2003 US-Japna Workshop on H-H-F-C and PSI for Next Fusion Devices & High Power Density Devices and Designs
Workshop Agenda
July 28-31, 2003 Port Townsend, Washington, USA

Edge plasma and PSI studies in the tandem mirror GAMMA 10

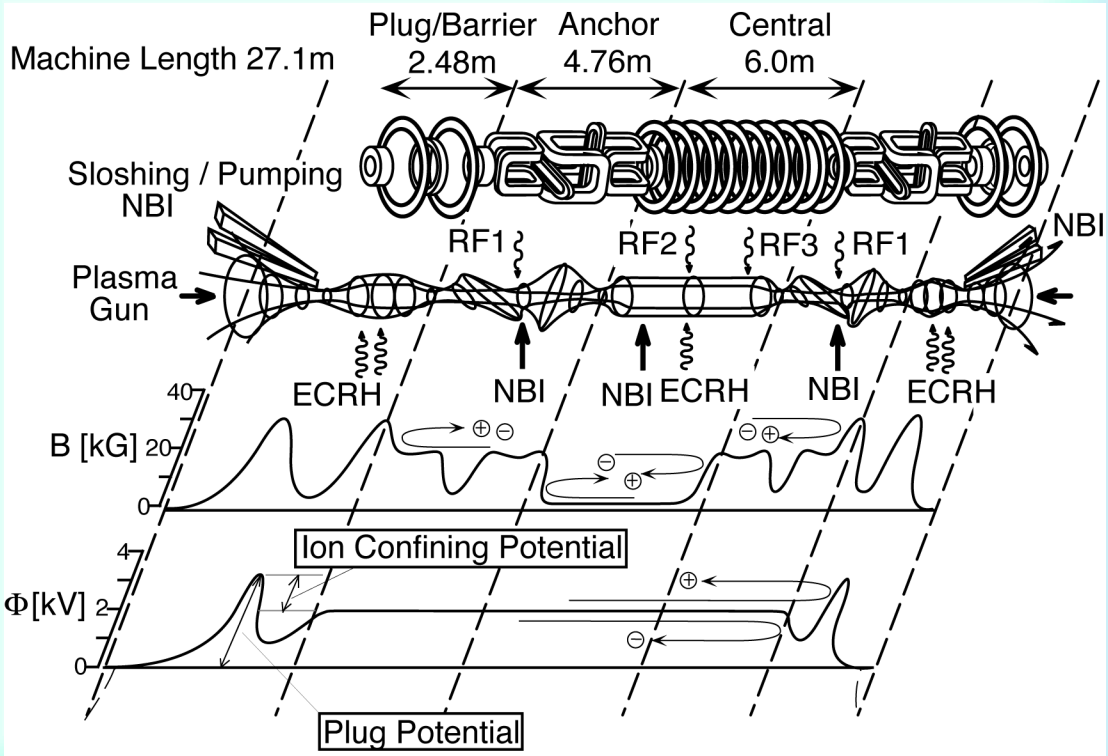
Plasma Research Center, University of Tsukuba
presented by Y. Nakashima

- - - O u t l i n e - - -

1. Introduction of GAMMA 10 Tandem Mirror
2. Behavior in Non-axisymmetric Minimum-B Anchor Region
   - Edge Plasma Measurements and Topics on PSI
   - Neutral Transport (Hα measurements and DEGAS simulation)
3. Application of Carbon Materials for Dumping High-energy Neutral Flux (for control of hydrogen recycling in tandem mirror plasmas)
4. Summary

GAMMA 10 and the Operation Modes

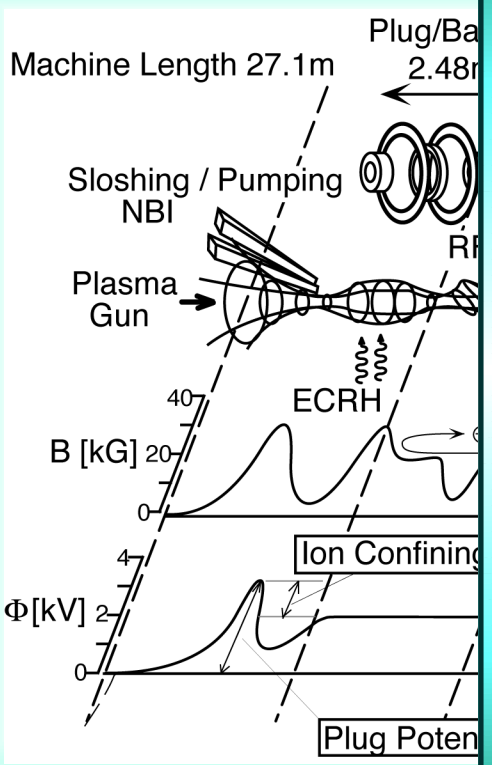
Schematice view of the GAMMA 10 Tandem Mirror



- Coil Arrangement
- Magnetic Flux Tube and Heating Systems
- Magnetic Field Strength
- Axial Potential Profile

GAMMA 10 and the Operation Modes

Schematice view of th



- Two Operational Modes have been studied:

1. ECH start-up Mode (High Potential Mode)

Ion Temperature	0.5 keV
Plug Potential	2 kV
Thermal Barrier	1.4 kV

2. ICRF start-up Mode (Hot Ion Mode)

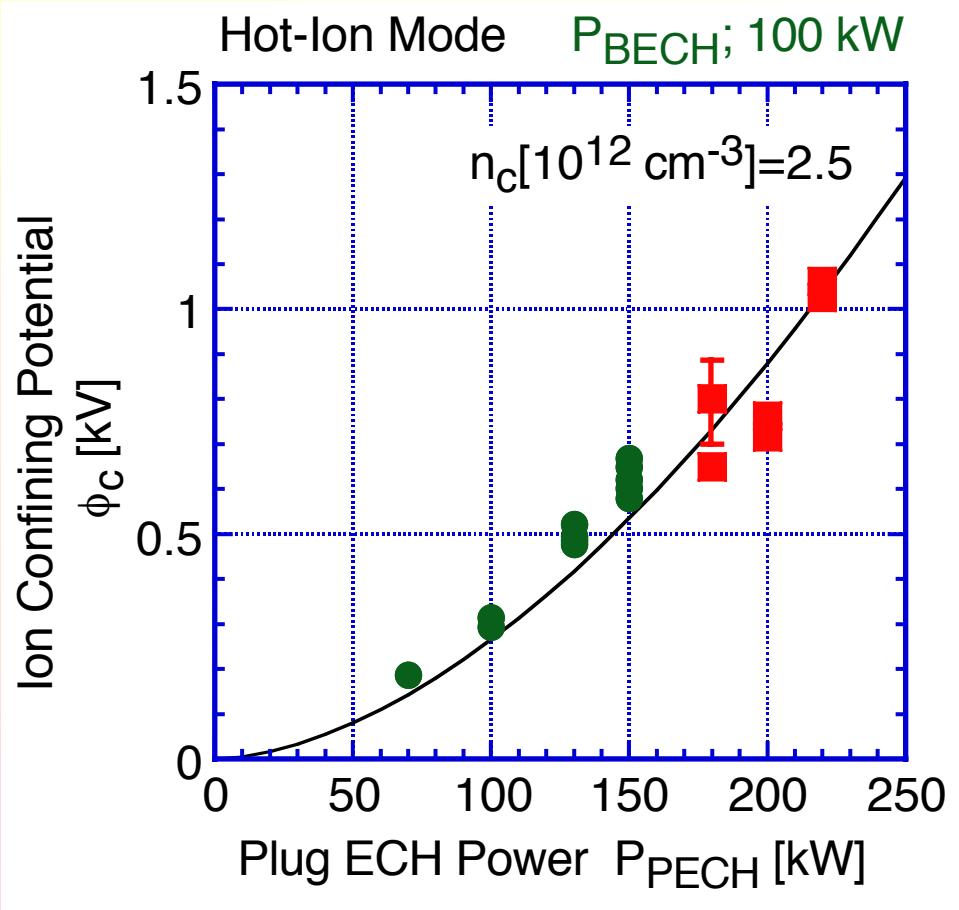
Ion Temperature	10 keV
Plug Potential	1.0 kV
Thermal Barrier	0.5 kV

A new operation condition was found in which a remarkable increase in the plasma density during the potential formation in hot-ion-mode plasmas by optimizing the heating systems.

⇓

The main objective of the GAMMA 10 experiment has been focused on the potential formation and confinement in high-density tandem mirror plasmas.

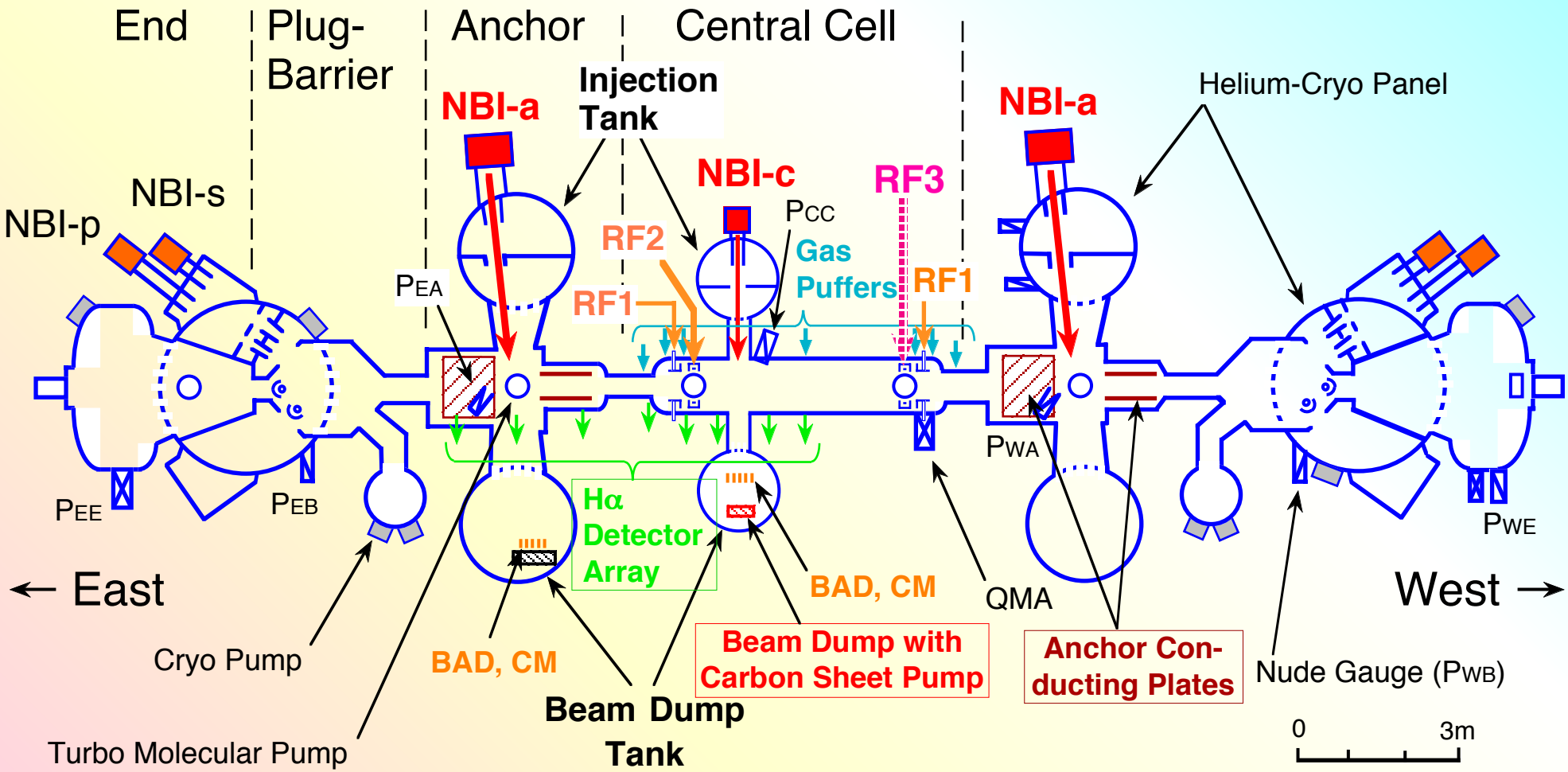
Relationship between ion confining potential ϕ_c and the plug ECH power



