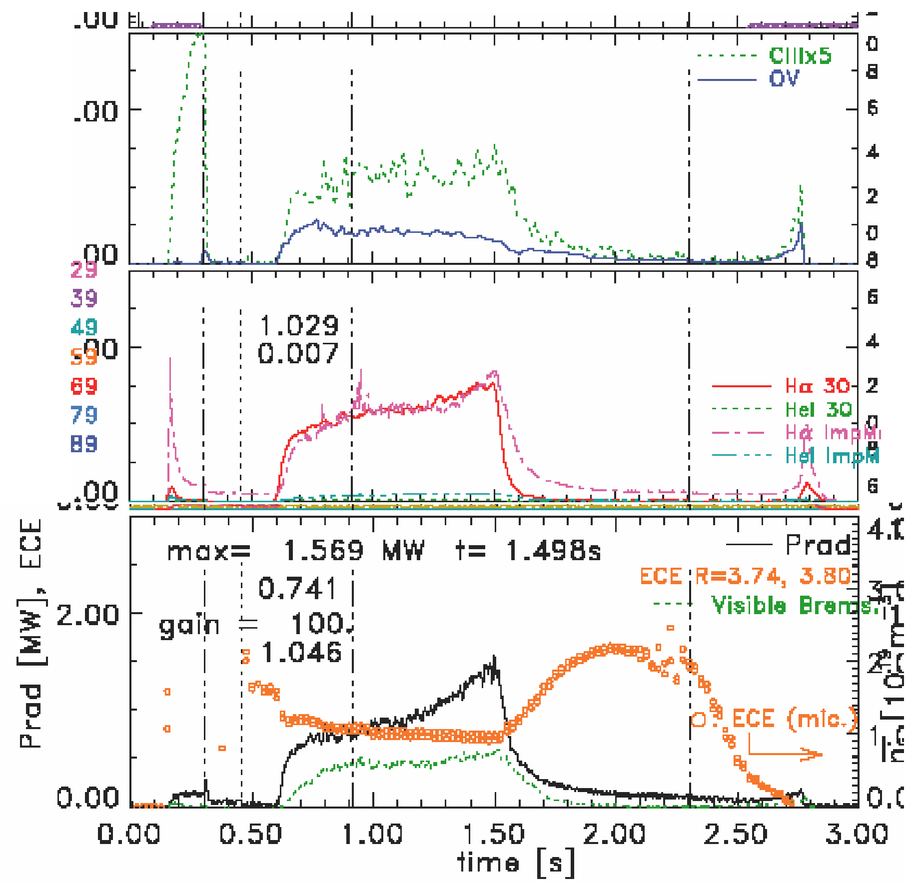

* Positive $E_r$ in the island region (LID).

* Negative $E_r$ (Limiter).

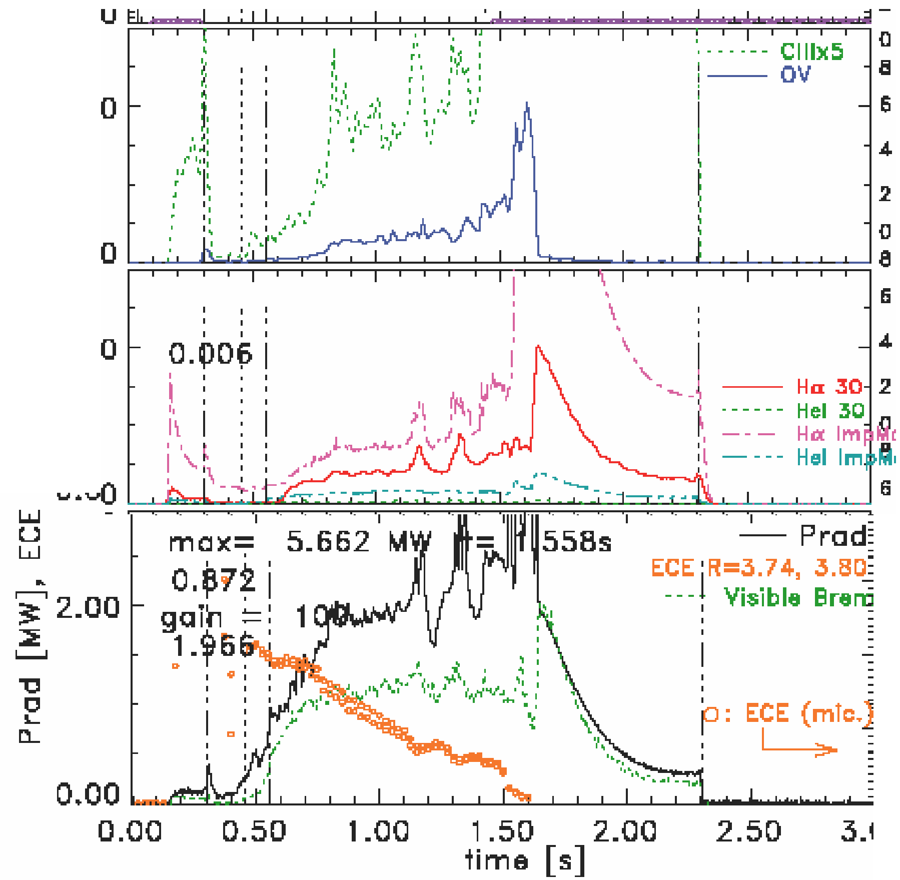
* Effect of $E_r$ on impurity behavior is unclear.

