Divertor geometry effects on particle pumping in JT-60U and DIII-D

H. Takenaga, A. Sakasai, H. Kubo, N. Asakura

Japan Atomic Energy Research Institute, Naka-machi Naka-gun Ibaraki-ken, 311-0193, Japan

M.J. Schaffer, T.W. Petrie, M.A. Mahdavi, D.R. Baker

General Atomics, P.O. Box 85608, San Diego, CA, 92186-5608, USA

S.L. Allen, G.D. Porter, T.D. Rognlien, M.E. Rensink

Lawrence Livermore National Laboratory, Livermore, CA, USA

D.P. Stotler, C.F.F. Karney

Princeton Plasma Physics Laboratory, Princeton, NJ, 08543, USA

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Divertor Geometry Effects on Particle Pumping in JT-60U and DIII-D[1] H. TAKENAGA, A SAKASAI, H. KUBO, N. ASAKURA, Japan Atomic Energy Research Institute, M.J. SCHAFFER, T.W. PETRIE, M.A. MAHDAVI, D.R. BAKER, General Atomics, S.L. ALLEN, G.D. PORTER, T.D. ROGNLIEN, M.E. RENSINK, Lawrence Livermore National Laboratory, D.P. STOLTER, C.F.F. KARNEY, Princeton Plasma Physics Laboratory — Several types of pumped divertors have been installed in tokamaks. It is important to compare the pumping characteristics with different divertor geometries for optimization of the divertor pumping scheme. In the W-shaped divertor of JT-60U with the pumping from the inner private flux region, the divertor pumping rate was estimated to be 2.4% of the divertor particle flux in the high density region, and it depended strongly on the main plasma density. In DIII–D with the pumping from the outer divertor region, a large divertor pumping rate was observed, due to the pumping configuration. Also a strong dependence on the main plasma density was observed. The comparison of the pumping characteristics between JT-60U and DIII–D will be presented based on analysis results using the UEDGE/DEGAS2 modeling.

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☐ Prefer Oral Session
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D.R. Baker
baker@gav.gat.com
General Atomics

Special instructions: DIII-D Poster Session 2, immediately following JR Watkins

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OUTLINE

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3. Pumping characteristics

4. UEDGE/DEGAS2 modelling

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Introduction

Background

Divertor pumping is important for
- Density control in the main plasma for fusion power control
- Divertor control for effective heat removal
- Effective helium ash exhaust

Several types of divertor geometry are adopted in tokamaks
- Open, semi-closed and closed divertor
- Horizontal, inclined and vertical targets and dome
- Strike-point pumping and private flux pumping

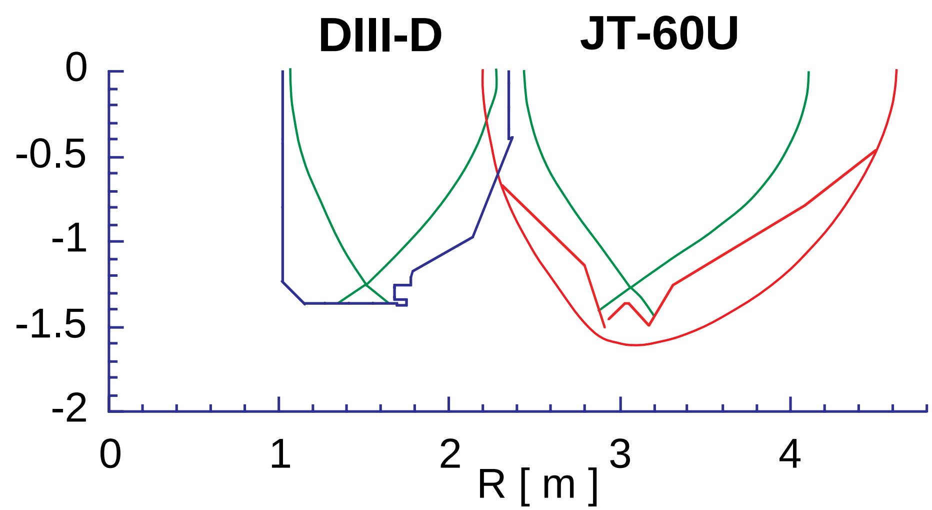
Which is the best for pumping?

Objectives

To clarify the geometry effects on particle pumping.

⬇

Optimization of pumping scheme in a future machine



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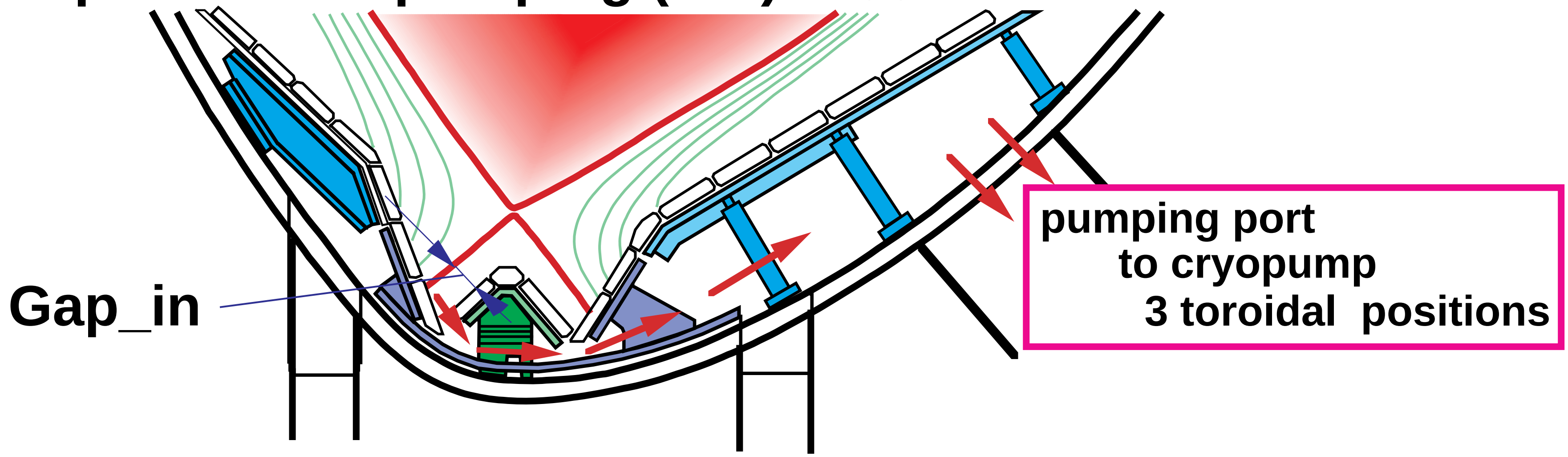
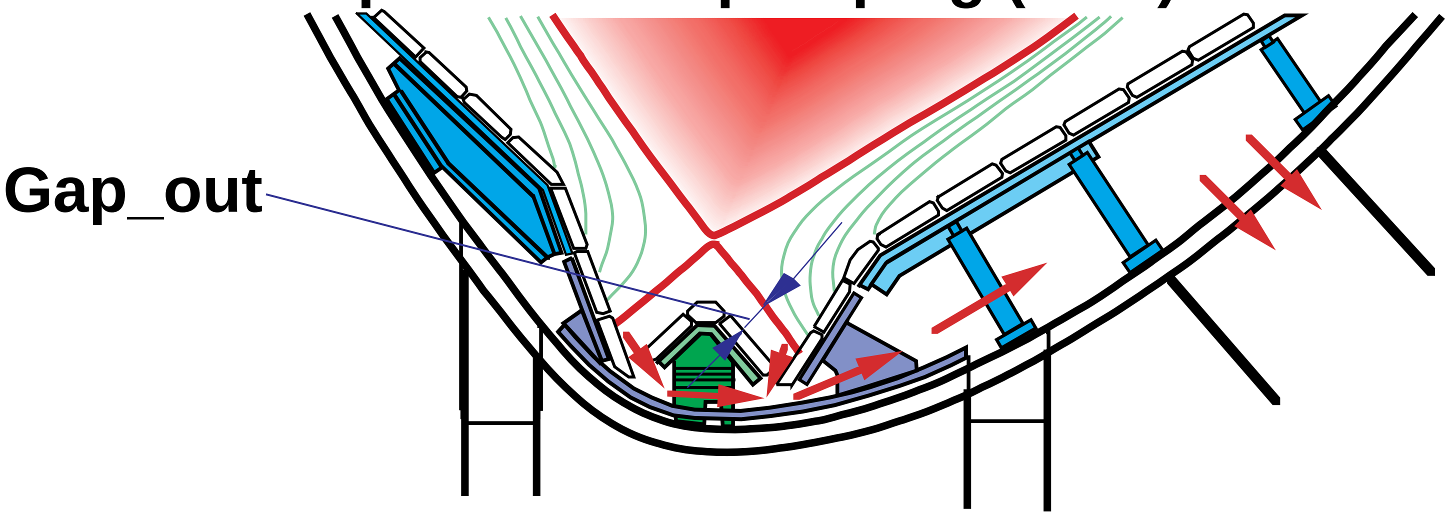
Divertor geometry in JT-60U

