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Study of SMBI fueling in GAMMA 10 based on experiment and Monte-Carlo simulation

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Contents

Introduction

- ❖ Control of gas fueling is one of the most important issues to obtain a high density and good performance plasmas.
- ❖ Fueling control enables the profile control of the core plasma density and reduction in neutral particles in the peripheral area.

Fueling system

- ➢ Conventional gas puffer:
- ❖ Very simple system but low fueling efficiency.
- ➢ Pellet injector:
- ❖ High fueling efficiency but the system is complicated.
- ➢ Supersonic molecular beam injector: Supersonic molecular beam injection (SMBI) system has been developed as a new fueling method that can combine both advantage of the conventional gas puffer and the pellet injection. SMBI provides high-speed and high-directive gas injection by using a plenum pressure higher than what is used in conventional gas puffing, so that neutral particles can be injected deeper into the core plasma.

- ❖ In GAMMA 10, central-cell has a simple solenoidal magnetic configuration by using ten pancake coils. In addition, GAMMA 10 has many observation ports at the central-cell. Thus, the central-cell is suitable for analyzing the plasma behavior during SMBI.

Background and Purpose

<Background>

In GAMMA 10 SMBI experiment has been carried out by three conditions:

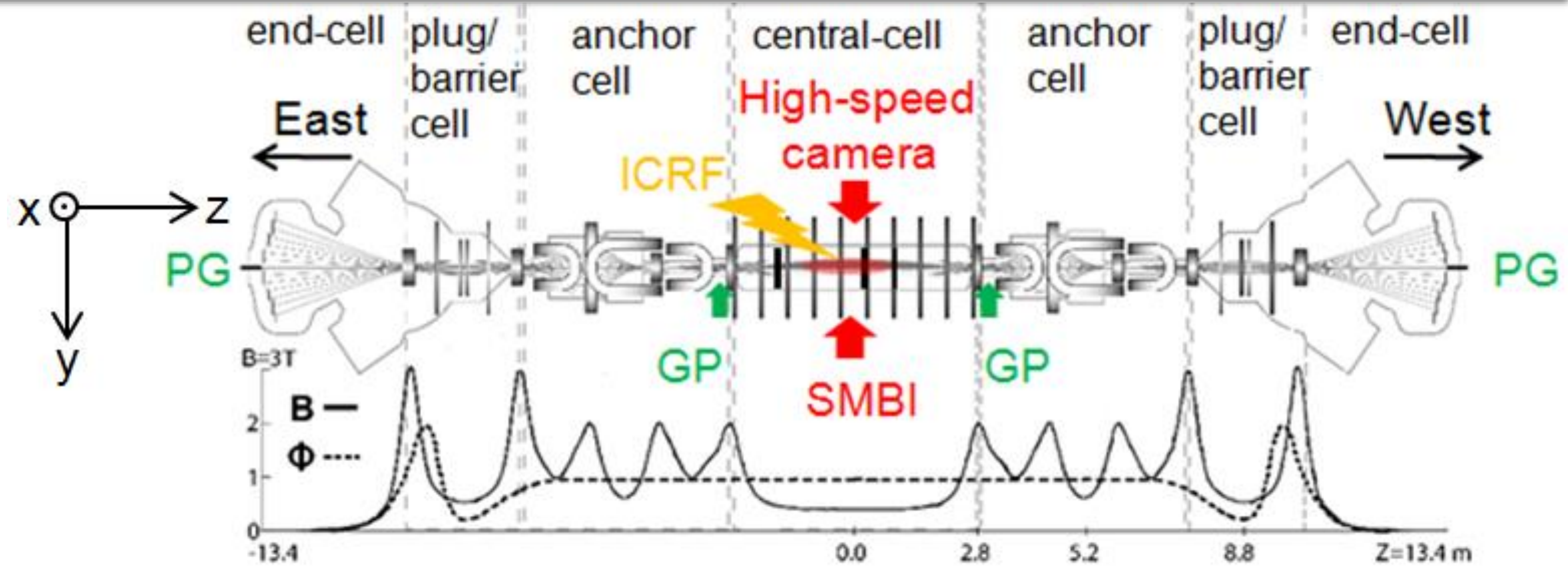
- ❖ Without any nozzle
- ❖ With straight nozzle
- ❖ With laval nozzle.

<Purpose>

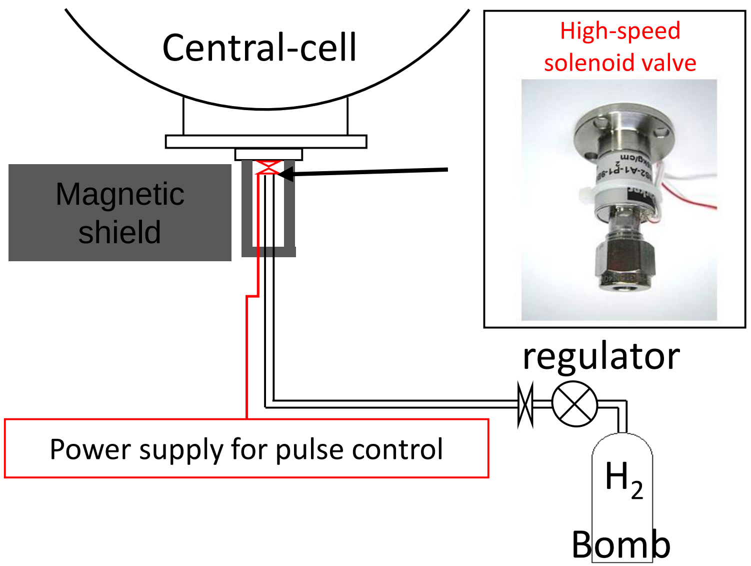
- ❖ To investigate the neutral particle during SMBI with laval nozzle by using high-speed camera and a Monte-Carlo simulation.
- ❖ To compare the results with obtained by straight nozzle.