# Time behavior of impurity quantity, $P_{rad}$ and $T_{e0}$

LID



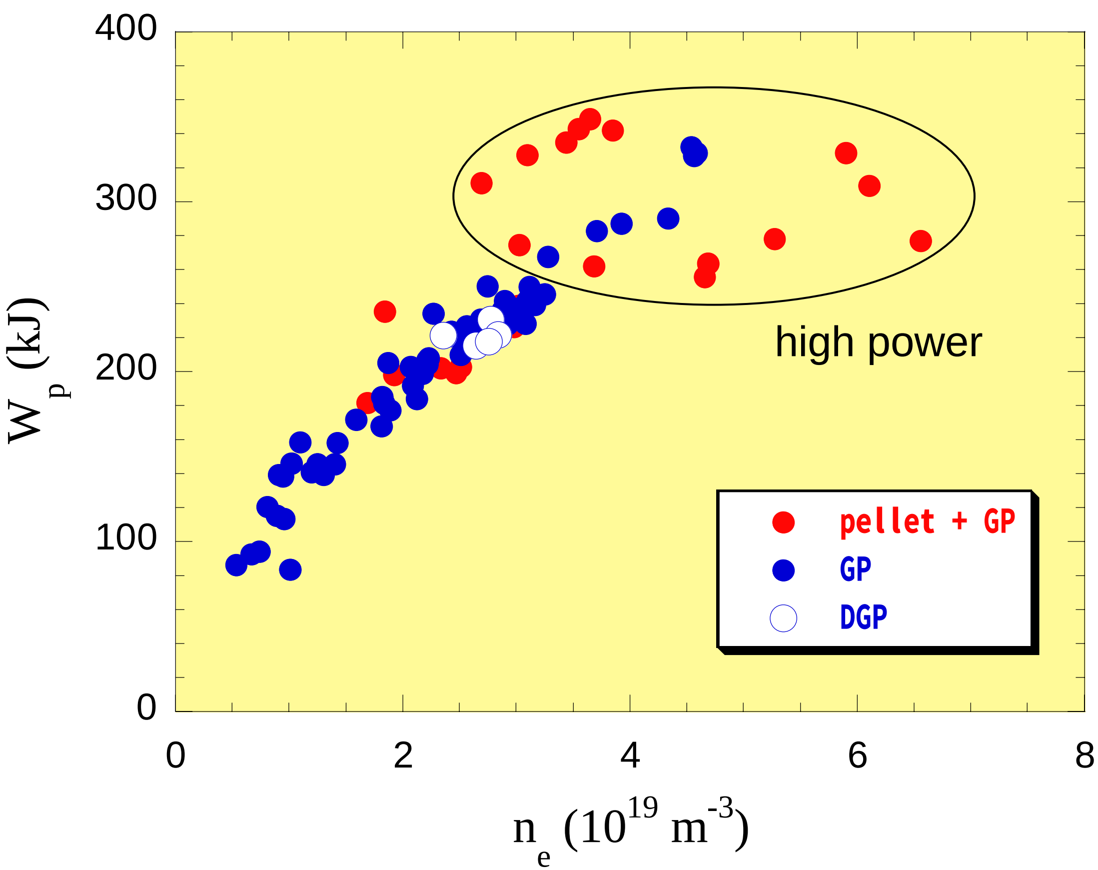

Limiter




* In limiter configuration during high power discharge, impurities (carbon) are released from the leading edge.