W-shaped pumped divertor

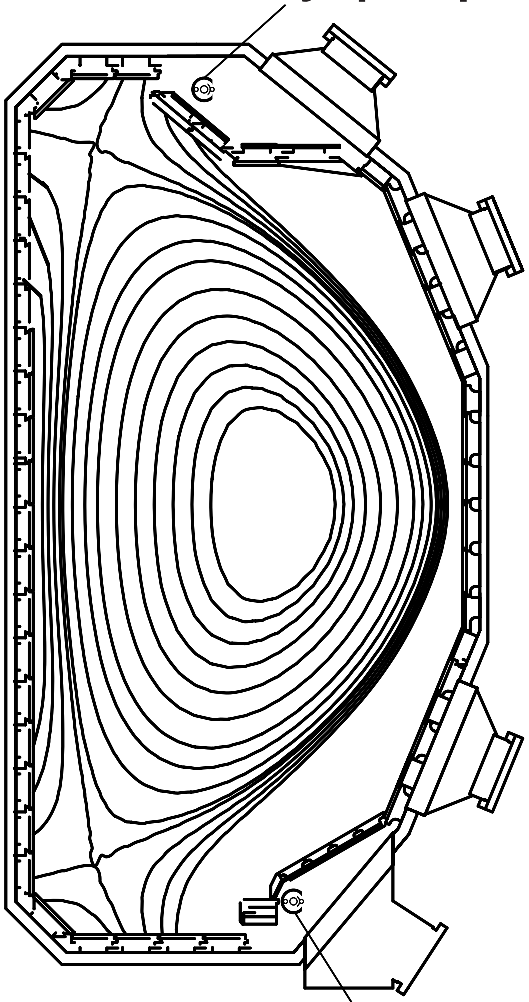
Inner private flux pumping (IPP) 1997~



Both side private flux pumping (BPP) 1999~



Divertor geometry in DIII-D

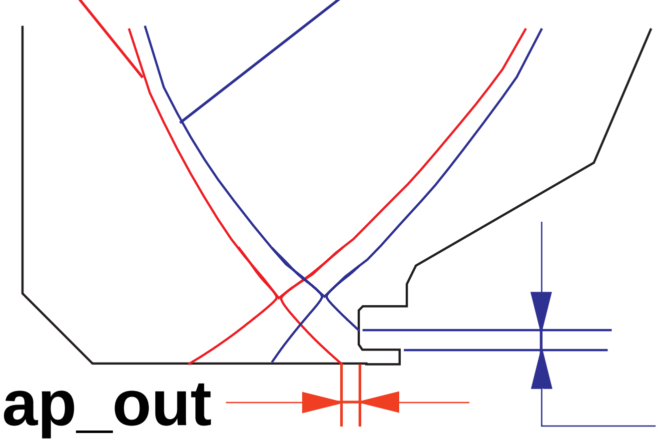


Upper divertor (Baffled divertor)

- **Outer strike-point pumping (UOP)**

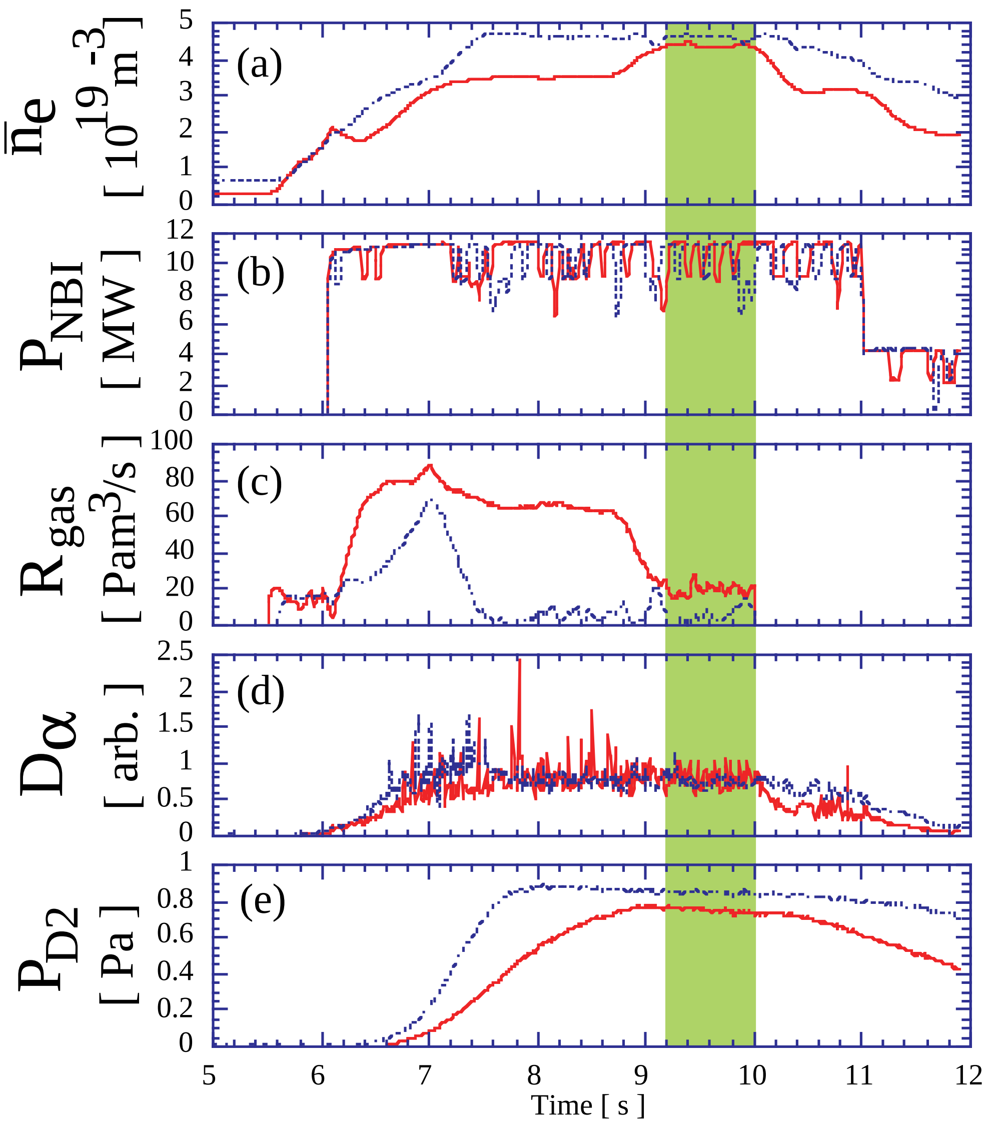
Lower divertor (Open divertor)

- **Outer strike-point pumping (LOP)**
- **Private flux pumping (LPP)**



Estimation of pumping flux in JT-60U

w pump, w/o pump



Inner private flux pumping

I_p=1.5 MA, B_T=3.5 T, q_{95}=3.94,

Gap_in=3.5 cm

w pump

$\Phi_{NB}+\Phi_{GP}^1=\Phi_{absorb}+\Phi_{pump}$

w/o pump

$\Phi_{NB}+\Phi_{GP}^2=\Phi_{absorb}$

$\Phi_{GP}^1-\Phi_{GP}^2=\Phi_{pump}$

$\Phi_{NB}=1\times10^{21}$ /s

$\Phi_{GP}^1=1\times10^{22}$/s

$\Phi_{GP}^2=3.9\times10^{21}$/s

$\Phi_{pump}=6.2\times10^{21}$ /s

$\Phi_{absorb}=4.9\times10^{21}$ /s

Pumping speed~31 m^3/s

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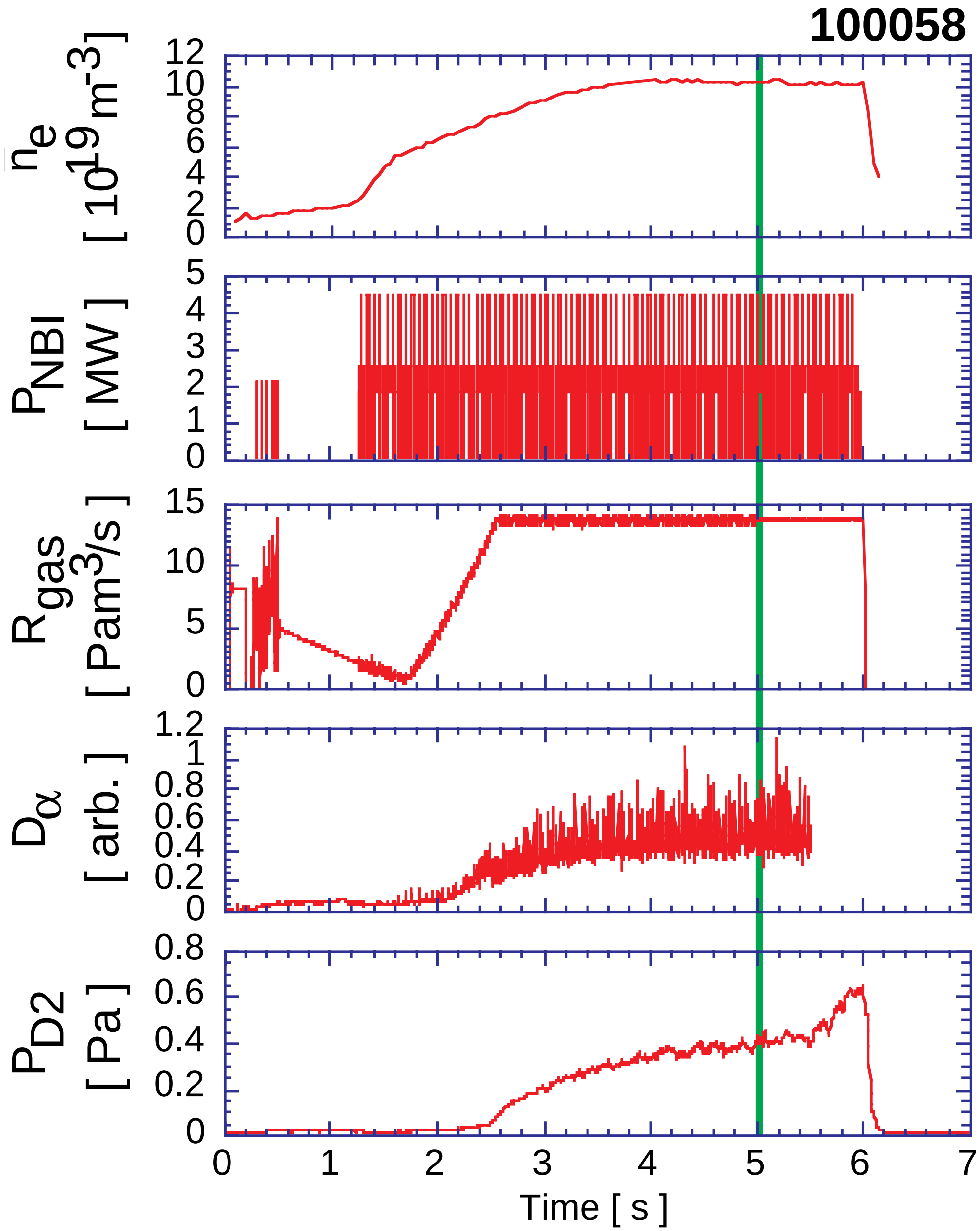
Estimation of pumping flux in DIII-D