- Neutral transport was estimated by using 2-D image of light emission during SMBI.
- The neutral transport was estimated by the calculated profile of Hα line light emission.
- Comparison between experimental and simulation results.

Experimental set up(G-10 & SMBI)



Overall view of GAMMA 10



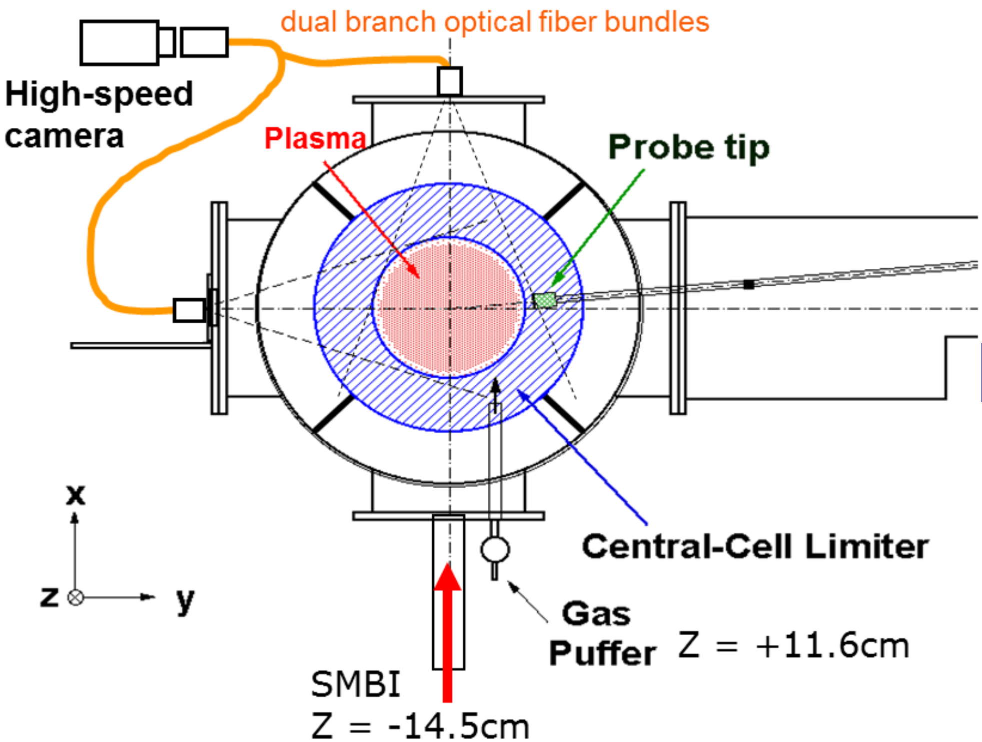
- The initial plasma is produced by plasma guns located in both ends. Then the plasma is heated by ion cyclotron range of frequency (ICRF) waves.

- The SMBI system consists of a fast solenoid valve with a magnetic shield. The plenum pressure is usually 1 MPa and pulse width is 0.5-1.0 ms.

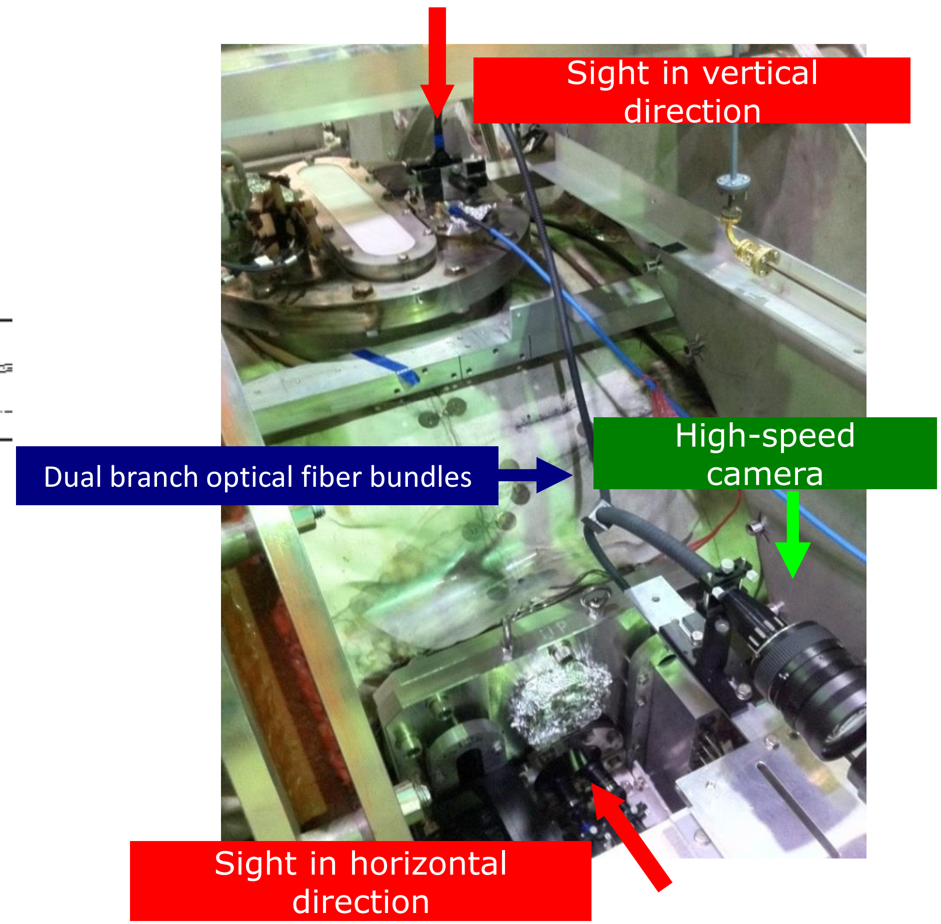
High-speed camera

A fast camera has been installed at the central-cell in order to observe plasma behavior. The camera system has two lines of sight in the horizontal and vertical direction of the cross-section by using dual branch optical fiber bundles.