--> $P_{rad}$ increase --> $T_e$ decreasess

# Confinement property with different fueling methods




**** Low power region (P<4MW).***

- Little difference is seen in different fueling method.

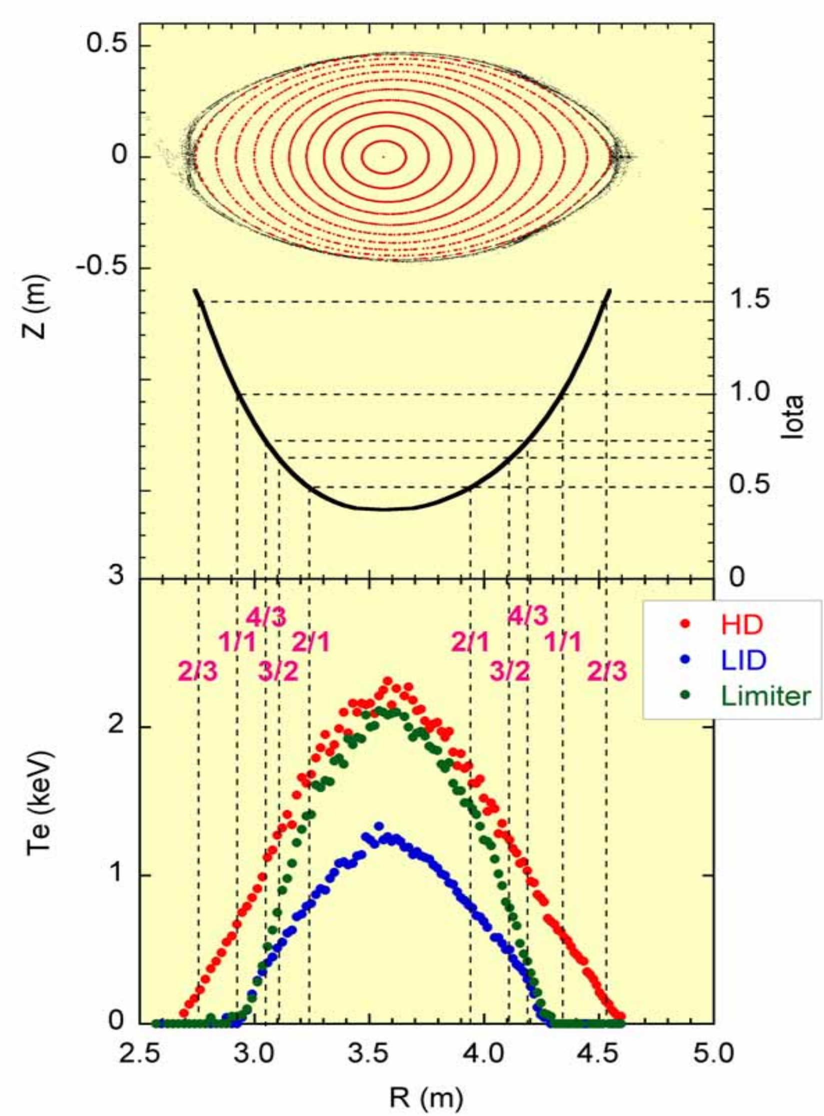
**** High power regime (P~9MW).***

- Pellet injection is superior to gas puff.

**** Higher power + pellet injection***

--> higher $W_p$ is expected.