Outer strike-point pumping

I_p=1.2 MA , B_T=-1.6 T,

q_{95}=3.0, Gap_in= 3.1 cm

Φ_{pump} =(Pumping speed)$\times P_{D2}$

$= 43.7\ m^3/s \times 0.39$ Pa

$= 16.9\ Pam^3/s$

$= 8.45\times10^{21}$ /s

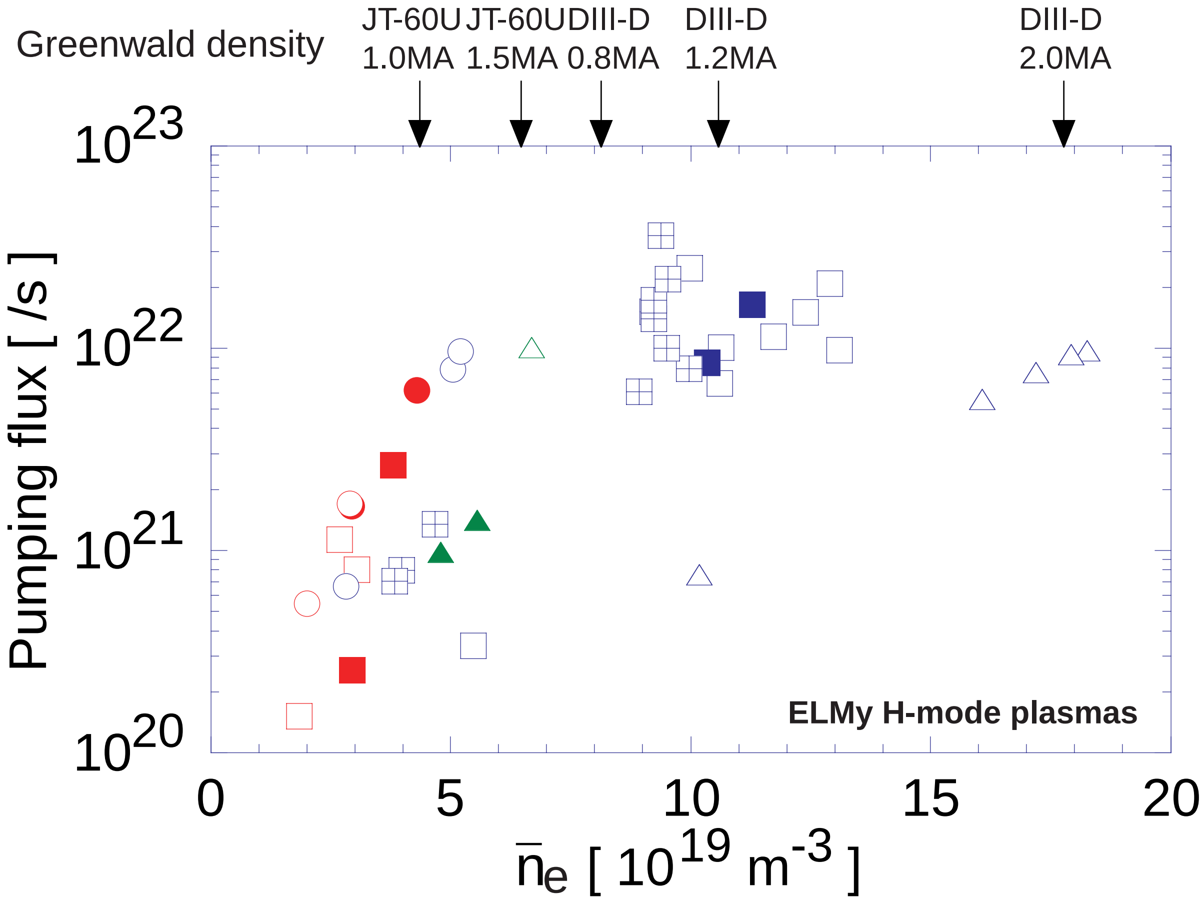
$\Phi_{NB} = 2.7\times10^{20}$ /s

$\Phi_{GP} = 6.9\times10^{21}$ /s

$\Phi_{absorb} = \Phi_{GP} + \Phi_{NB} - \Phi_{pump}$

$= -1.3\times10^{21}$/s (fuelling)

Density dependence



JT-60U

IPP ● I_p=1.5 MA, B_T=3.5 T, P_{NBI}=12 MW, Gap_in=3.5 cm

○ I_p=1.0 MA, B_T=3.8 T, P_{NBI}=12 MW, Gap_in=3.5 cm

BPP ■ I_p=1.5 MA, B_T=3.5 T, P_{NBI}=12 MW, Gap_out=3.0 cm, Gap_in=3.5 cm

□ I_p=1.0 MA, B_T=3.8 T, P_{NBI}=12 MW, Gap_out=3.0 cm, Gap_in=3.5 cm

DIII-D

LPP ○ I_p=0.8 MA, B_T=-1.6 T, P_{NBI}=3.2 MW, Gap_out=1.9-3.8 cm

□ I_p=1.2 MA, B_T=-1.6 T, P_{NBI}=1.8-2.5 MW, Gap_out=2-3.2 cm

⊞ I_p=1.2 MA, B_T=-2.1 T, P_{NBI}=3.1-5.5 MW, Gap_out=1.7-3.4 cm

△ I_p=2 MA, B_T=-1.6 T, P_{NBI}=3.1-4.3 MW, Gap_out=2.1-2.9 cm

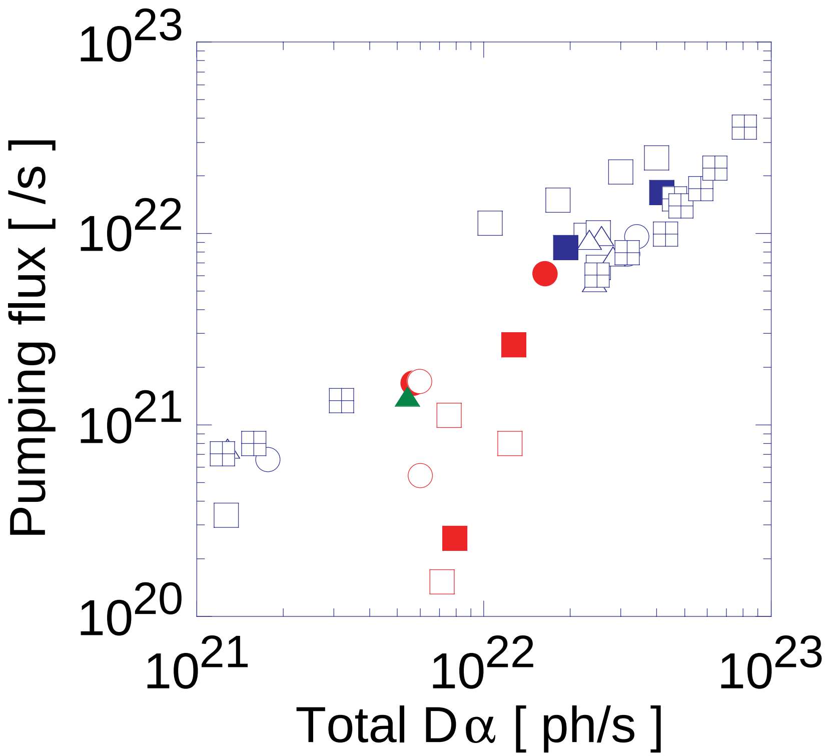
LOP ■ I_p=1.2 MA, B_T=-1.6 T, P_{NBI}=2 MW, Gap_out=3.8-4.9 cm

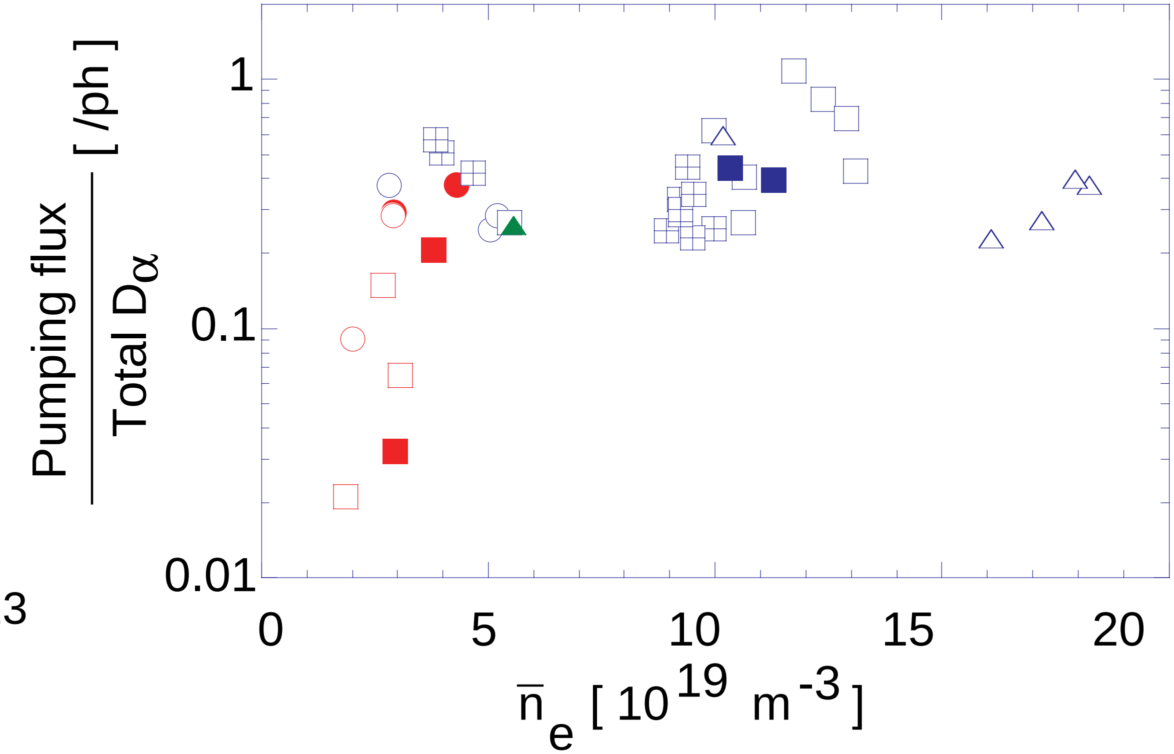
UOP ▲ I_p=1.5 MA, B_T=2.1 T, P_{NBI}=6.5 MW, Gap_out=1 cm