- Plug ECH power for the potential formation is increased up to 220 kW by the improvement of the microwave system and the plasma ion confining potential is achieved to be more than 1 kV in hot ion mode plasmas.
- Ion confining potential is steadily increasing with the plug ECH power according to the scaling law*.

*T. Cho, *et al*. Nucl. Fusion **43** (2003) 293-298.

Heating and Diagnostic Sytems for High-density Experiment in GAMMA 10

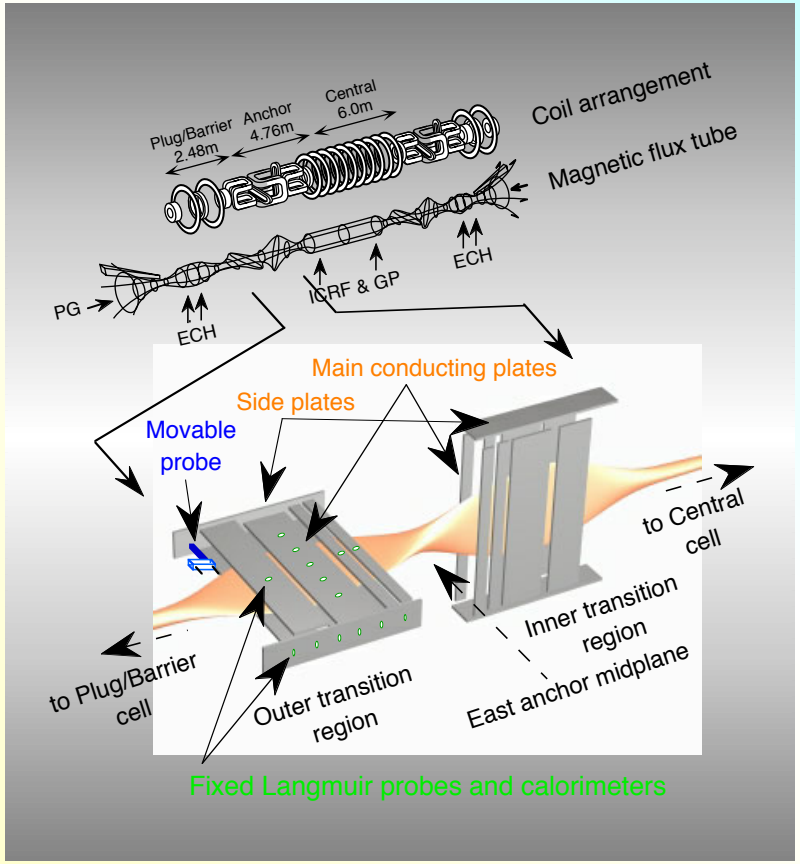


Recently a new ICRF wave system (RF3) with high harmonic frequency was introduced for achieving high density. In addition, NBIs were installed at the central and anchor cells for heating and fueling to target plasmas produced by ICRF waves.

Non-axisymmetric Minimum-B Anchor Region in Tandem Mirror

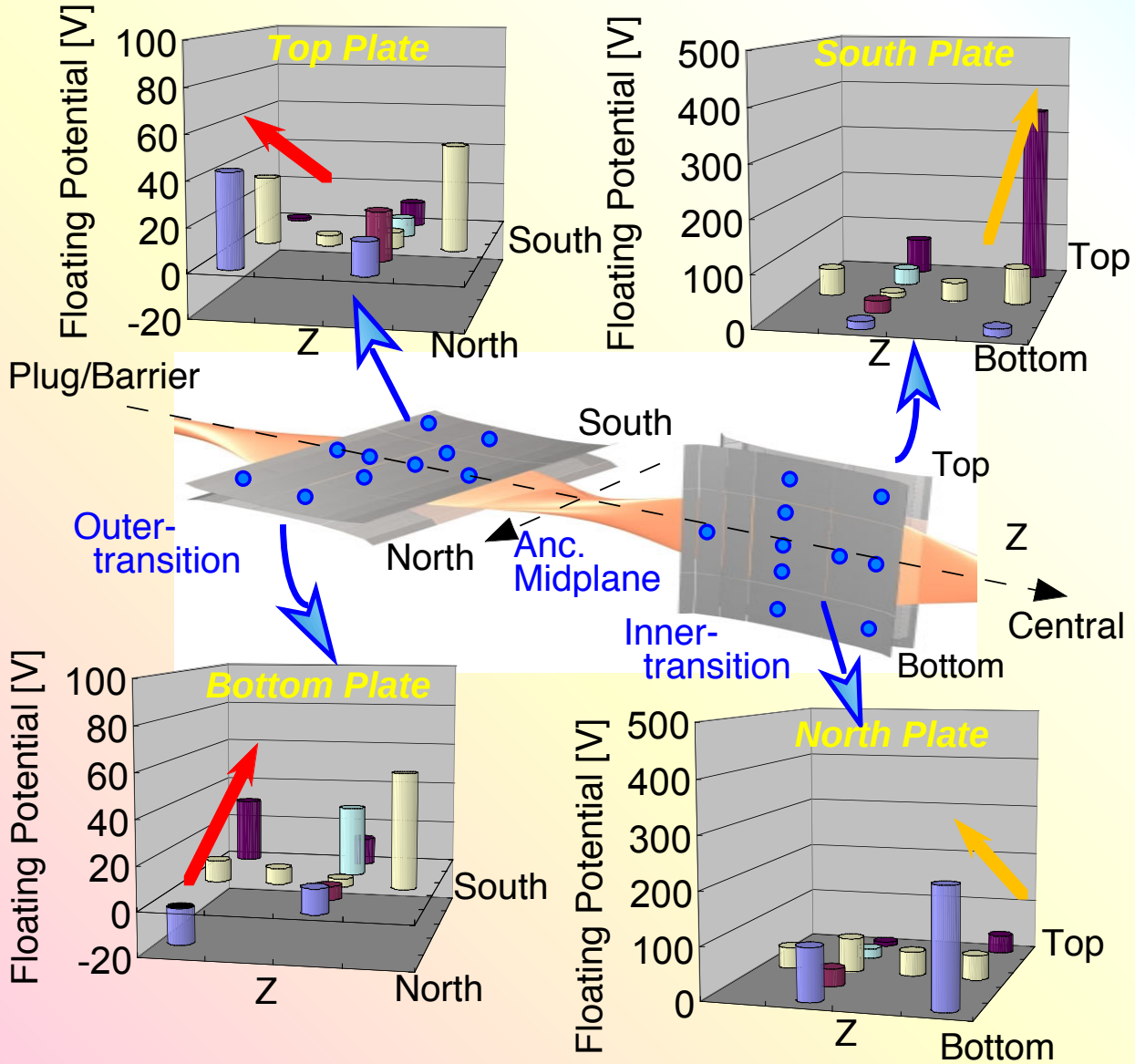
- **MHD stability**
  High-ß plasma production with ICRF and NBI
- **Existence of transition region**
  → Plasma cross-section with high ellipticity
  → Magentic field configuration with strong grad-B (∇B drift & Curvature drift of edge plasmas)
- **Achor conducting plates**
  → Control of radial transport
  → Strong plasma-wall interactions due to the narrow space between each other

Schmatic view of plasma shape and anchor conducting plates in east anchor transition region



Edge Plasma Behavior in Anchor Transition Region

~ Floating Potential near the Anchor Conducting Plates ~



Inner-transition Region:

South plate
Top > Bottom
North plate
Bottom > Top

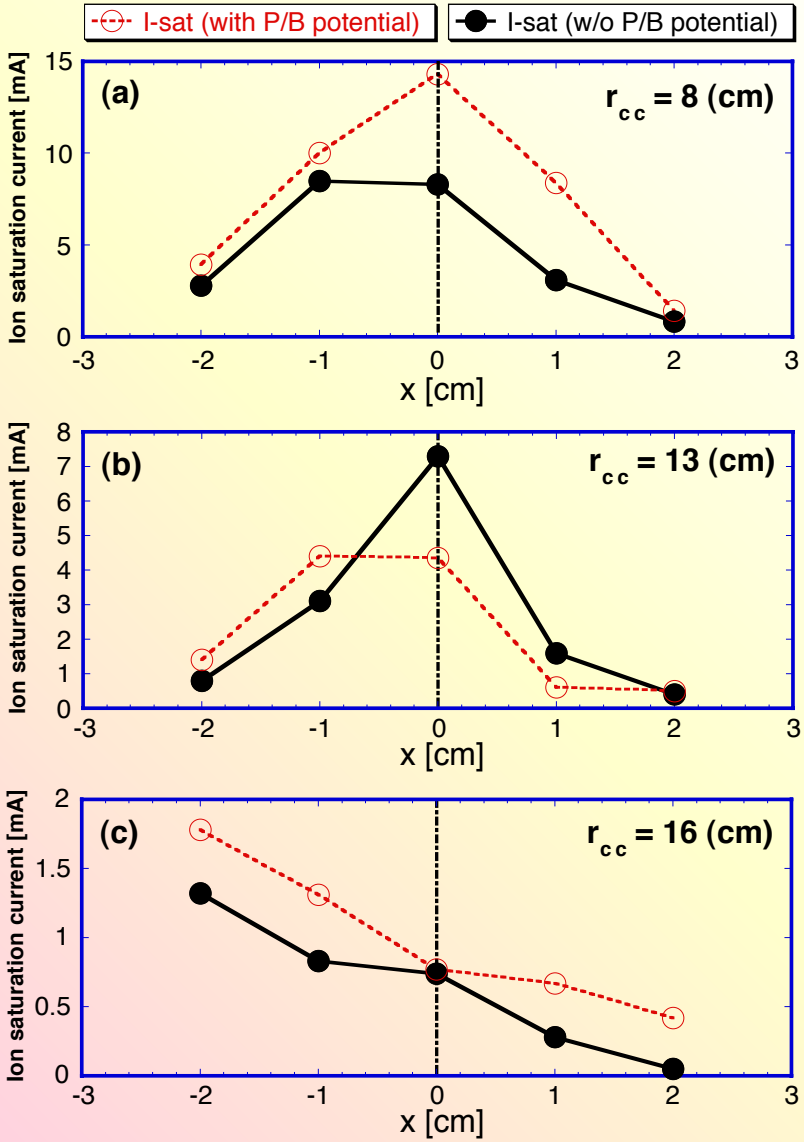
Outer-transition Region:

Top plate
North > South
Bottom plate
South > North

A rotational symmetry on the profile is suggested in both regions.

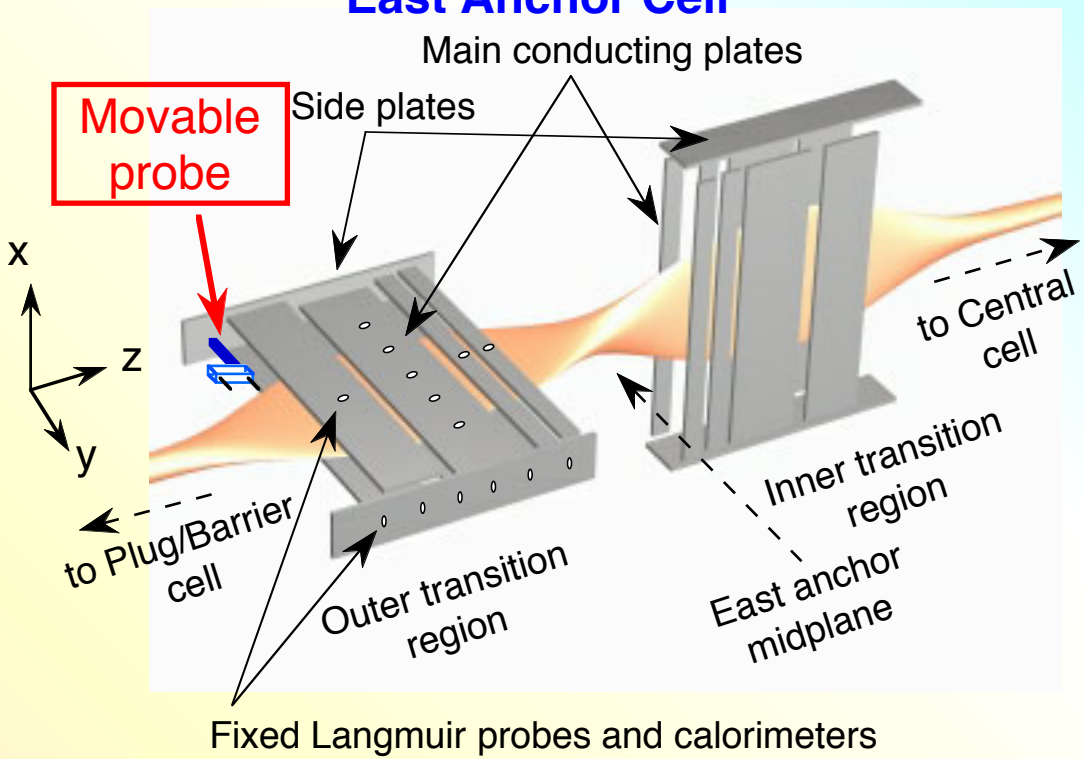
Edge Plasma Behavior in Anchor Transition Region

Vertical profile of Ion saturation current



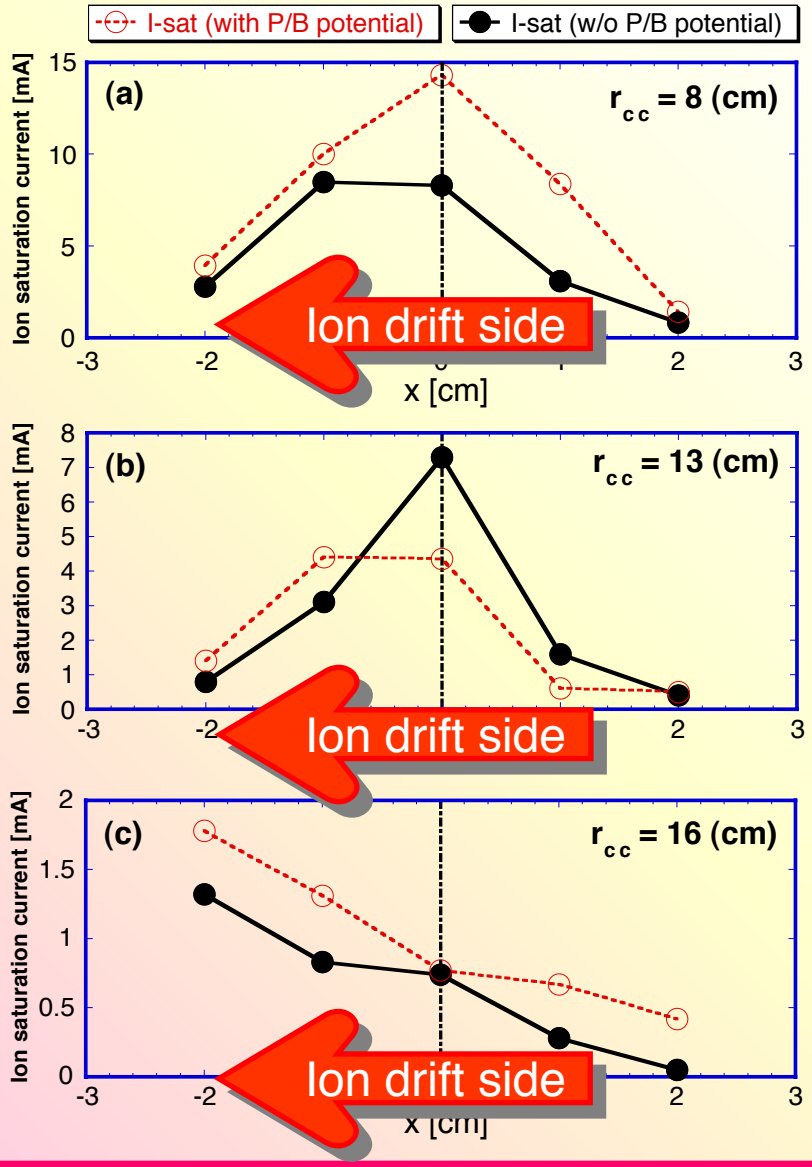
Spatial profile of Ion saturation current was measured with a movable Langmuir probe in outer-transition region.

East Anchor Cell



Edge Plasma Behavior in Anchor Transition Region

Vertical profile of Ion saturation current



- A considerable asymmetry in x (vertical) direction is observed in the periphery region ($r_{cc} \geq 13$ cm) .

  (r_{cc}: effective radius of the probe position mapped on the central-cell mid-plane along the magnetic field line.)

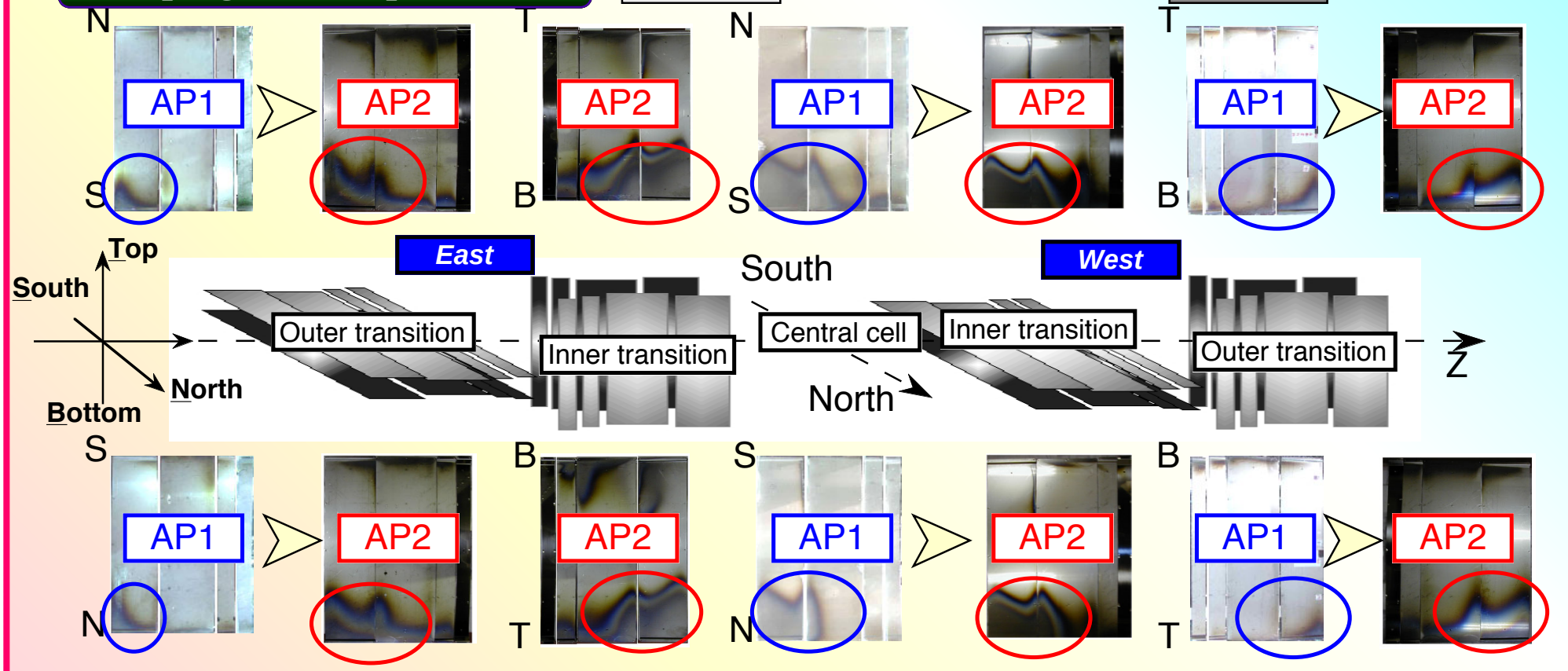
- The asymmetry has a tendency to be enhanced with the distance from the plasma axis.