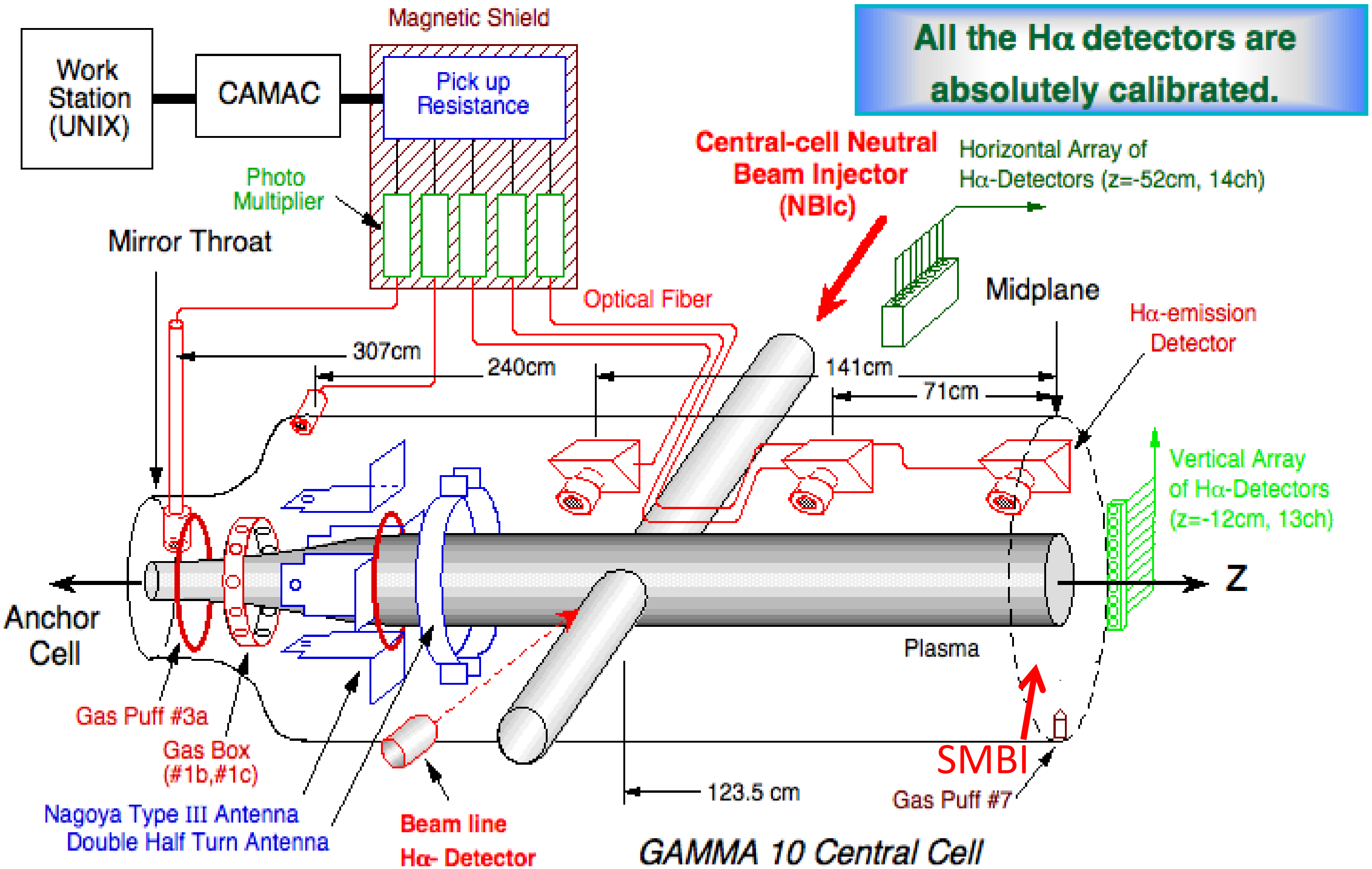
<cross-section of the central-cell midplane>