△ I_p=1.5 MA, B_T=2.1 T, P_{NBI}=6.5 MW, Gap_out=5.7 cm

- **DIII-D LPP data at Ip=0.8 MA is comparable or smaller than JT-60U IPP data.**
- **JT-60U BPP data is smaller than JT-60U IPP data, especially for low density case.**
- **Different dependence on plasma current in DIII-D LPP could be ascribed to different particle confinement.**

$\overline{n}_e$ vs pumping flux / total Dα





- **In JT-60U, pumping flux/total D_α, which indicates the pumping ratio, is comparable with that in DIII-D in the high density regime. However, it decreases in the low density regime.**
- **In DIII-D, the decrease of pumping flux/total D_α is not observed.**
- **The difference between JT-60U and DIII-D might come from the cryopump position.**
- **In DIII-D, the difference for different pumping scheme is not obvious.**

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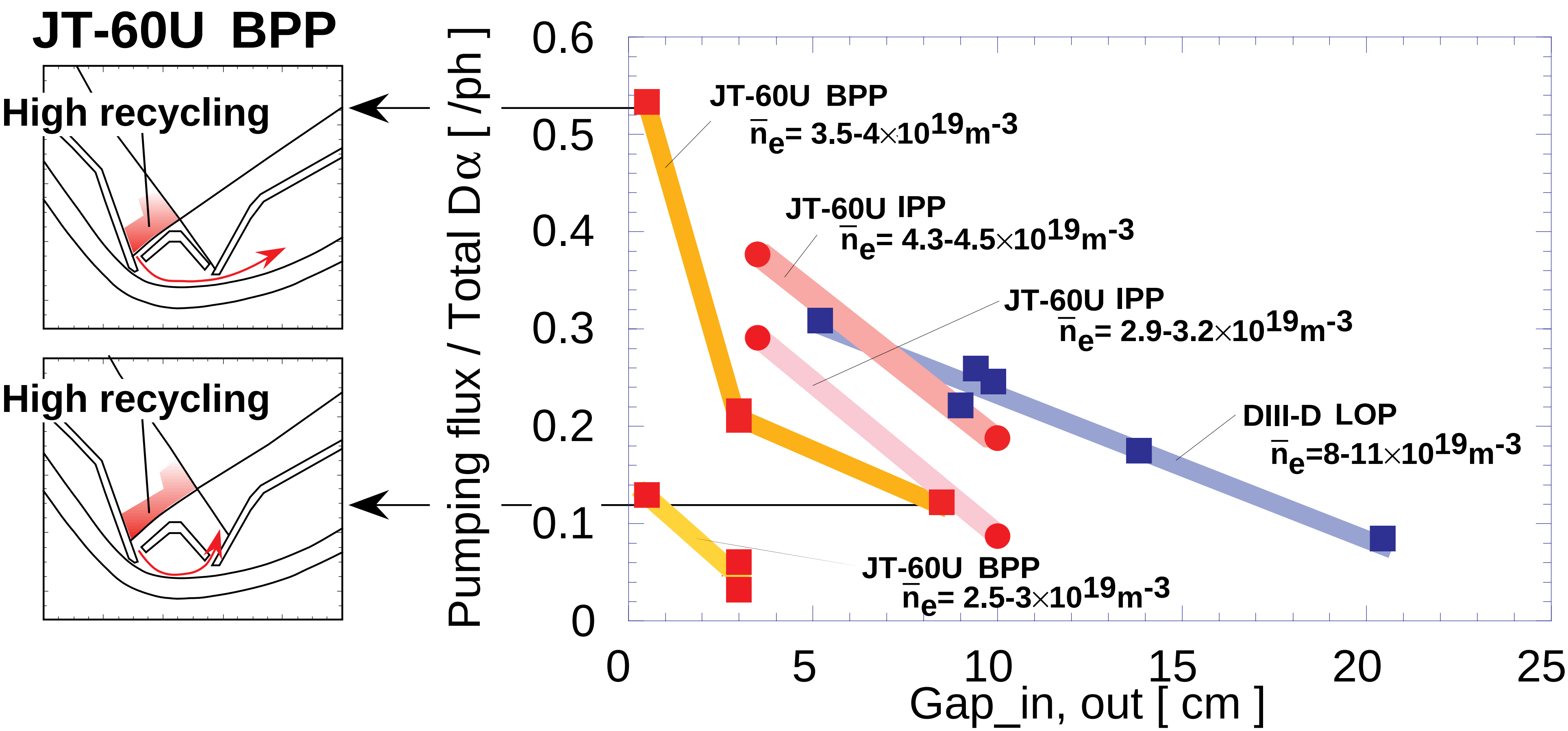
Gap dependence



- DIII-D LOP data is similar as JT-60U IPP high density data.
- JT-60U BPP high density data steeply decreases with Gap_out and is smaller than JT-60U IPP high density data at the same gap. It could be related to the back flow at the outer gap as shown in the inset due to in-out asymmetry.
- JT-60U BPP low density data becomes small due to strong in-out asymmetry even at small gap.

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UEDGE/DEGAS2 Modelling

Neutral behavior — DEGAS2

3-D Monte-Carlo code

Background plasma — UEDGE

2-D fluid code
fluid neutral model
sputtered impurity

- In this presentation, an iterative calculation between DEGAS2 and UEDGE was not performed.
- Pumping flux was calculated for various fpump which is the pumping ratio at the pumping slot.
- The background plasma was fixed during fpump scan.

  It means that the particle flux same as the pumping flux is fuelled to keep the plasma parameters.

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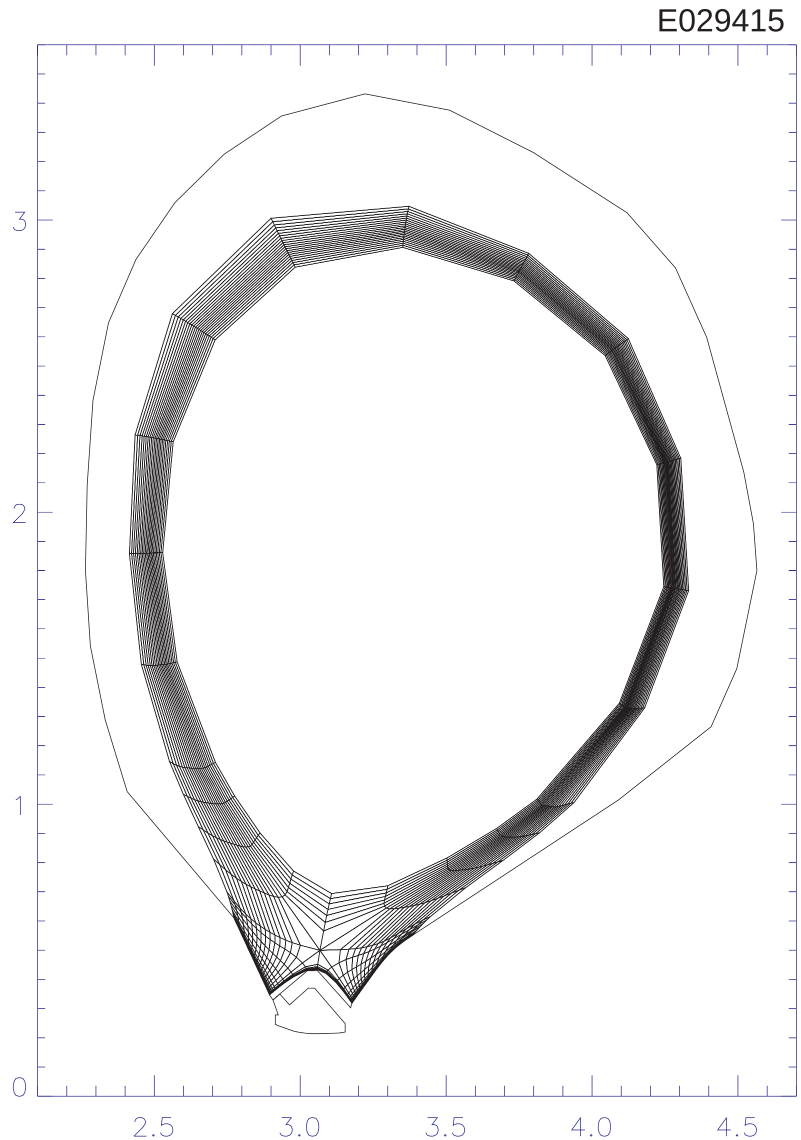
Calculation mesh for JT-60U