- The direction of shift of the peak position is ion drift side and is independent of the potential for-mation produced by ECH.

Plasma Wall Interactions in Anchor Transition Region

The areas are increasing with the progress of experiments.

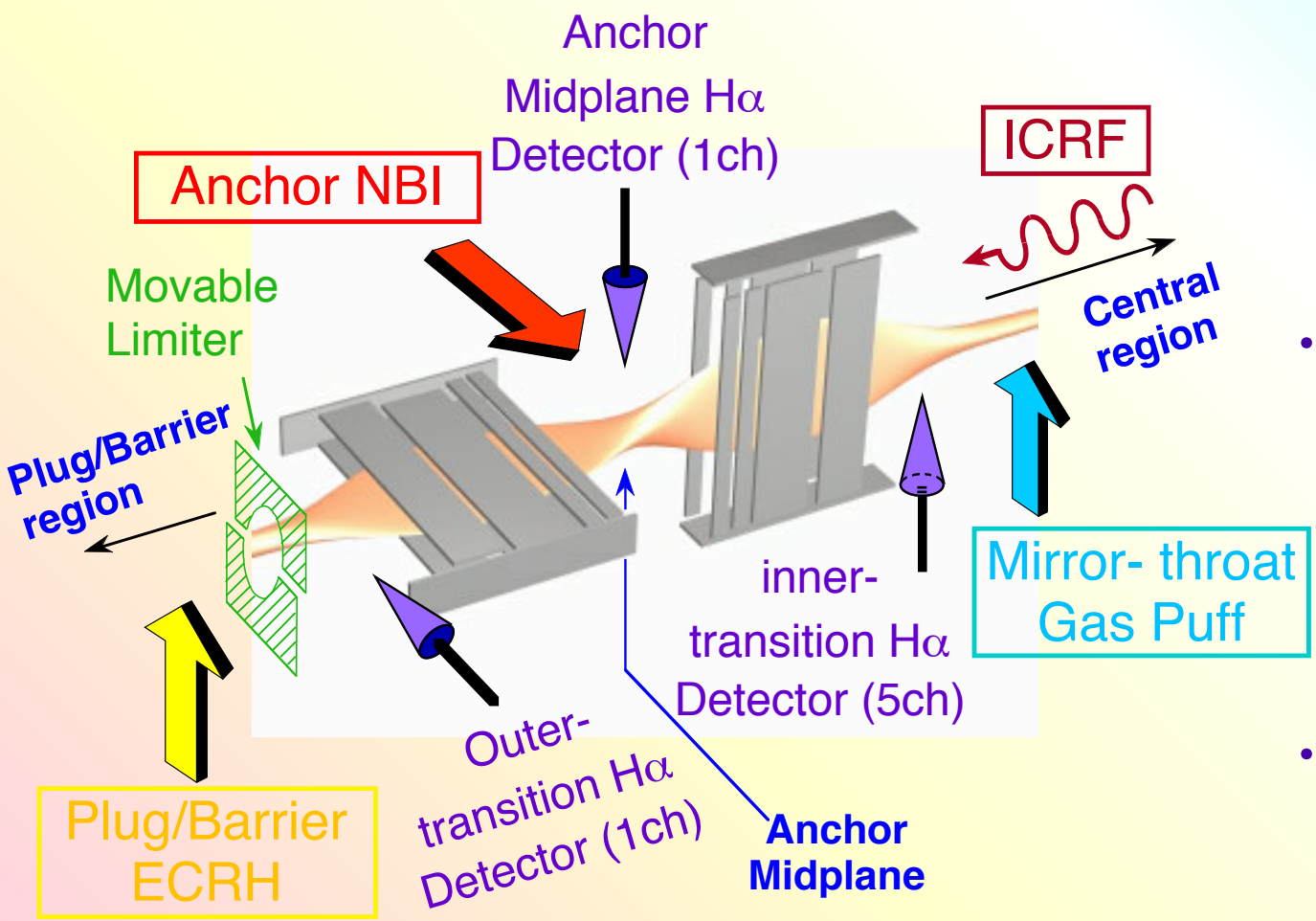
AP1 1997~1998 about 6000 shots → **AP2** 1999~2001 about 12000 shots



There were many areas containing deposited layers of impurity like carbon observed partially on the main plate and their locations show a rotational symmetry, which corresponds to electron drift side.

→ Strong Plasma-wall Interactions are revealed in this region.

Behavior of Neutrals in Anchor Region
(heating systems and diagnostics)



- Ion heating with ICRF and NBI for high β plasma production
  - → High Ti (few keV)
  - → Non-uniform fueling
- Elliptic plasma cross-section
  - → non-axisymmetry
  - → penetration of neutrals
    - $d_{plasma} < \lambda_{mfp}$
- Distance from vacuum vessel & limiter
  - → strong plasma-wall interactions (hydrogen recycling)

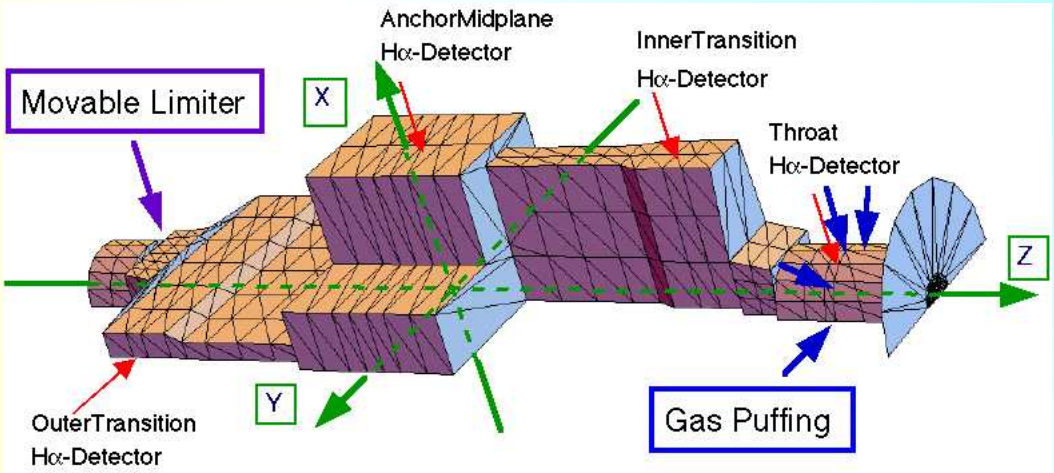
Mesh model and plasma grid for 3-dimensional neutral transport simulation with the DEGAS code

- A 3-dimensional neutral transport simulation based on the Monte-Carlo method has been performed in the GAMMA 10 anchor-cell in order to investigate the behavior of neutrals in non-axisymmetric region.

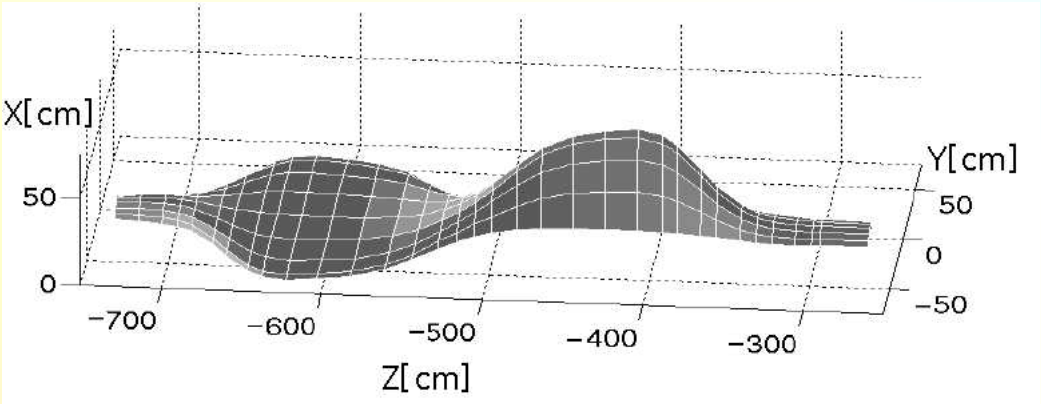
- Monte-Carlo simulation code:
  1. DEGAS ver. 63
  2. Effect of dissociative-excitation of H_2 is taken into account.

- Particle source:
  1. Gas puffing from the mirror throat
  2. Gas desorption from movable limiter (MLO)

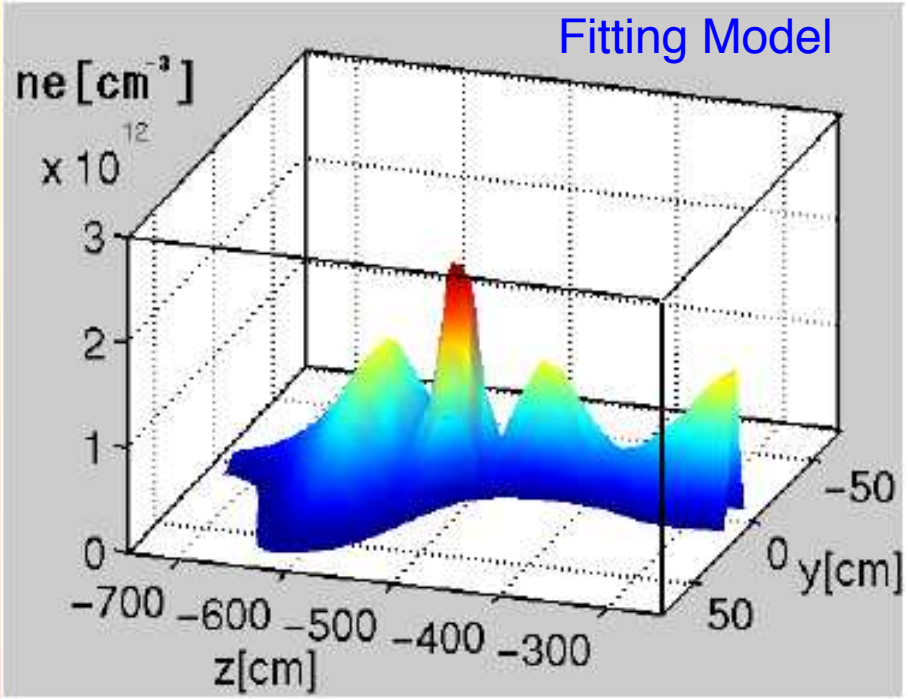
Surface mesh structure of the vacuum vessel wall