<Two-point Simultaneous Measurement System>



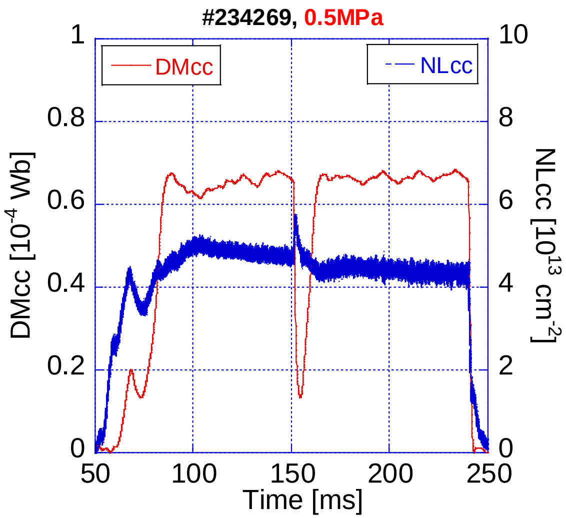
Hα line-emission detector system

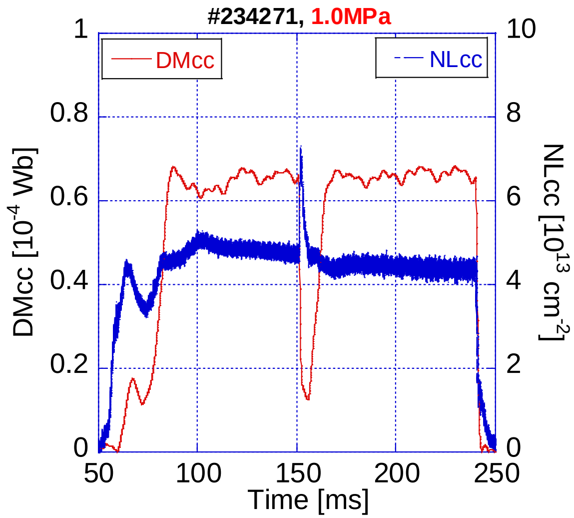


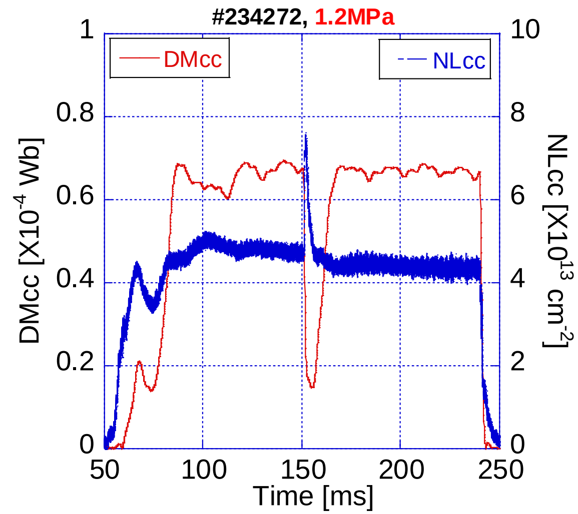
❖ Hα line emission detector consists of the Hα interference filter, a lens, an optical fiber and photomultiplier. The emission selected by the interference filter is obtained and is transferred to the photomultiplier with optical fiber. The optical signal is converted to the electronic signal in photomultiplier.

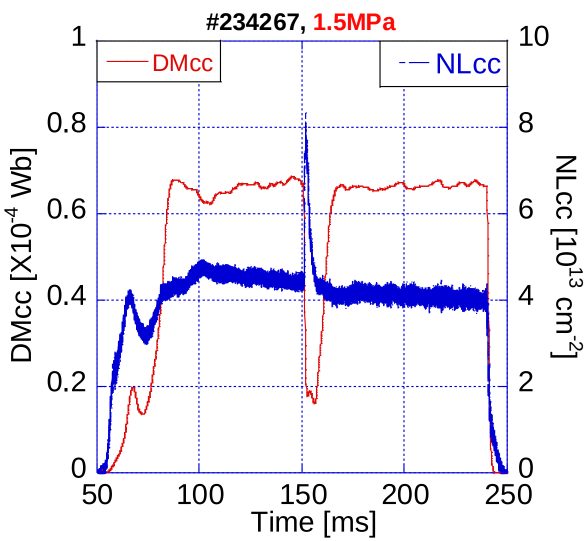
Typical experimental results of SMBI

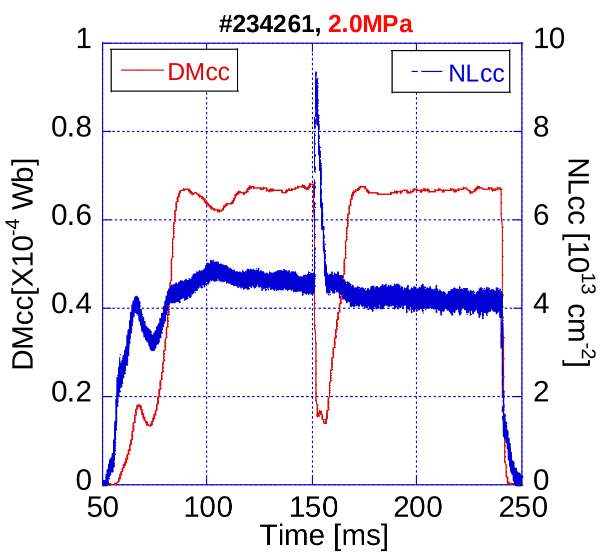
< Plenum pressure dependence of NLcc and DMcc in SMBI experiment>