UEDGE parameters

$n_{core} = 2.4 \times 10^{19}\ m^{-3}$, $P_{core} = 7.0$ MW

$D = 0.25\ m^2/s$, $\chi = 1.0\ m^2/s$

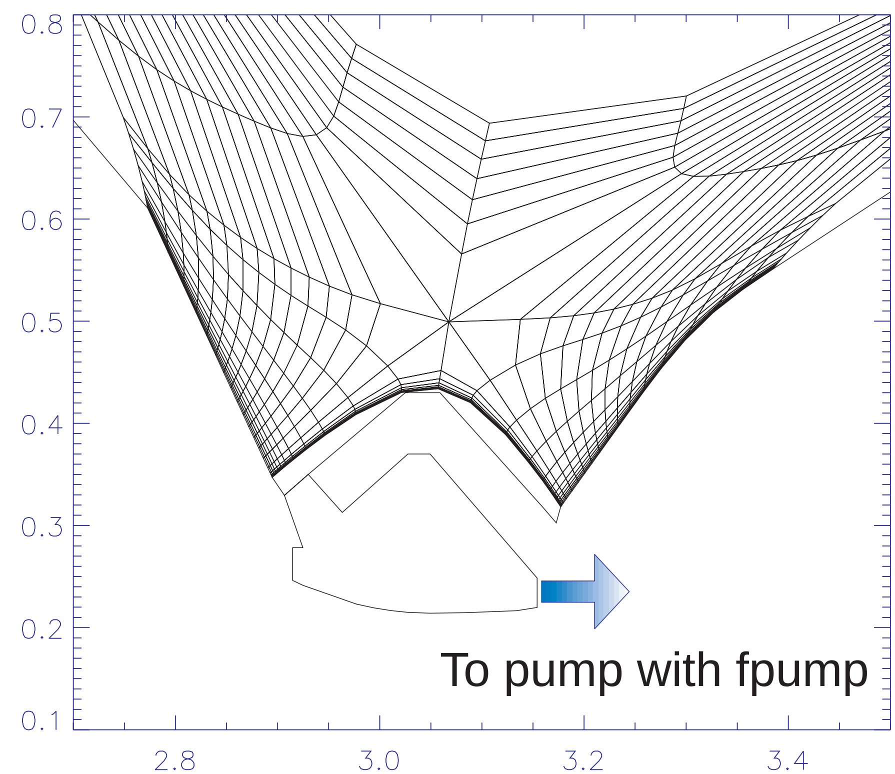
$R_{recycl} = 0.985$

Carbon yield=$0.5 \times$(Haasz yield)

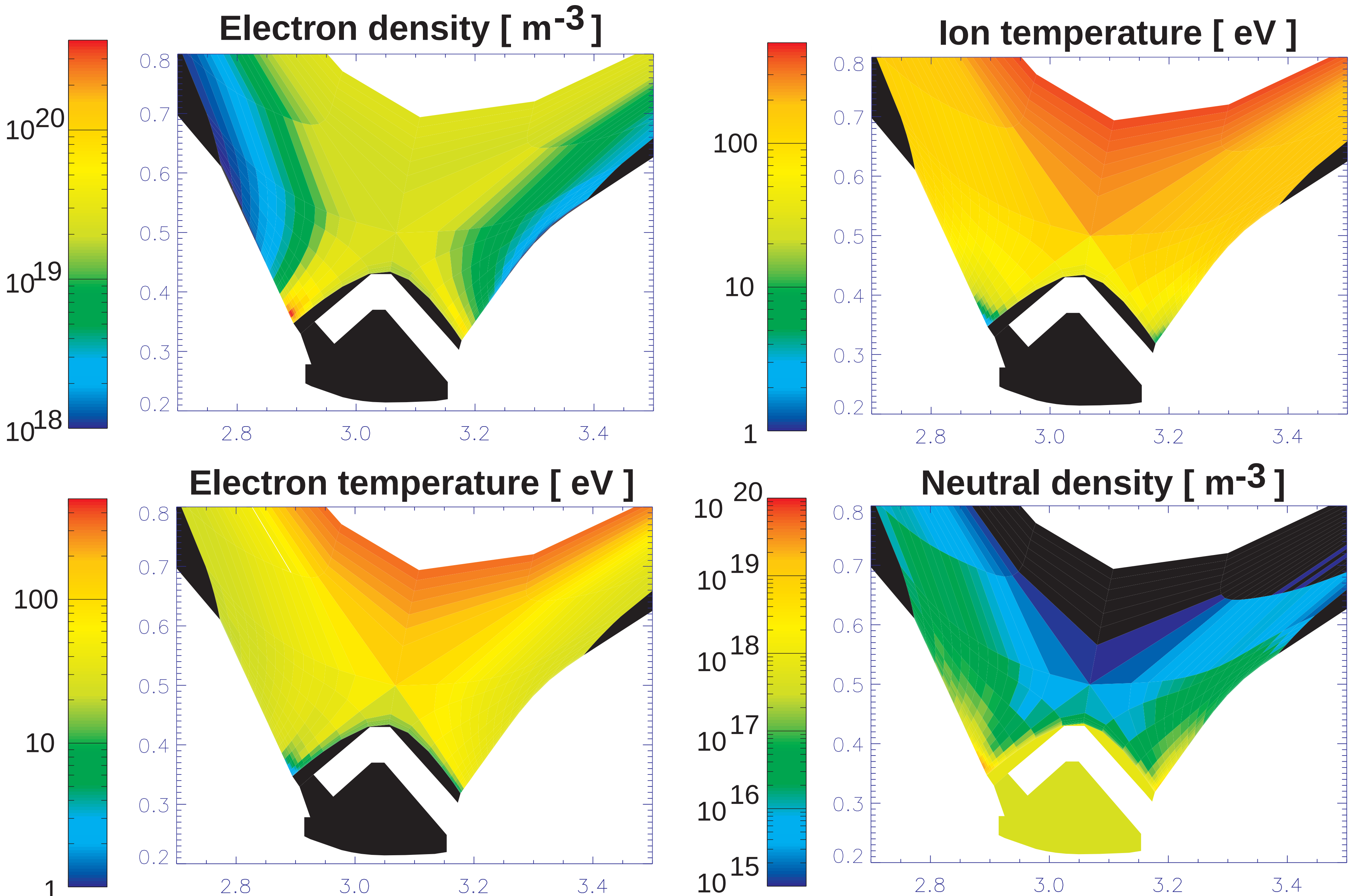
DEGAS2 parameters

$R_{recycl} = 0.995$ (wall), 1.0 (under dome)