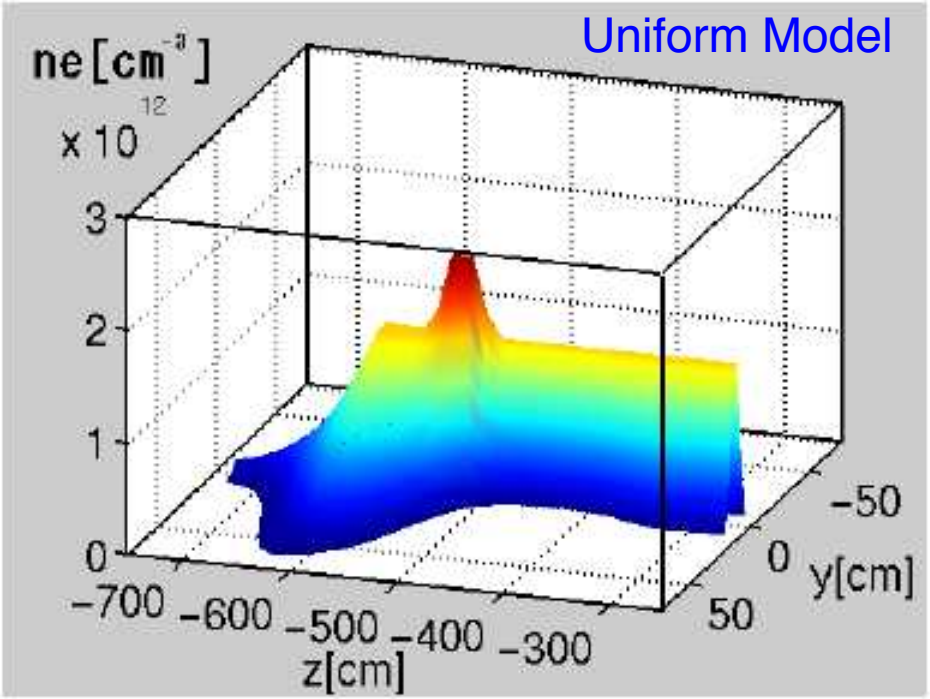


Grid shape of the plasma surface



Plasma parameters used for 3-d neutral transport simulation with the DEGAS code





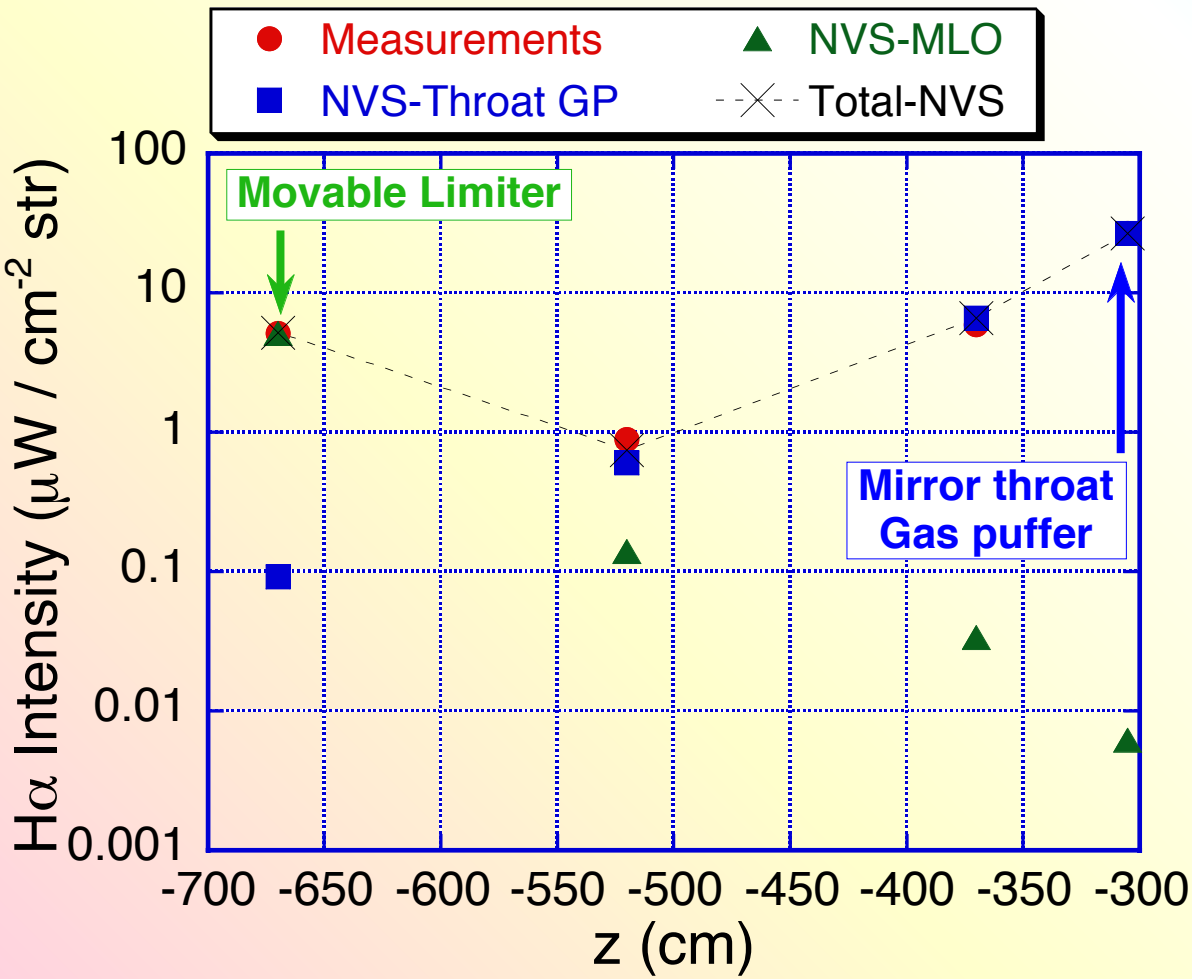
- Two types of the density profile were adopted in the simulation:

(1) Fitting the shape of the magnetic flux tube from the central-cell to the anchor-cell. (Fitting Model)

(2) Uniformity of the density on the magnetic axis is assumed. (Uniform Model)

Axial profile of Hα Intensity

(Measurements and Simulation)

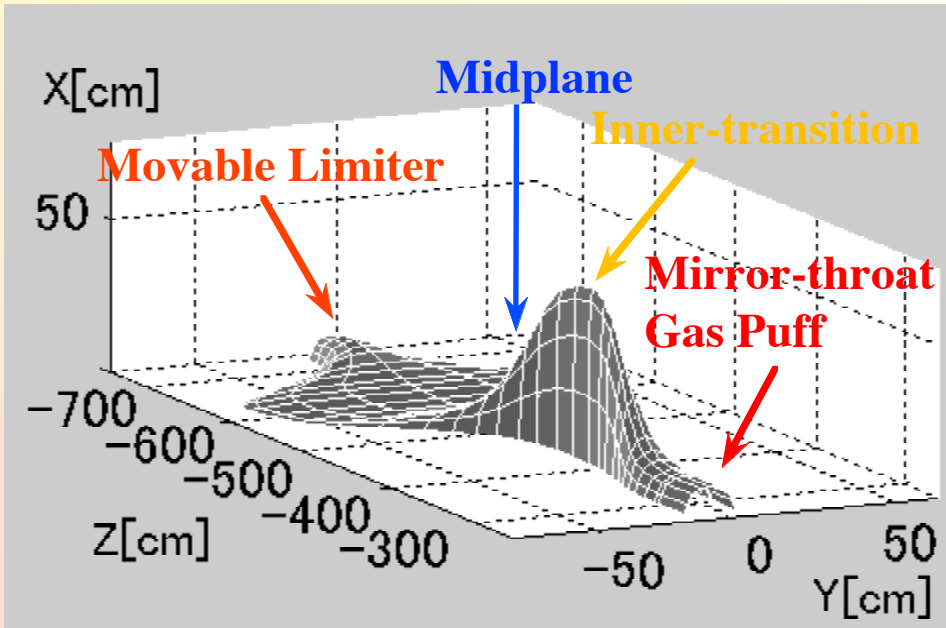


Neutral transport simulation assuming both particle sources from the mirror-throat gas puffer and from the movable limiter in the outer-transition successfully reproduces the axial profile of measured Hα intensity.

H-recycling on the movable limiter plays a impotant roll on the behavior of neutral particles in the non-axi-symmetric anchor region.

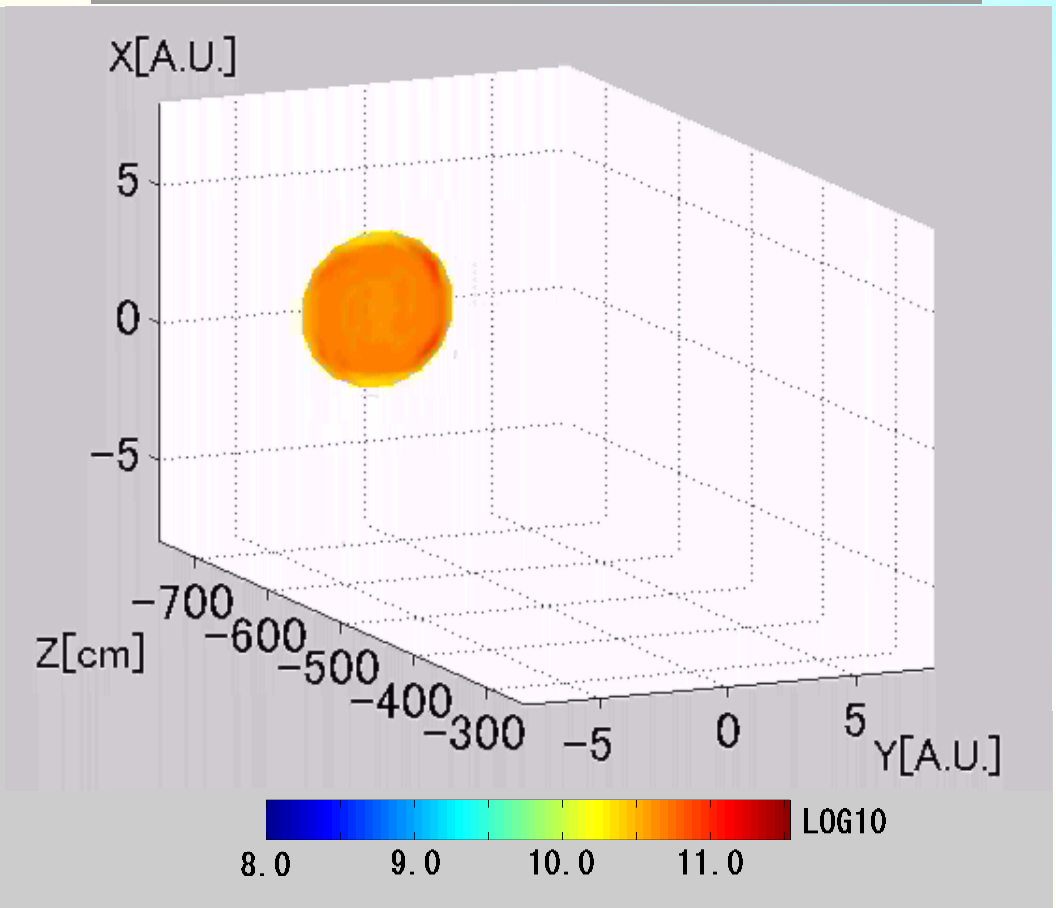
Results of 3-d neutral transport simulation in the anchor-cell with the DEGAS code