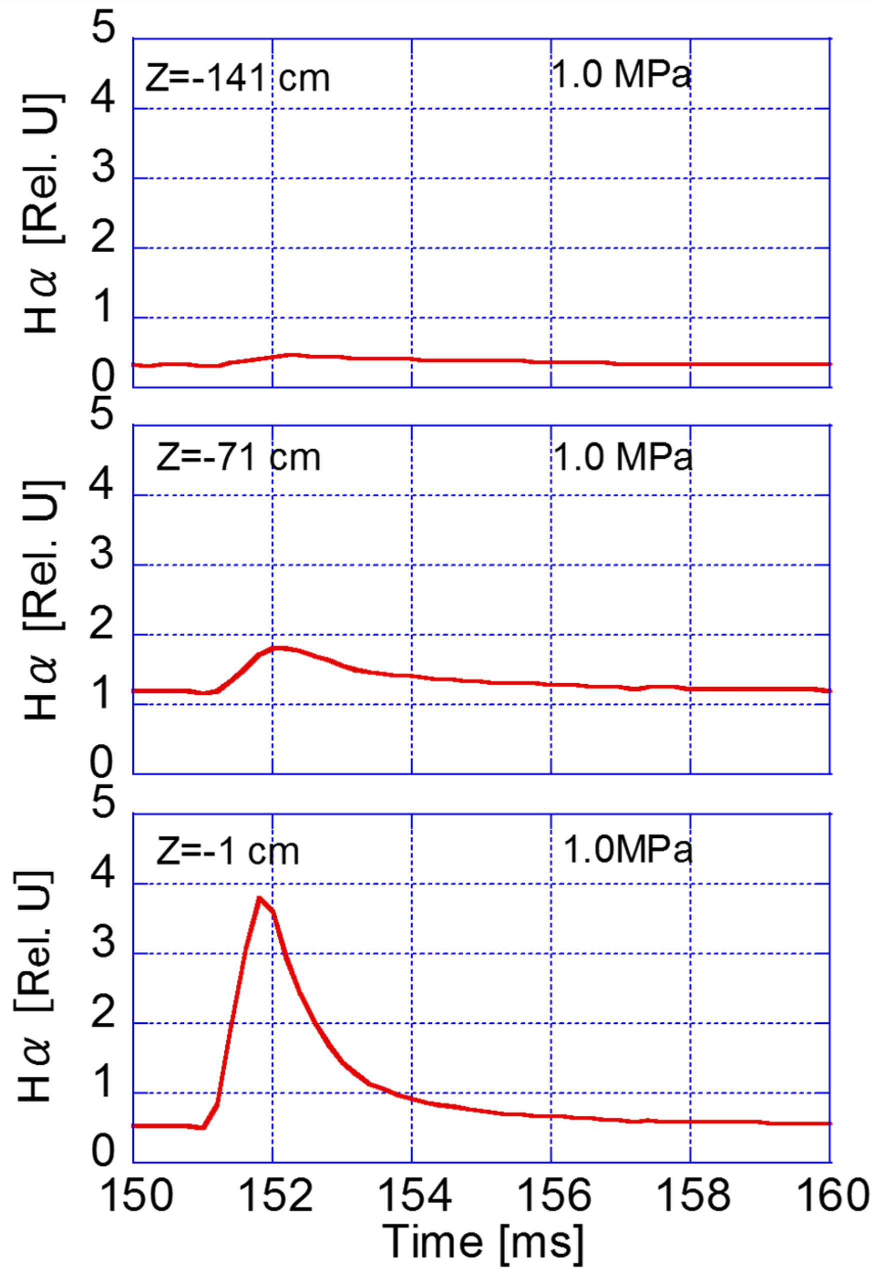




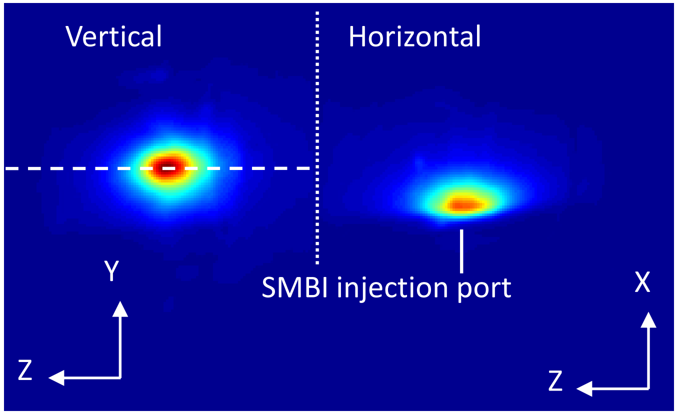
- SMBI is injected at 150 ms.
- Pulse duration: 0.5 ms (150-150.5 ms).
- NLcc increased but the DMcc decreased with plenum pressure [0.5MPa - 2.0MPa] during SMBI experiment with laval nozzle.

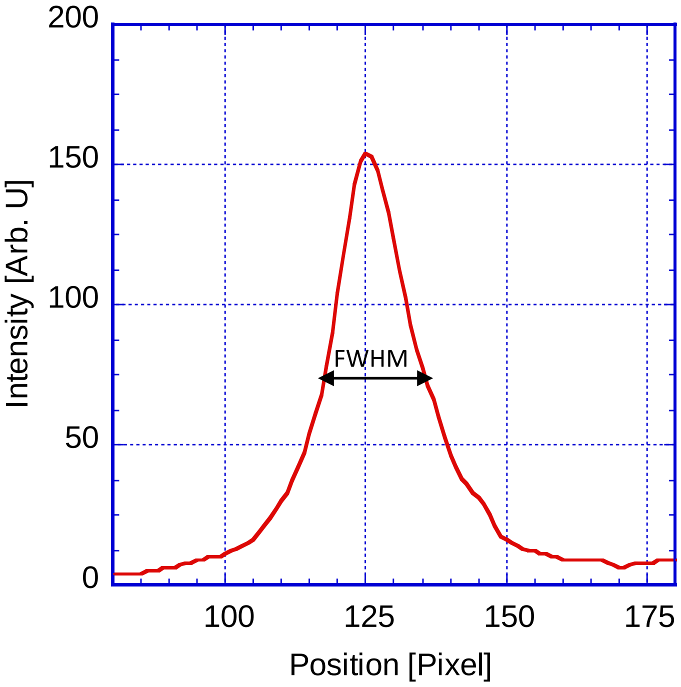
Hα Measurement

- To investigate the neutral behavior in the central cell, three Hα detectors have been installed at Z=-1 cm, Z=-71 cm and Z=-141 cm.
- Hα intensity was increased during SMBI. Hα at Z=-1 cm is higher, because this detector is close to the SMBI injection port (Z=-14 cm).
- The response of SMBI was decreased with increasing distance from the SMBI injection position.