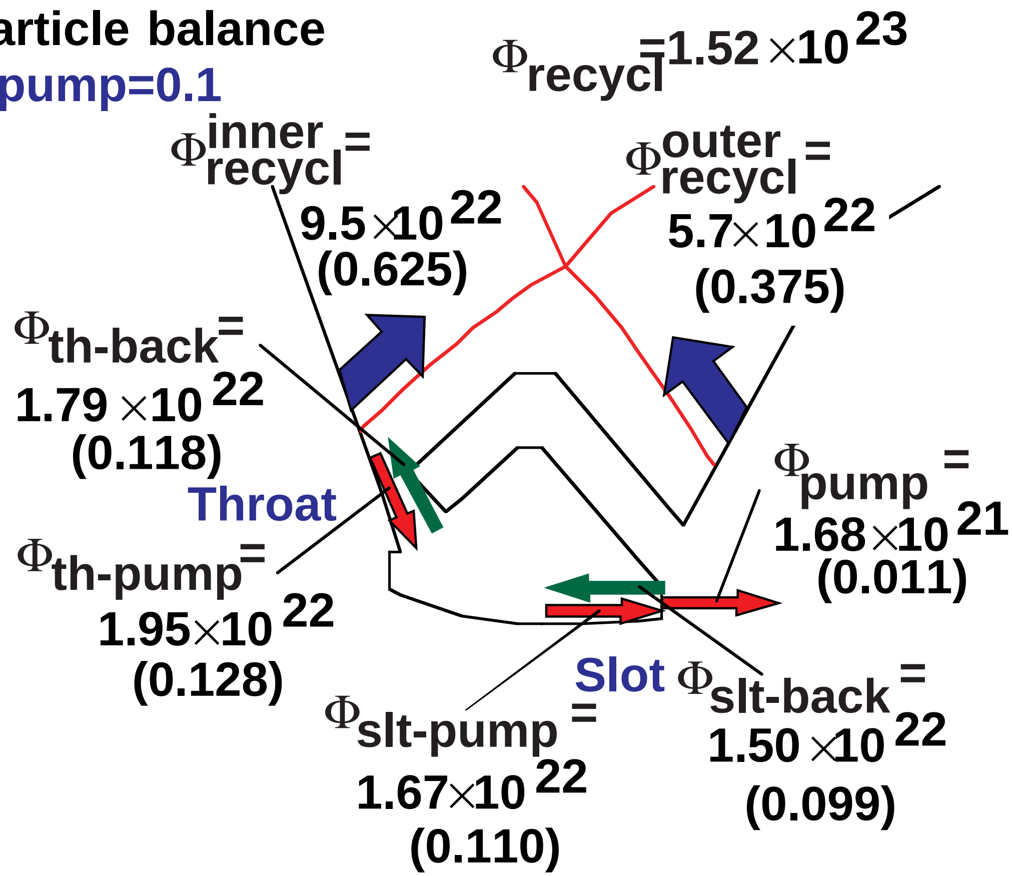
$T_{wall} = 300\,^{\circ}C$

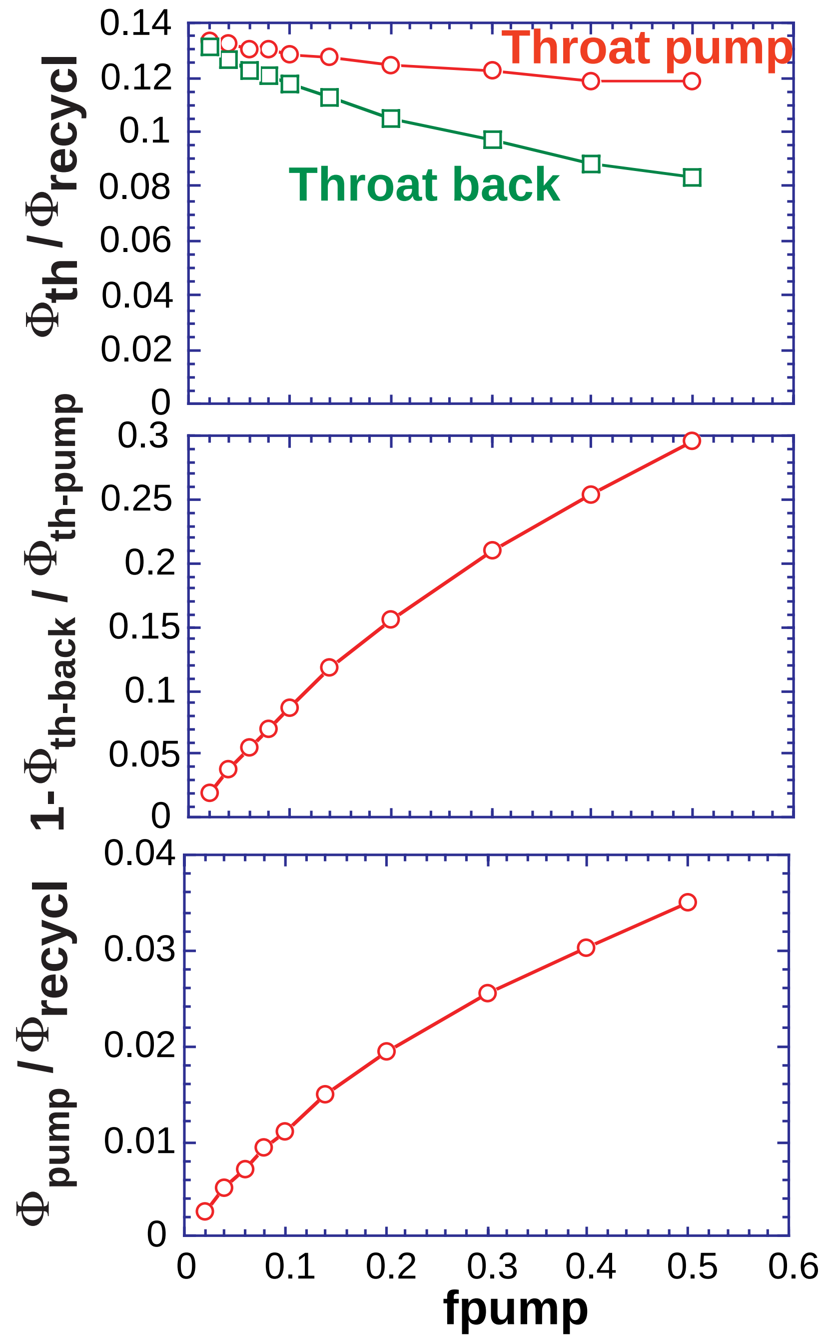


Calculation results with fpump=0.1



Calculation results 2 - fpump scan





- The calculated total Dα is smaller by a factor of 4 than experiment (Pcore of 7MA is different from the experimental value of 11MW).
- The pumping flux/total D$_\alpha$ with fpump=0.08 is almost the same as experiment.

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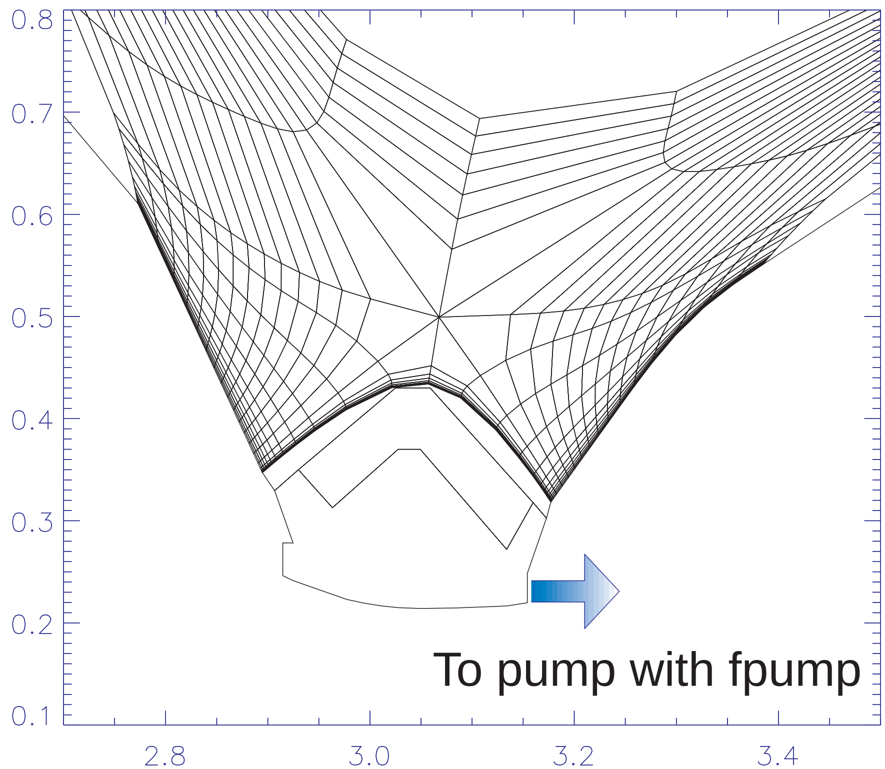
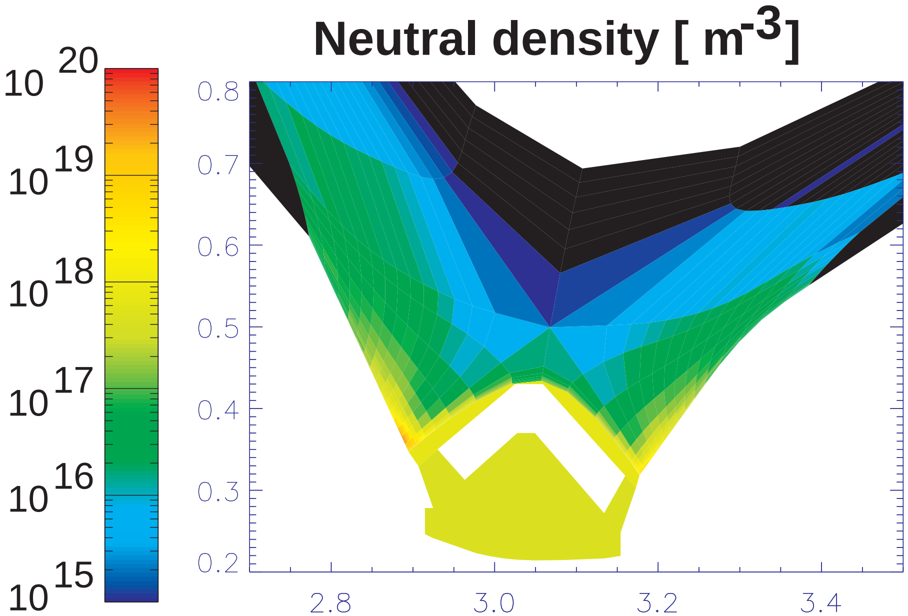
Both side private flux pumping