Surface mesh structure of the plasma



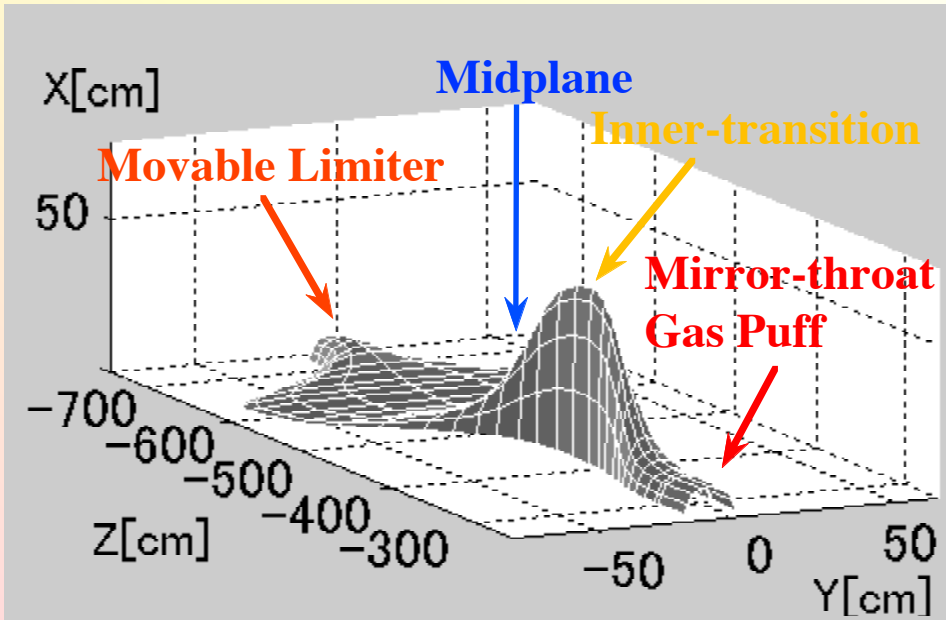
- Molecular density strongly decays from the mirror throat to anchor midplane.
- and also decays in the radial direction.

Molecular hydrogen density n_{H2} (cm^{-3})



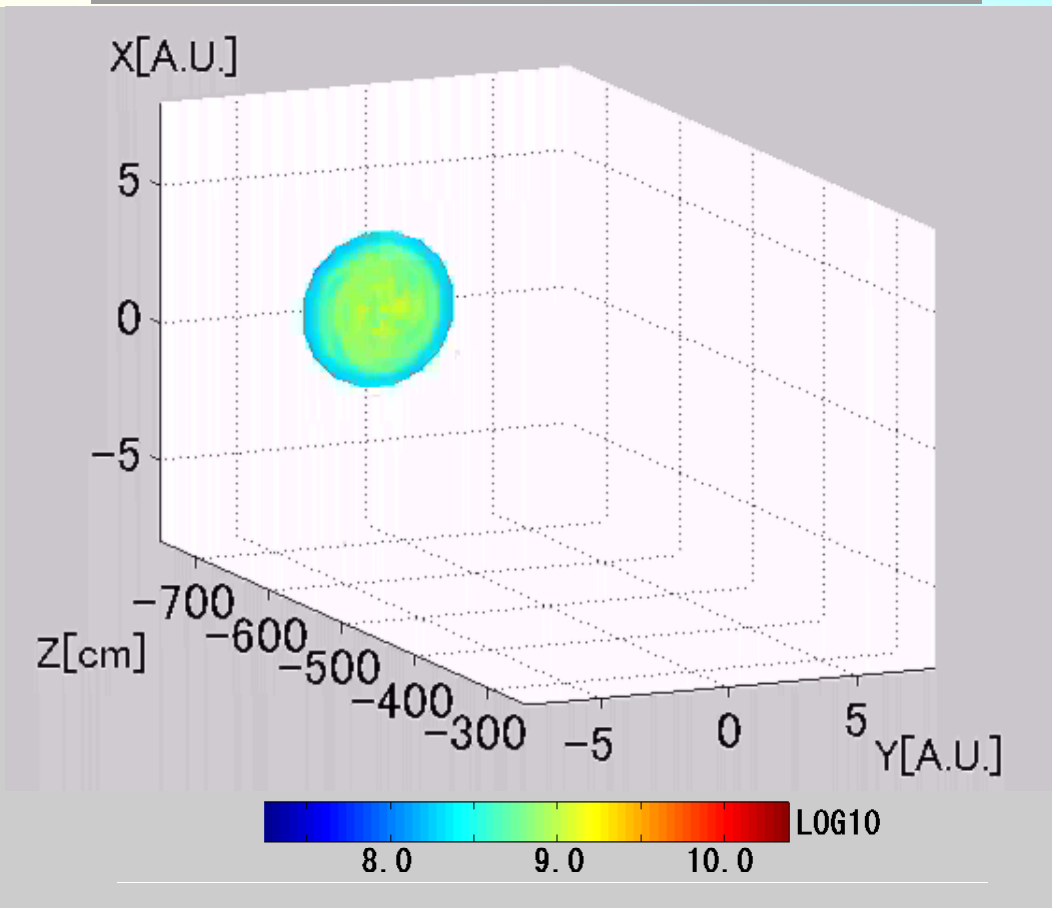
Results of 3-d neutral transport simulation in the anchor-cell with the DEGAS code

Surface mesh structure of the plasma

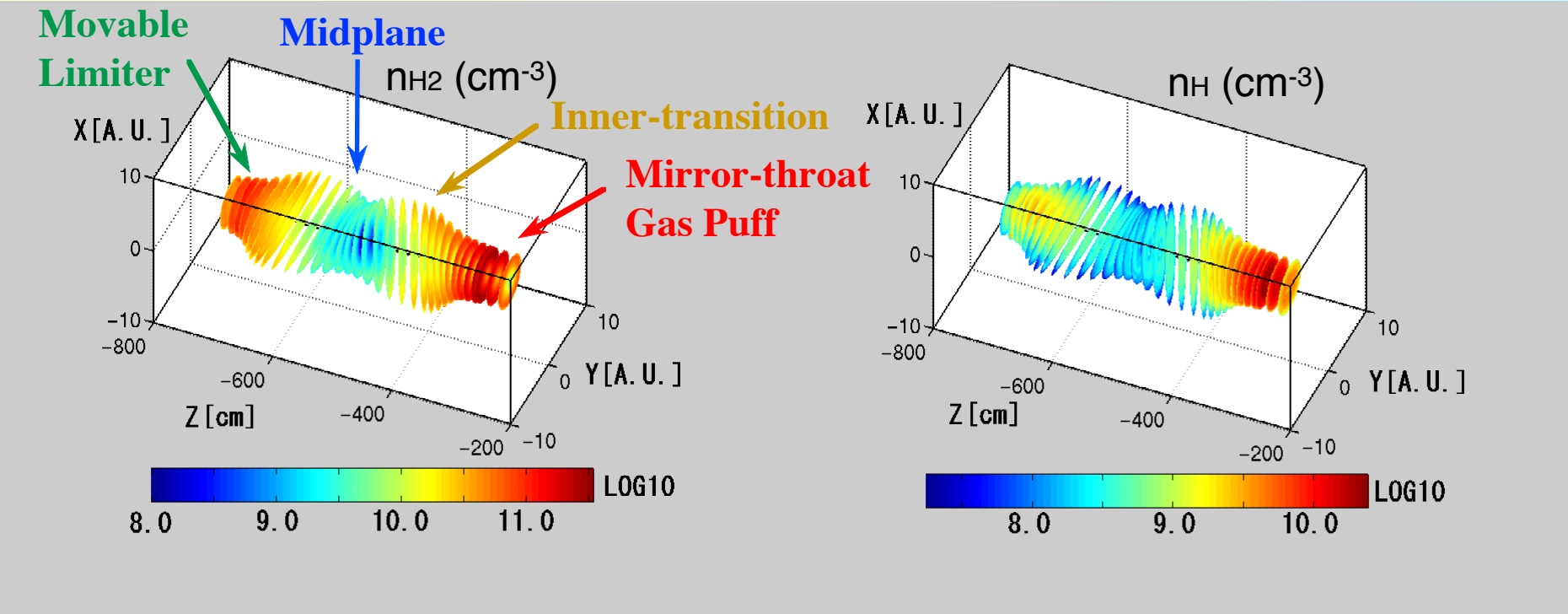


- Atomic density is concentrated to the core region near the particle source.
- and become almost uniform in the region where the plasma cross-section is flatly elongated.