Analysis of neutral transport

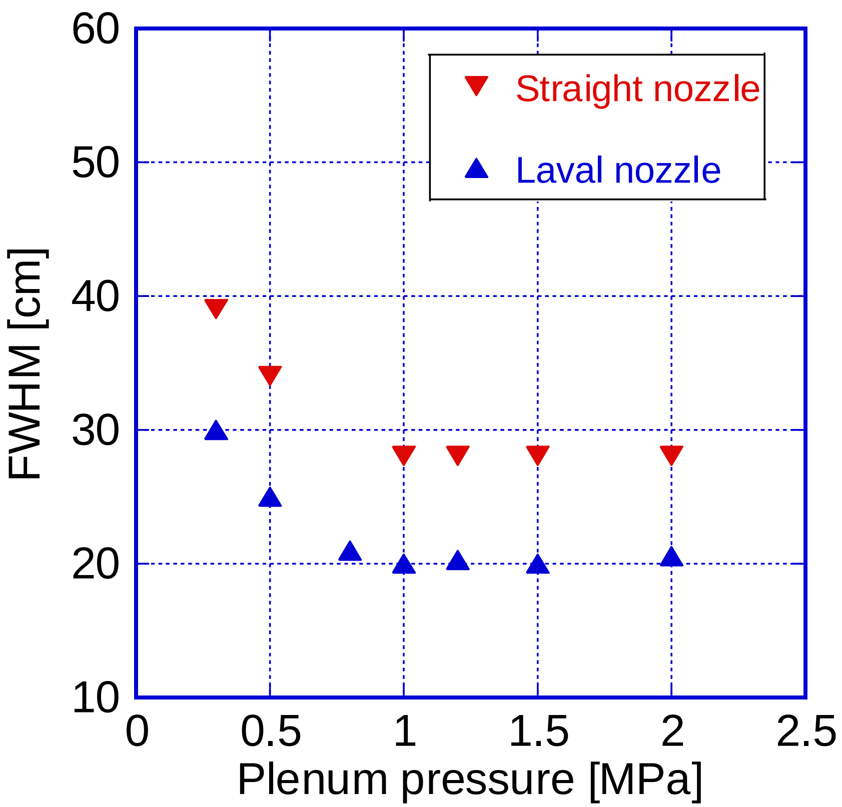




- 2-D image of visible emission during SMBI from GAMMA 10 plasma captured by high-speed camera.
- It took 1.2 ms to achieve the peak intensity after the SMBI. It indicates SMBI with laval nozzle is faster than that with straight nozzle (2ms)[2].
- To investigate the directivity of the molecular beam injected by SMBI, the axial profile of the neutral transport is investigated based on the 2-D vertical direction image.
- We used the full width at half maximum (FWHM) of the distribution of the emission intensity as an index of the axial neutral transport.

[1] K. Hosoi et al., J. Plasma Fusion Res. **7**, 2402126 (2012)
[2] K. Hosoi et al., J. of Trans. Fusion Sci. and Technol., **63**, 244 (2013)

Analysis of neutral transport



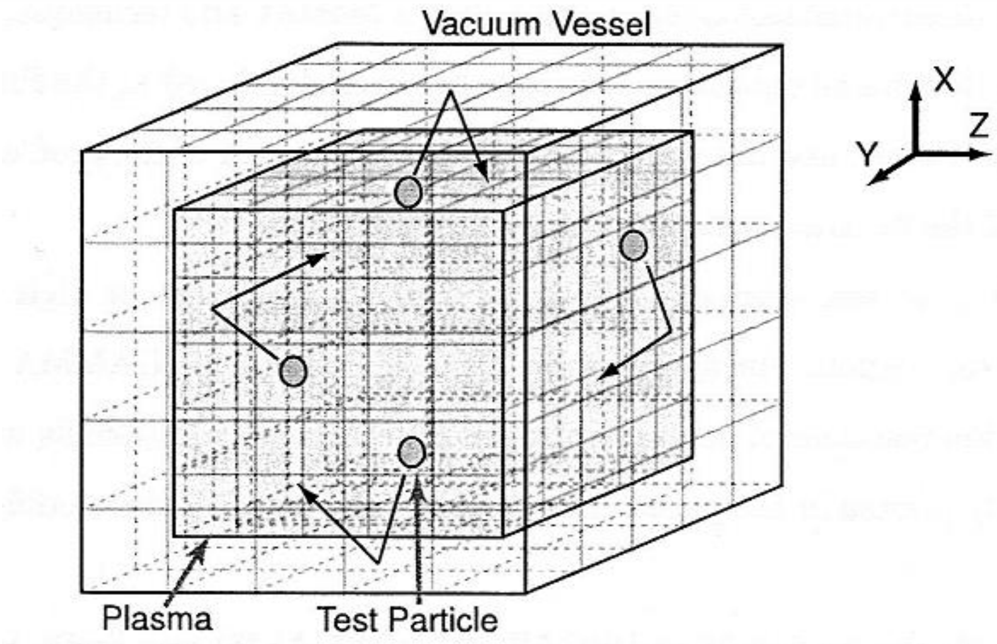
- Remarkable reduction of FWHM is achieved using laval nozzle.