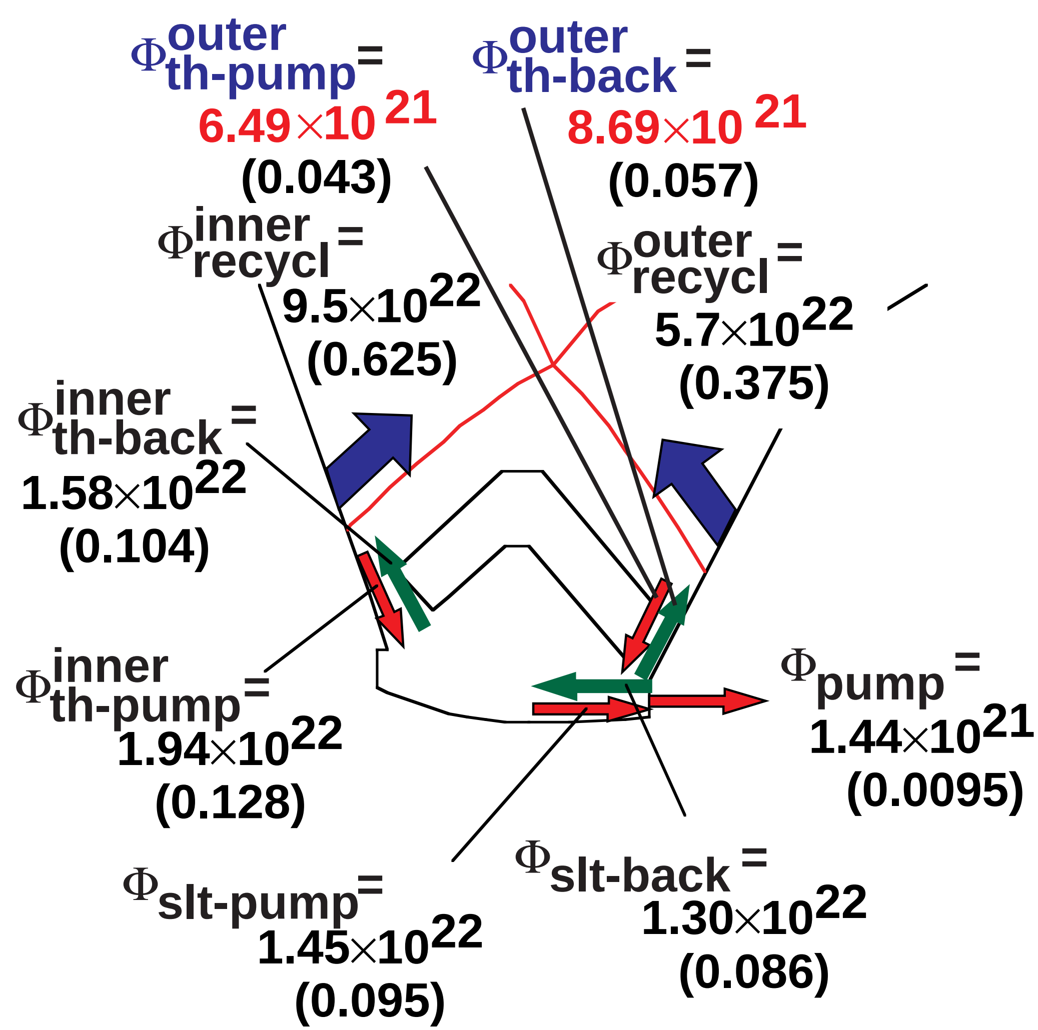




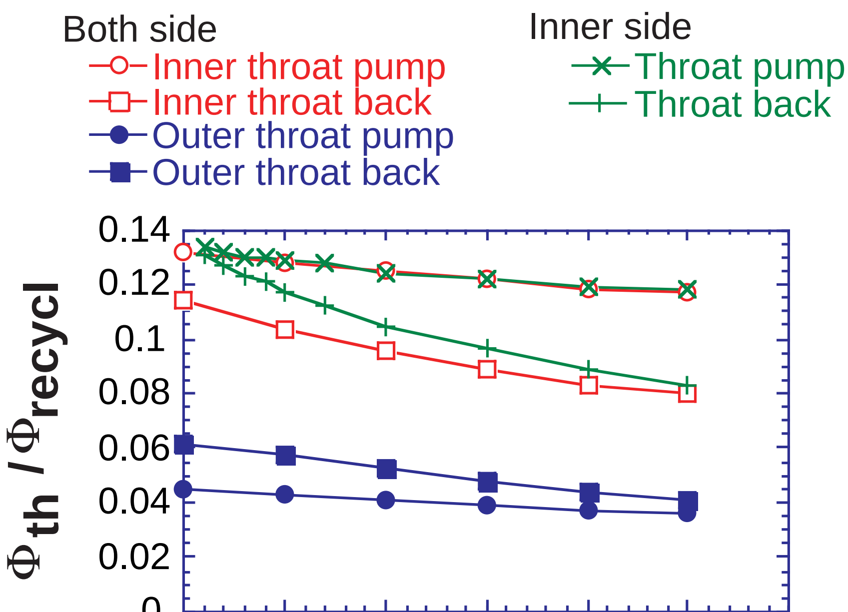
Particle balance

fpump=0.1

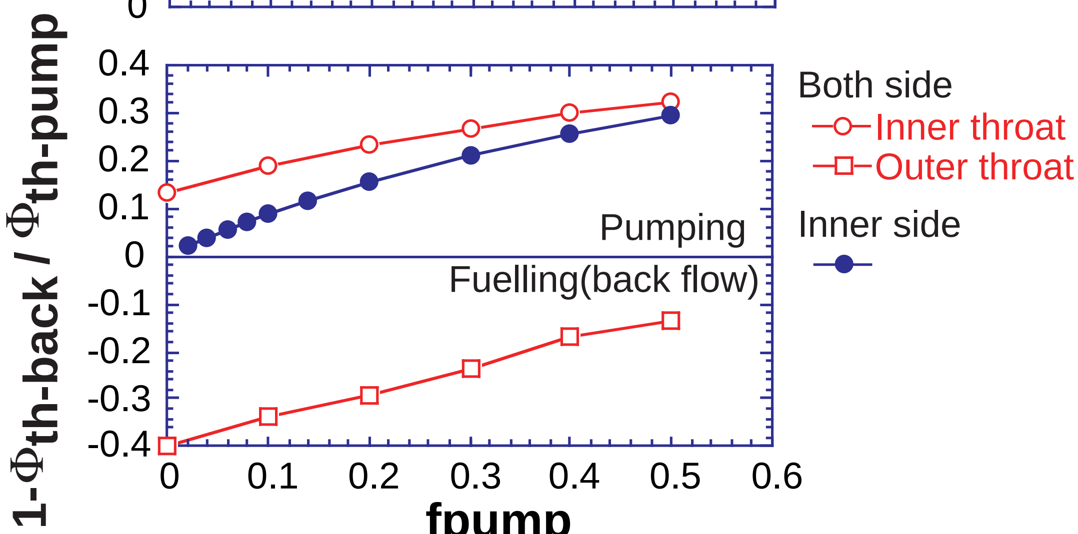
Φ_{recycl} =1.52 $\times 10^{23}$

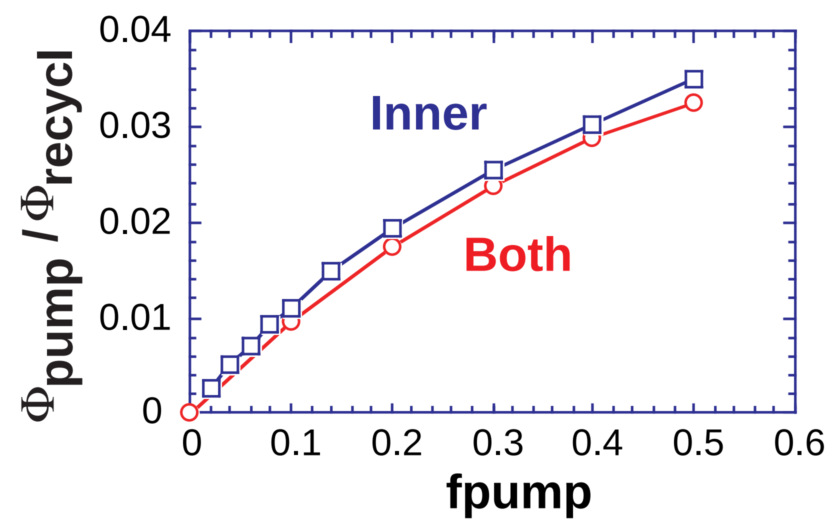


Comparison between inner and both side



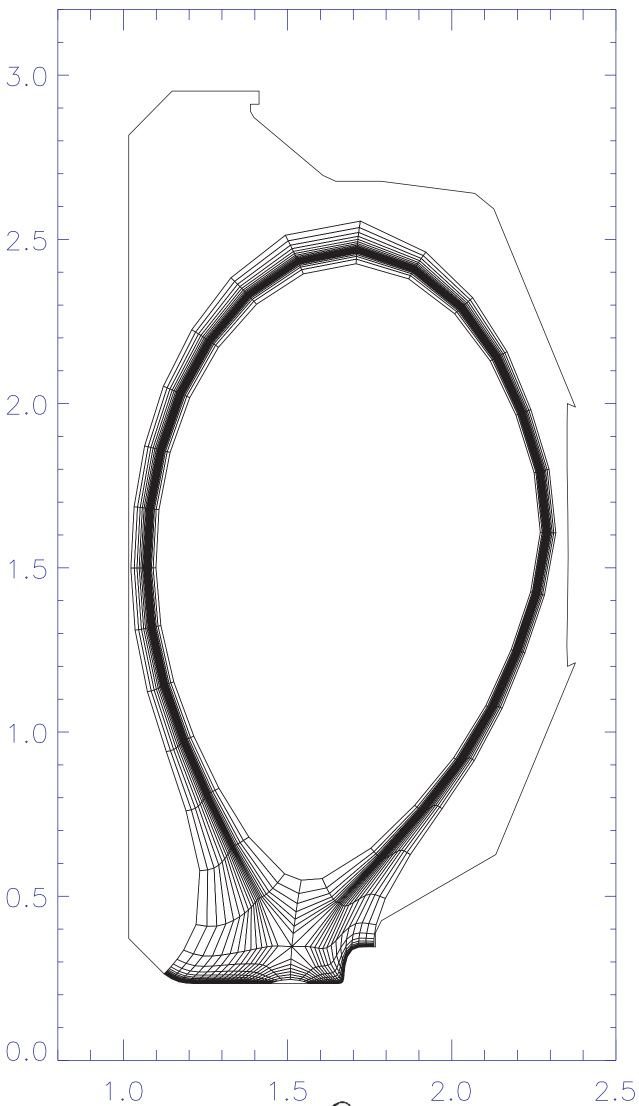
- $\Phi^{outer}_{th\text{-}back}$ is larger than $\Phi^{outer}_{th\text{-}pump}$, which suggests the back flow at the outer throat from under the dome due to in-out asymmetry as expected from the experiment.
- However, pumping flux in both side private flux pumping is smaller by a only few percent than inner side private flux pumping at the same fpump.
- Calculated pumping flux/total Dα with fpump=0.05 is the same as experiments.