Atomic hydrogen density n_H (cm^{-3})

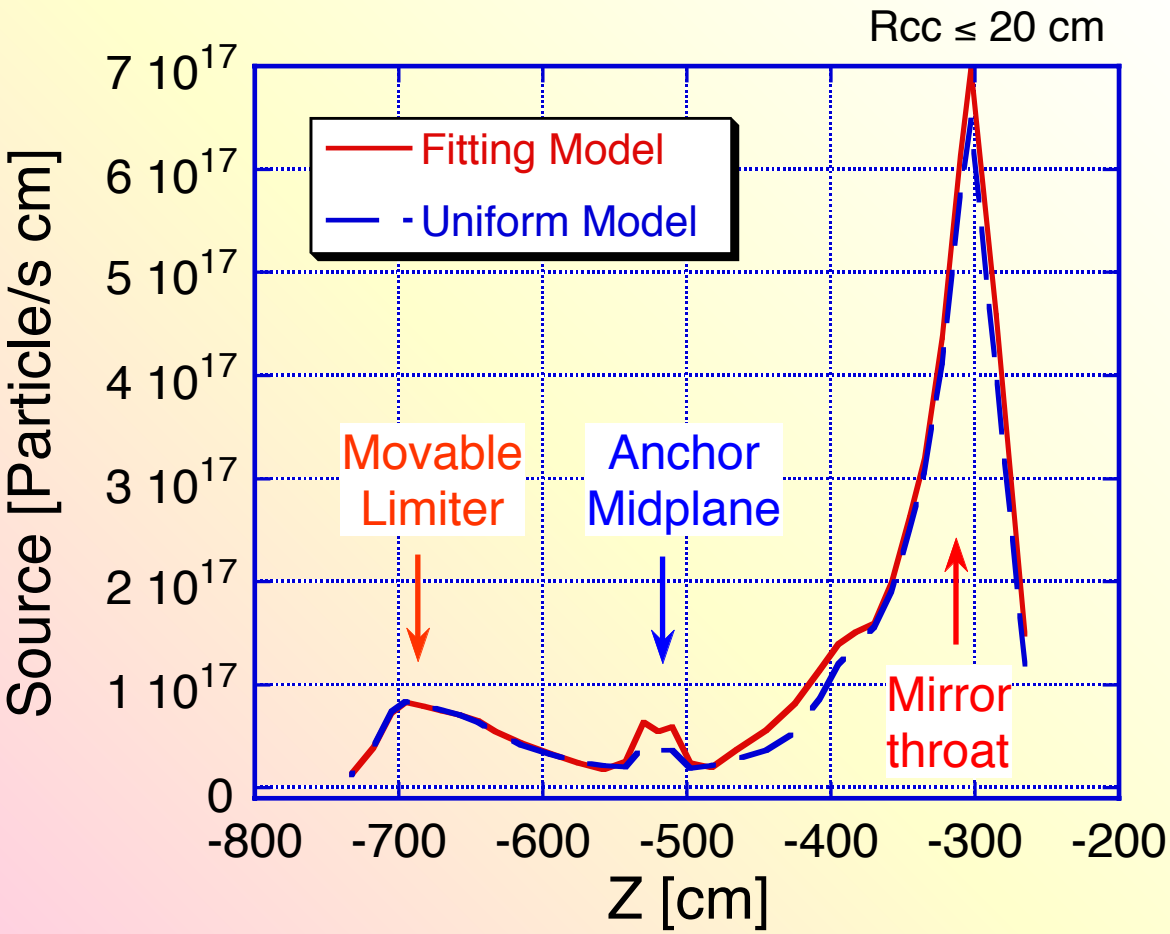


Results of 3-d neutral transport simulation in the anchor-cell with the DEGAS code



- The molecular density decreases toward the core region of the plasma and further reduces along with the magnetic field line toward the anchor midplane.
- Penetration of neutrals is taking place in the edge region where the plasma thickness becomes thin.
- Injected hydrogen molecules from the gas puffer are transported to the anchor transition region with significant attenuation and only a small amount of them reaches the anchor midplane.
- Atomic hydrogen density has a tendency to concentrate in the plasma core region.

Axial profile of particle source rate integrated within $R_{cc} \leq 20$ cm



By accumulating the information of the neutral density and of plasma parameters, total particle source rate in the anchor-cell is evaluated.

Particle source rate in the mirror throat is dominant compared with that in the anchor midplane and in movable limiter at the outer-transition region.

Application of Carbon Materials for Dumping High-energy Neutral Flux

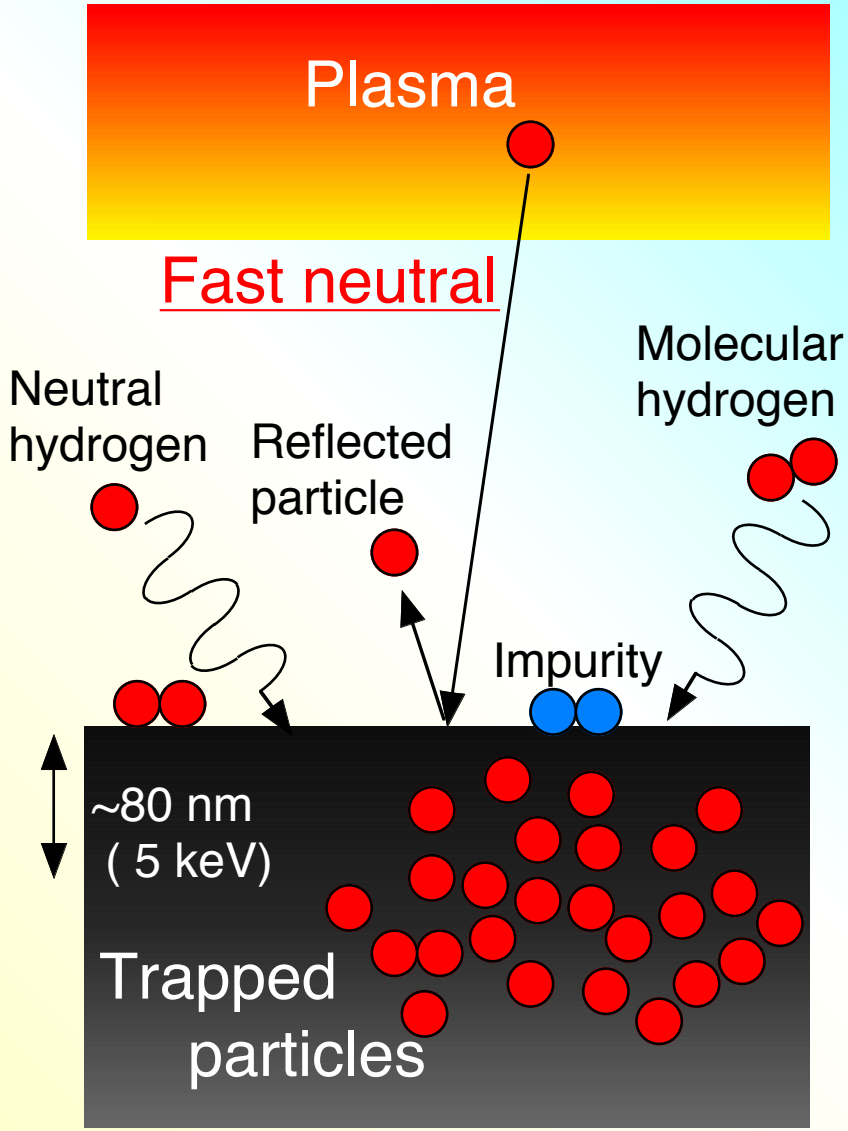
Plasma facing component

for reduction of hydrogen recycling

Almost all incident particles are not reflected but are trapped in the material.

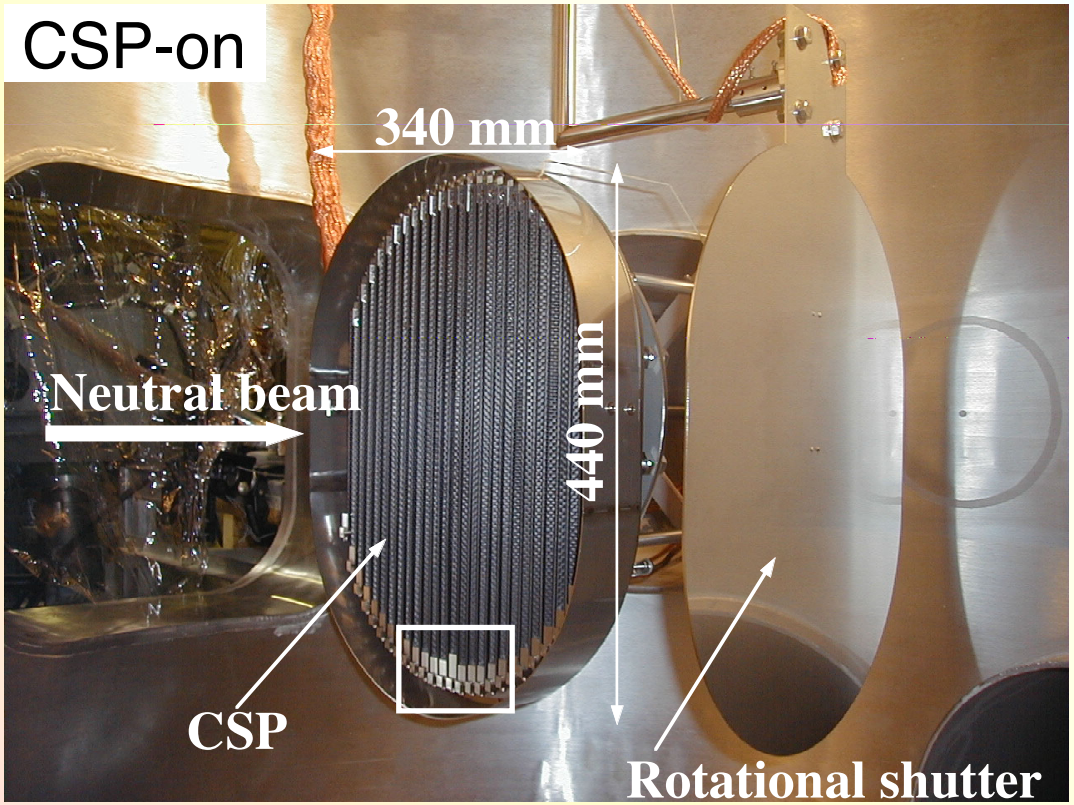
Advantage of CSP :

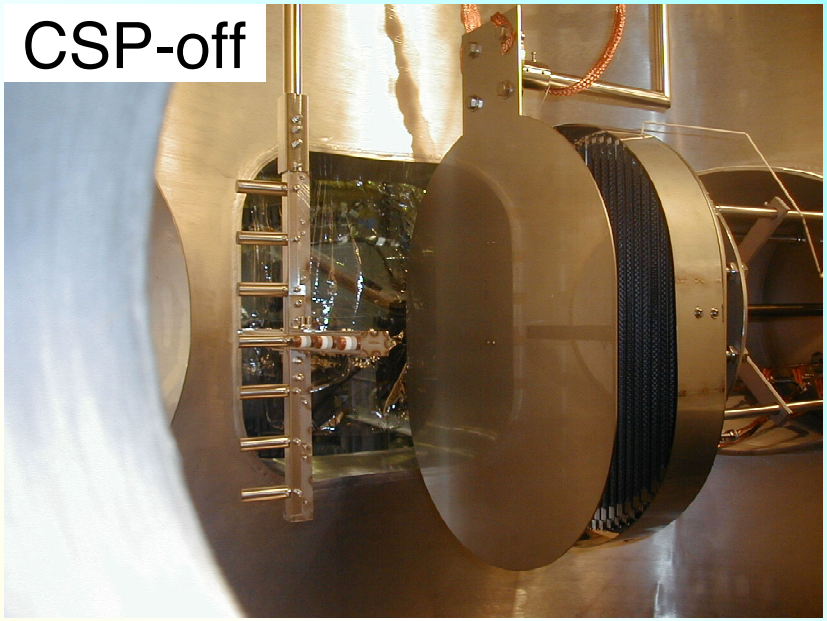
1. Carbon is one of the low Z materials
2. Suitable for pumping fast neutrals under low heat flux
3. CSP can be easily regenerated by direct joule heating up to 800°C in short intervals.
4. Structure of CSP is simple compared with that of other mechanical pumps.