- The FWHM value decreases with increasing the SMBI plenum pressure in both cases. In low plenum pressure the flow of molecular beam is thought to be not supersonic. The FWHM decrease with increasing plenum pressure up to 1.0MPa and then the flow become supersonic. At high plenum pressure (1.0 MPa or higher) FWHM is saturated it could be due to the convergence of molecular beam.

Simulation Results

Monte-Carlo Simulation Code (DEGAS)

DEGAS code
Schematic View



The DEGAS code is numerical calculation code that simulates the transport of neutral particles in 3-D plasma by using a Monte-Carlo technique.

- Simulation spaces are divided by mesh structures.
- Cell parameters are given from the experimental data.

Test particles as neutral hydrogen are traced through the simulation areas in consideration of physical processes (atomic-molecular processes, plasma-wall interactions, etc.).

D. Heifetz, D. Post, M. Petravic et al., J. Comput. Phys. **46**, 309 (1982).

Atomic and molecular process in the DEGAS code

Charge exchange :

$p + H \rightarrow H + p$
$H_2^+ + H_2 \rightarrow H_2 + H_2^+$
$p + H_2 \rightarrow H_2^+ + H$

Electron impact ionization :

$e + H \rightarrow e + H^+ + e$
$e + H_2 \rightarrow e + H_2^+ + e$

Ion impact ionization :

$p + H \rightarrow p + H^+ + e$
$p + H_2 \rightarrow p + H_2^+ + e$

Electron dissociation :

$e + H_2 \rightarrow e + H + H$
$e + H_2 \rightarrow e + H + H^+ + e$
$e + H_2^+ \rightarrow H + H$
$e + H_2^+ \rightarrow e + H^+ + H$
$e + H_2^+ \rightarrow e + H^+ + H^+ + e$

Recombination :

$e + p \rightarrow H$

Monte-Carlo Simulation Code (DEGAS)

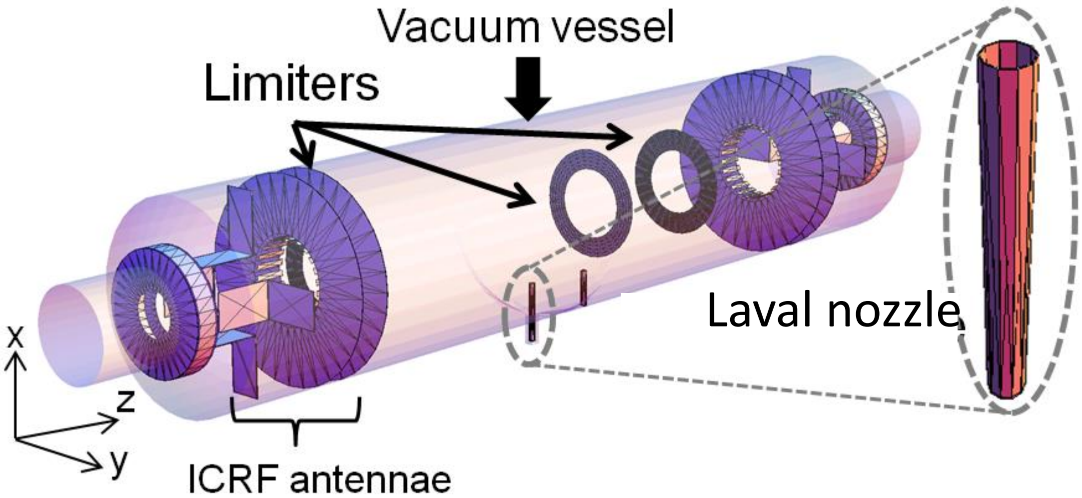
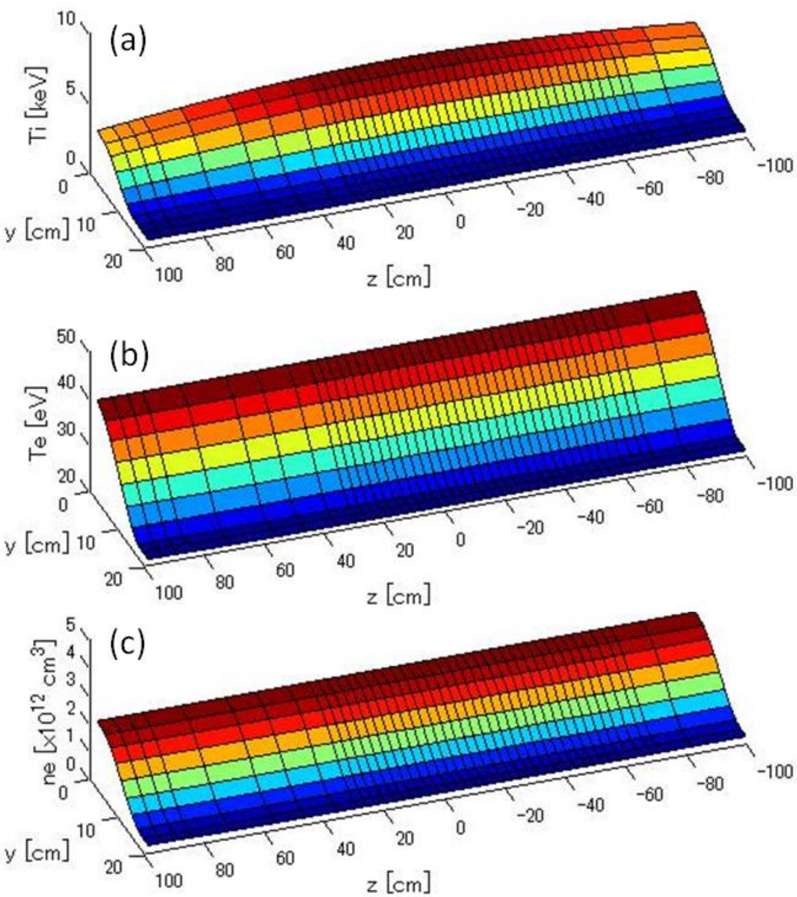
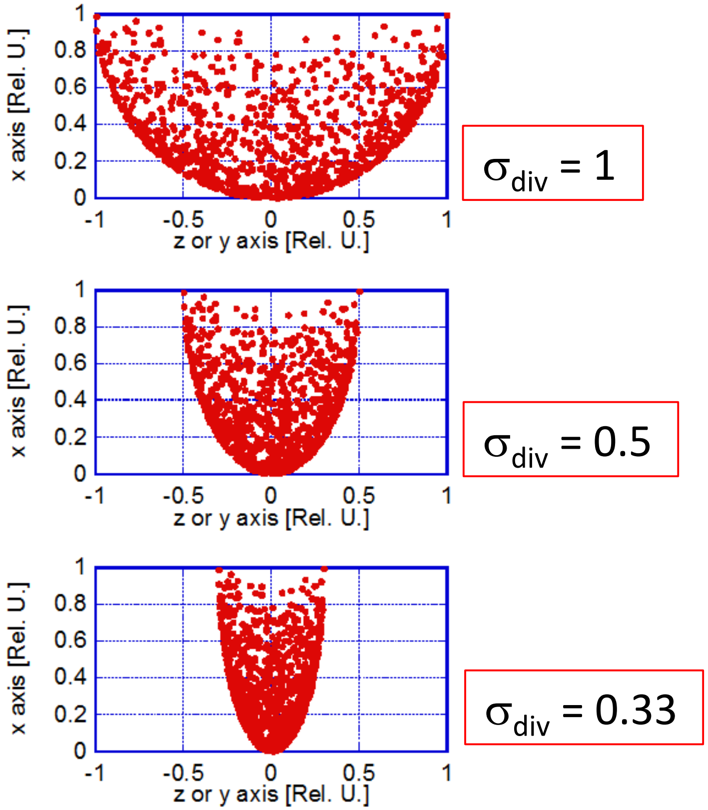