Calculation mesh for DIII-D

Outer strike-point pumping

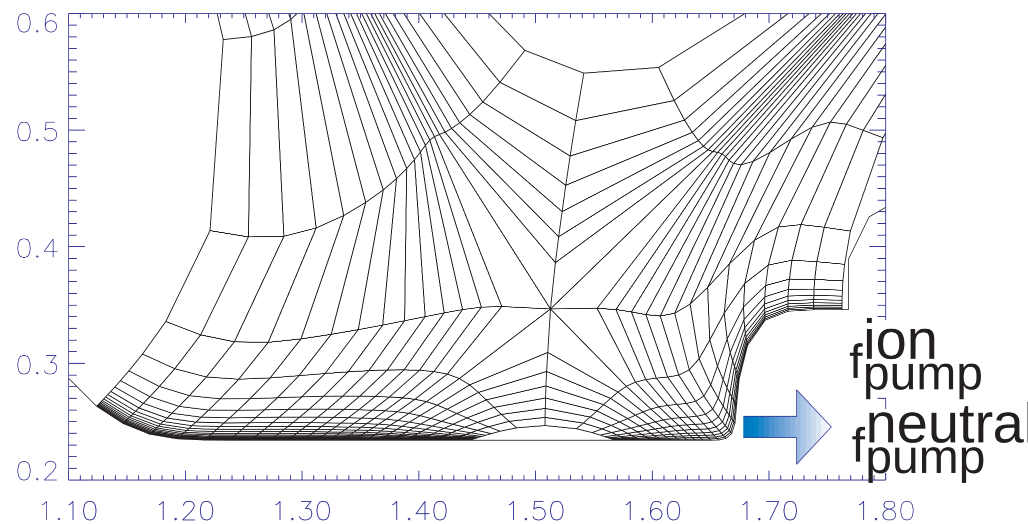


UEDGE parameters

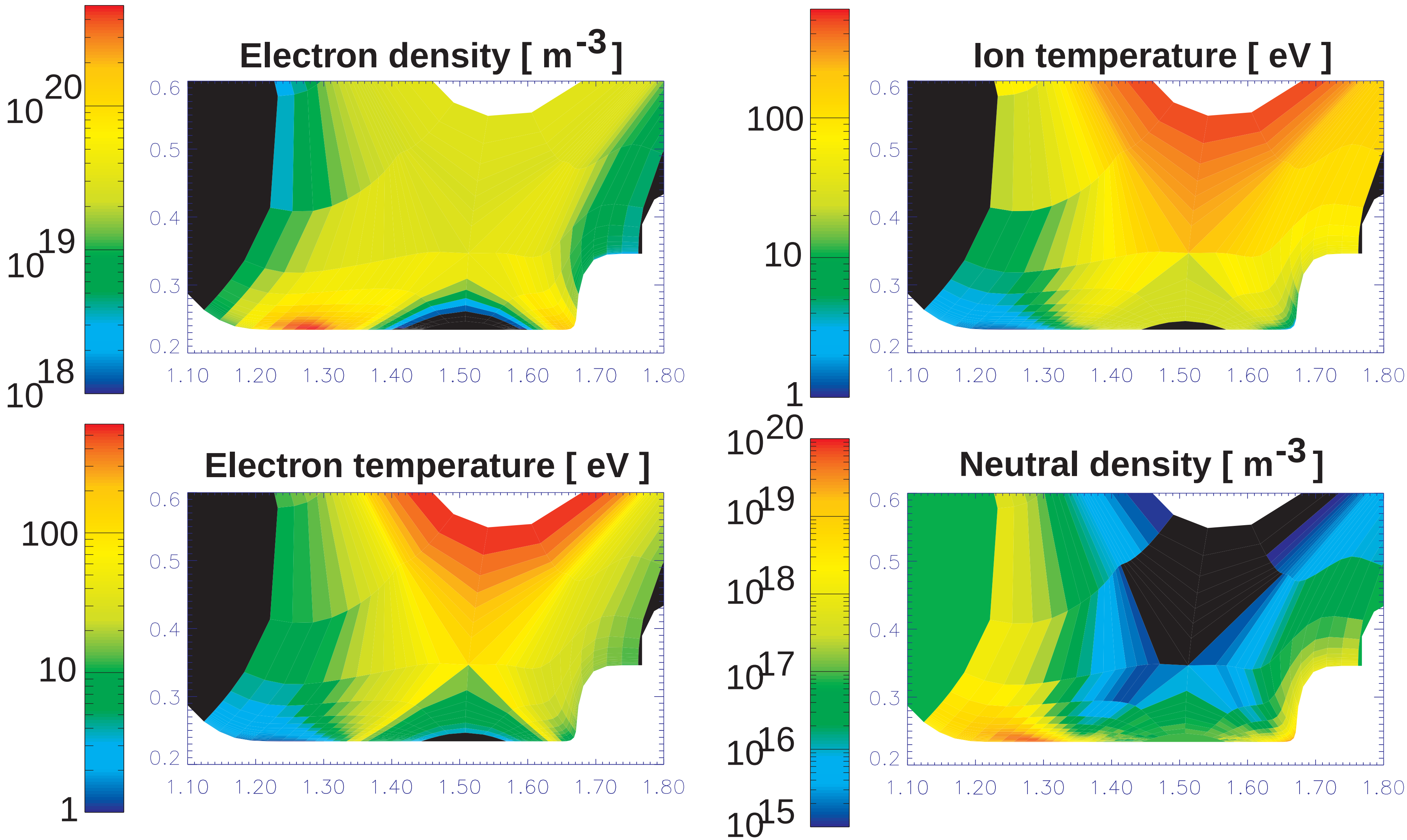
- $n_{core} = 2.75 \times 10^{19}\ m^{-3}$
- $P_{core} = 5.0$ MW
- $D = 0.2\ m^2/s$, $\chi = 0.4\ m^2/s$
- $R_{recycl} = 1.0$
- Carbon yield=0.5×(Haasz yield)

DEGAS2 parameters

- $R_{recycl} = 1.0$, $T_{wall} = 30^\circ C$
- f_{pump}^{ion} : pumping ratio for ion flux onto the pumping slot
- $f_{pump}^{neutral}$: pumping ratio for neutral at the pumping slot



Calculation results in DIII-D



Comparison between JT-60U and DIII-D

Particle balance

$f^{ion}_{pump}=0.1$

$f^{neutral}_{pump}=0.1$

$\Phi_{ion} = 2.15\times10^{23}$

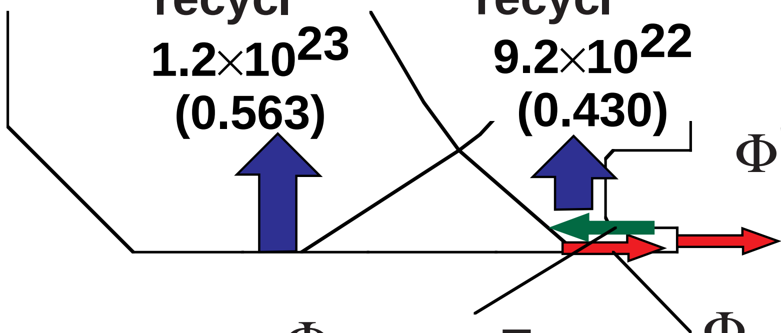
$\Phi_{recycl} = 2.13\times10^{23}$

$\Phi^{inner}_{recycl} =$ 1.2×10^{23} (0.563)

$\Phi^{outer}_{recycl} =$ 9.2×10^{22} (0.430)

$\Phi^{ion}_{pump} =$ 1.68×10^{21} (0.008)

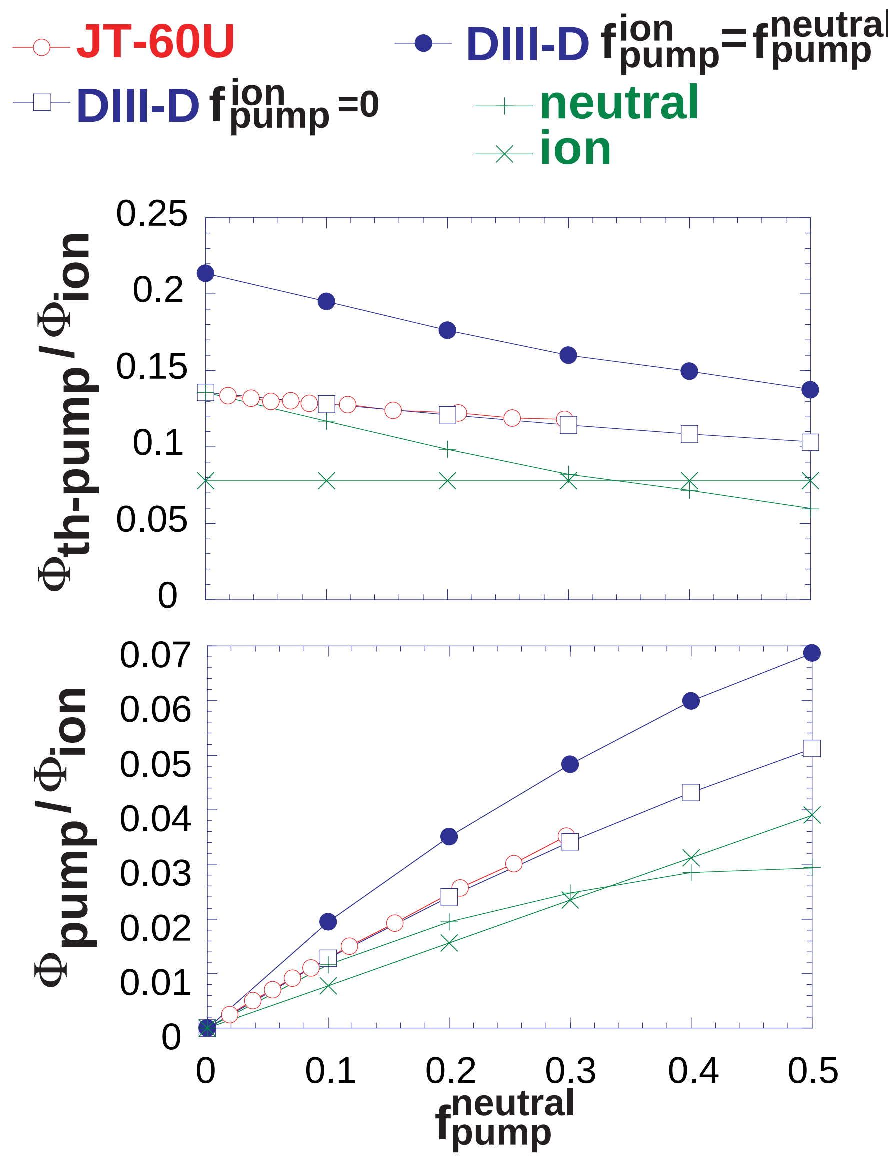
$\Phi^{neutral}_{pump} =$ 2.51×10^{21} (0.012)



$\Phi_{th\text{-}back} =$ 2.27×10^{22} (0.105)

$\Phi_{th\text{-}pump} =$ 2.52×10^{22} (0.117)

- The pumping ratio for DIII-D is larger by 30-50% than that for JT-60U with $f^{ion}_{pump} = f^{neutral}_{pump}$, and is almost the same as for JT-60U with $f^{ion}_{pump} = 0$.



Data for JT-60U are plotted as a function of pumping ratio at the throat.

Summary

Experimental analysis

- Pumping flux / total Dα in JT-60U is comparable with that in DIII-D in the high density regime. However, it decreases in the JT-60U low density regime.
- Pumping flux / total Dα in the both side private flux pumping in JT-60U steeply decreases with increasing gap, and is smaller than that in the inner private flux pumping at the same gap.
- In DIII-D, the decrease of pumping flux / total Dα is not observed, and the difference for different pumping scheme is not obvious.

UEDGE/DEGAS2 Modelling

- Back flow at the outer gap from under the dome was observed as expected from the experimental data in the both side private pumping in JT-60U.
- Pumping ratio for DIII-D is larger by 30-50% than for JT-60U at the same fpump.

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