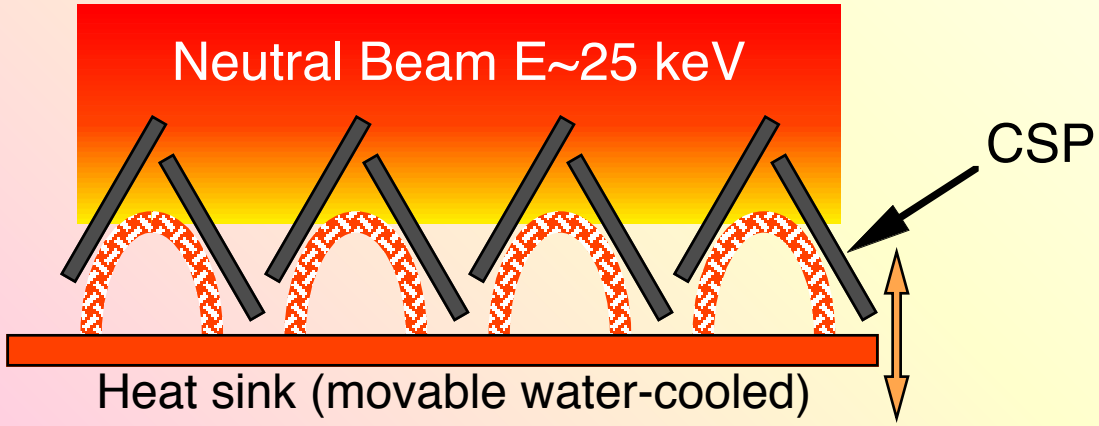


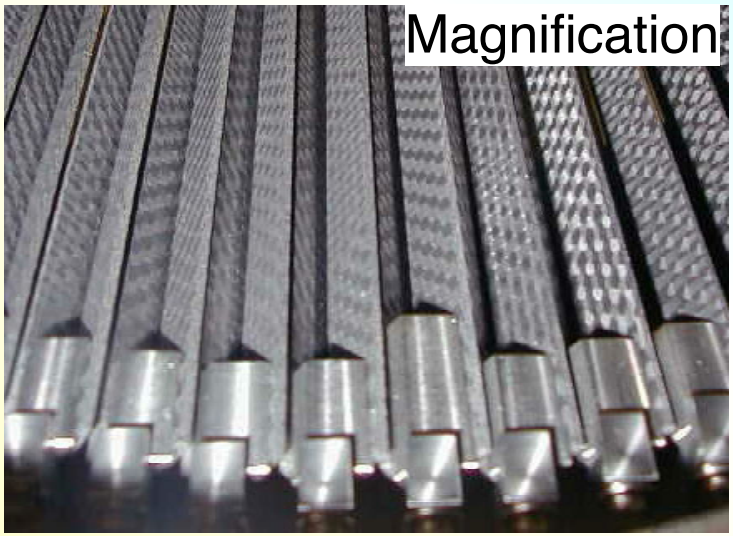
This work was carried out under the colaboration research with NIFS.

Carbon Sheet Pump Designed for Beam Dump

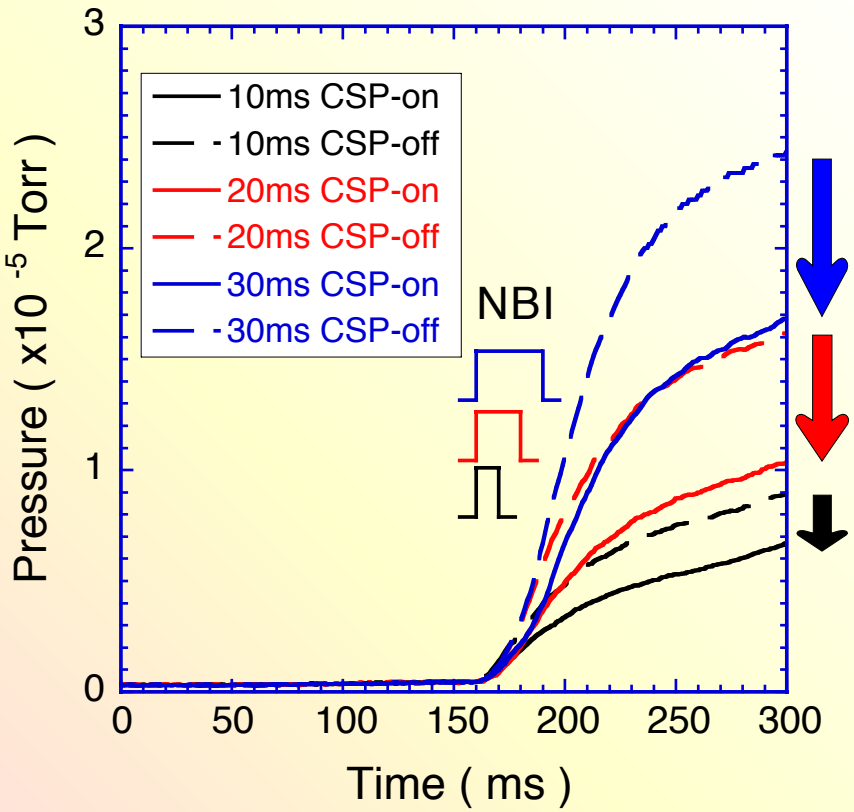


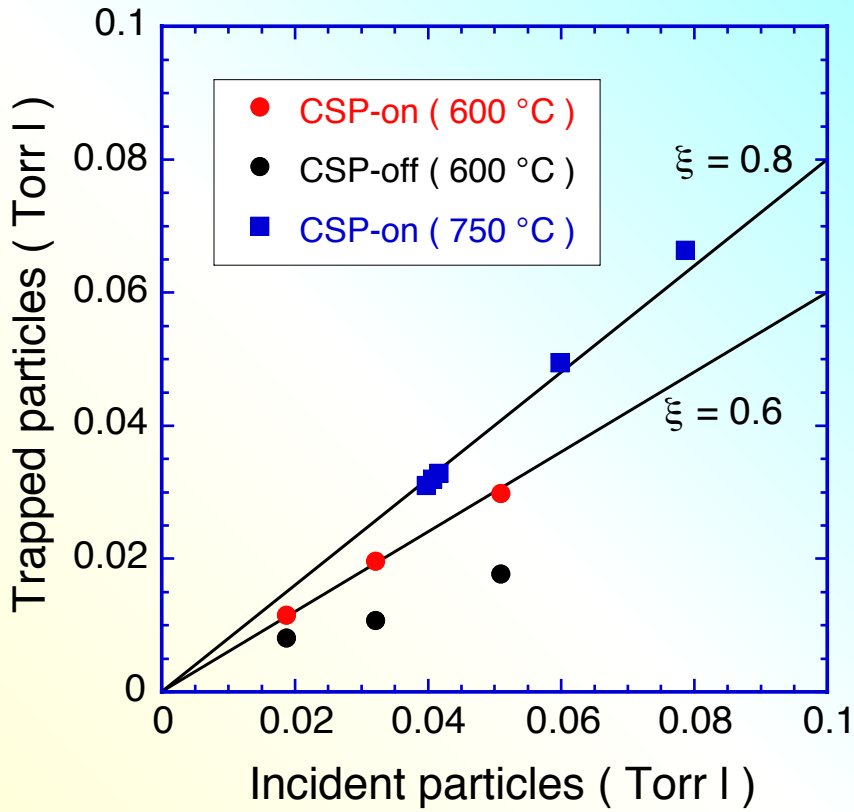






Evaluation Results of the Pumping Effect for Neutral Beam





Remarkable reduction of the measured pressure was observed in the CSP-on case, which indicates **the pumping effect of CSP on High-energy neutral flux.**

The pumping efficiency is improved to be **0.6 to 0.8** by increasing the regeneration temperature from **600 ˚C to 750 ˚C**.

→ 150 m^3/s as an effective pumping speed.

SUMMARY

Edge plasmas in the anchor outer-transition region was investigated by using Langmuir probe array and a movable probe.

1. A significant asymmetry in the ion saturation current and the floating potential was recognized, which corresponds to the ion drift side due to ∇B and the curvature of the magnetic field.
2. Impurity deposited areas observed on the conducting plates also showed the same asymmetry and the structure of rotational symmetry in 180°, which revealed a strong plasma-wall interactions in this region.

Hα line-emission measurements have been performed in the anchor-cell and the results were compared with the Monte-Carlo neutral transport simulation.

1. 3-D neutral transport simulation using the DEGAS ver.63 code was successfully performed in non-axisymmetric anchor region and a noticiable amount of H-recycling was suggested in this region.
2. The spatial profile of the total amount of particle source rate was quantitatively evaluated by using the measured results of Hα line-emission.

SUMMARY (continued)

A Pumping system using carbon material (CSP) was newly applied for dumping high-energy particle flux in order to examine applicability of CSP beam dump for NBI under the present experimental condition of GAMMA 10 tandem mirror.

1. A remarkable reduction of pressure in the beam dump tank was recognized in the case of CSP-on and the pumping effect on the high-energy neutral flux was clearly confirmed.
2. The pumping efficiency is improved to be 0.6 to 0.8 by increasing the regeneration temperature from 600 ˚C to 750 ˚C.

Workshop Agenda