Fig. Fully 3-D mesh model applied to the central cell.



- ❖ In this mesh model, the limiters and antennae of the ICRF are precisely implemented in a realistic configuration.
- ❖ Furthermore this mesh model was improved for modeling SMBI experiments; it was expanded around the SMBI injection port and new mesh was added in a realistic configuration about the SMBI valve, straight nozzle, laval nozzle.
- ❖ The background plasma parameters ($T_e \approx 40$ eV, $T_i \approx 5$ keV, $n_e = n_i \approx 2.0\times10^{12}$ cm^{-3}, *etc*) on each mesh were determined based on the experimental data.

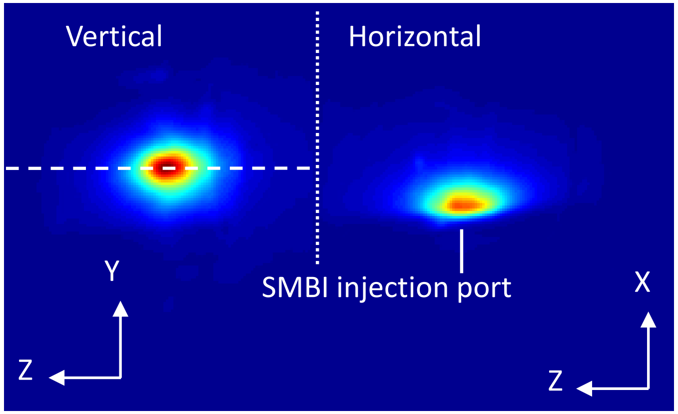
Initial condition of test particles



Initial condition of test particles.
(σ_{div} = 1 : cosine distribution)

- In the DEGAS simulation in GAMMA 10, neutral source is given in a cosine distribution. However the neutral source from SMBI makes different profile from the conventional process such as gas puffer and recycling phenomena according to the experimental results. Hence, the neutral source is modified for the neutral source due to the SMBI.
- To simulate the molecular beam injected by SMBI, we introduce σ_{div} to index the divergence angle of the initial particles.
- If the angular profile of launched particles has a cosine distribution, the divergence-angle index is $\sigma_{div} = 1$.
- If $\sigma_{div} = 0.5$, the horizontal component of the velocity vector in the cosine distribution is reduced to half.

Comparison between experimental and simulation results



(a)

(b)

Comparison between (a) 2-D image captured by high-speed camera
(b) 2-D Hα image calculated by DEGAS code.

Summary

Main results are obtained as follows:

<Experiments>

- ❖ The FWHM value of Hα emission during SMBI with laval nozzle is lower than that with the straight nozzle. So, the effect of the Laval nozzle reduces the diffusion of the neutral particle from SMBI in the peripheral region. At high plenum pressure (1.0 MPa or higher) FWHM is saturated.

<Simulation>

- ❖ The simulation work has been started by using a Monte-Carlo technique under initial condition of different divergence angle index.
- ❖ Above results contribute to the optimization of fueling.

Thank you for your kind attention

The End