# MHD



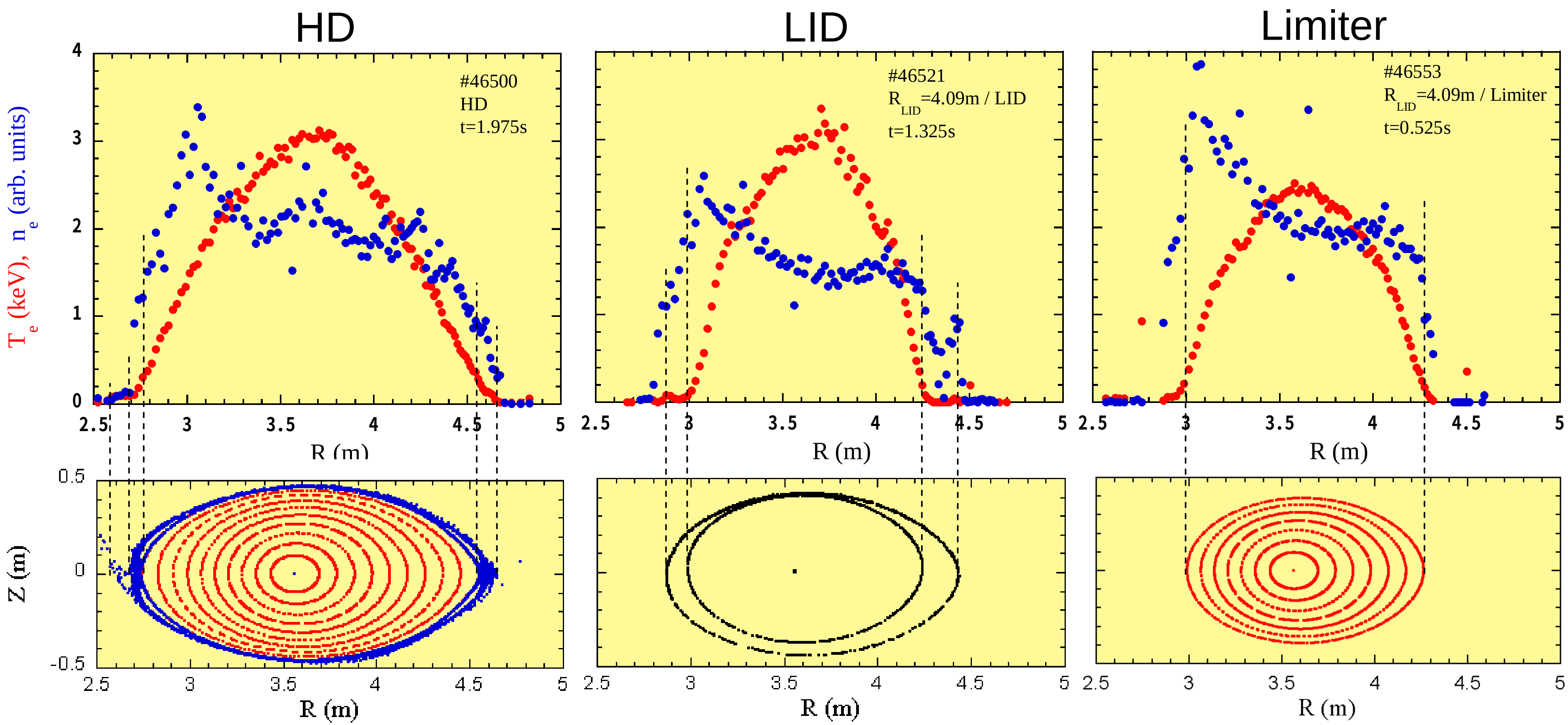

Rax=3.6m, Bt=2.75T, Bq=100%, gamma=1.25

gas=H,

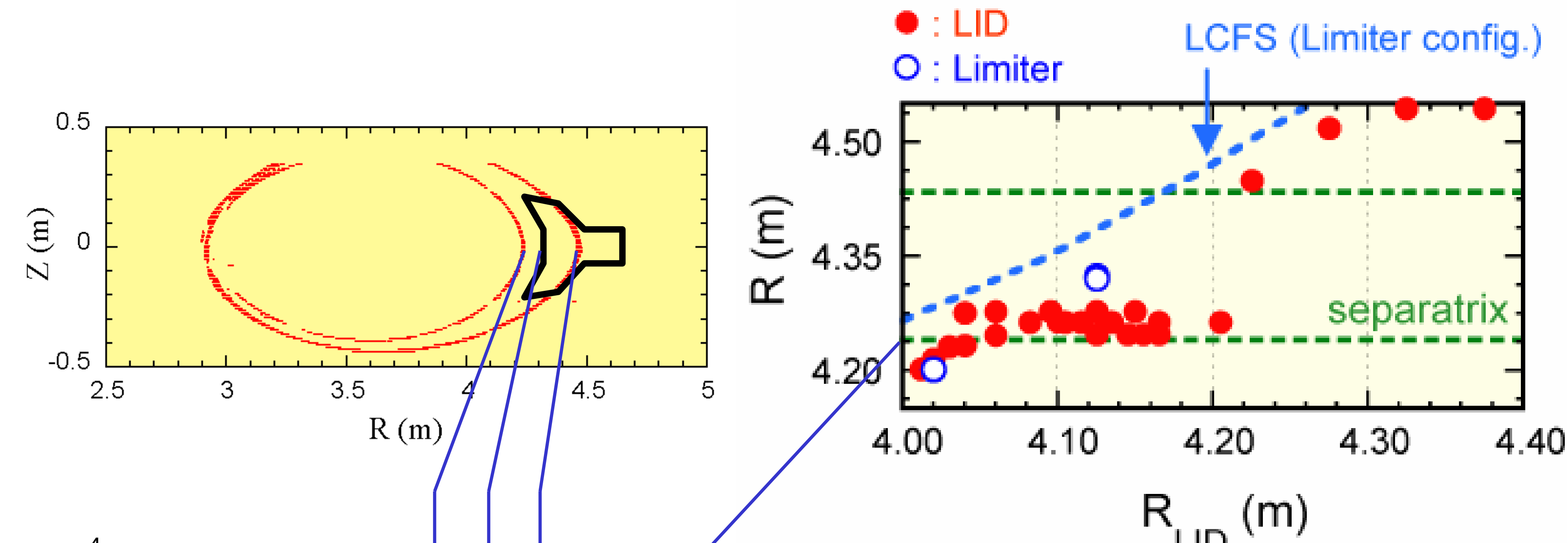
ne_bar~2.8 x $10^{19}$ $m^{-3}$ (const.)

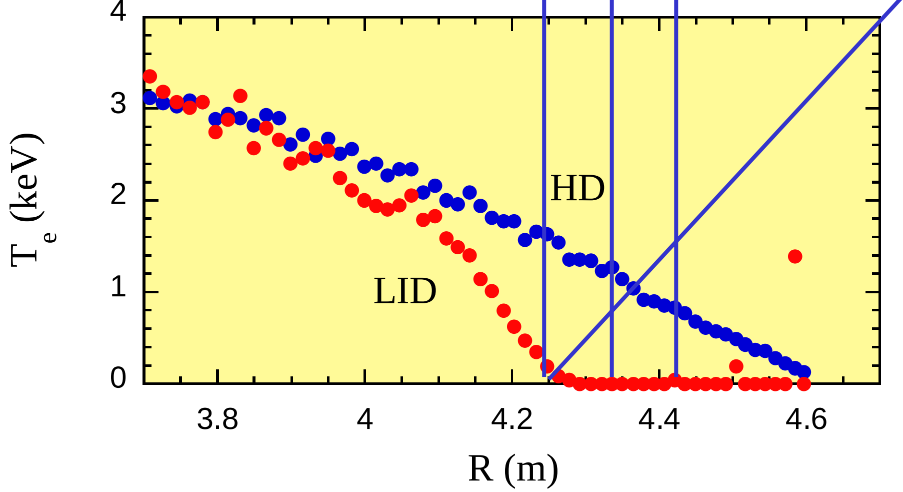
| | in | | | | | | out |
|---|---|---|---|---|---|---|---|
| iota_bar | 0.5 | 0.67 | 0.75 | 1 | 1.25 | 1.33 | 1.5 |
| m/n | 2/1 | 3/2 | 4/3 | 1/1 | 4/5 | 3/4 | 2/3 |
| HD | | | | ** | *** | *** | *** |
| Limiter | * | *** | *** | | | | |
| LID | | *** | *** | | | | |

# $T_e$ and $n_e$ profiles at $R_{ax}$=3.60m



# $T_e$ profile and separatrix position

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--> because divertor head does not

touch the core plasma.