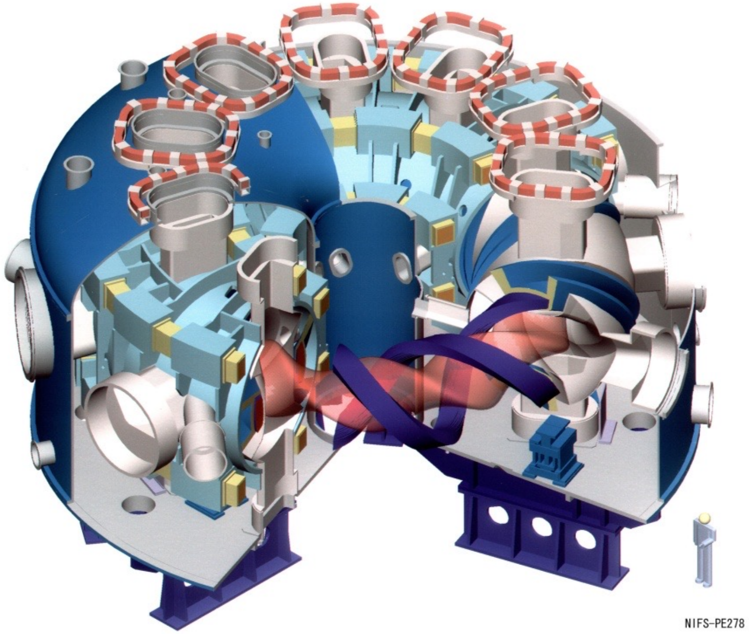
24th LHD experiment campaign

- LAST deuterium campaign in LHD -

N. Tamura (NIFS)
on behalf of LHD experiment group

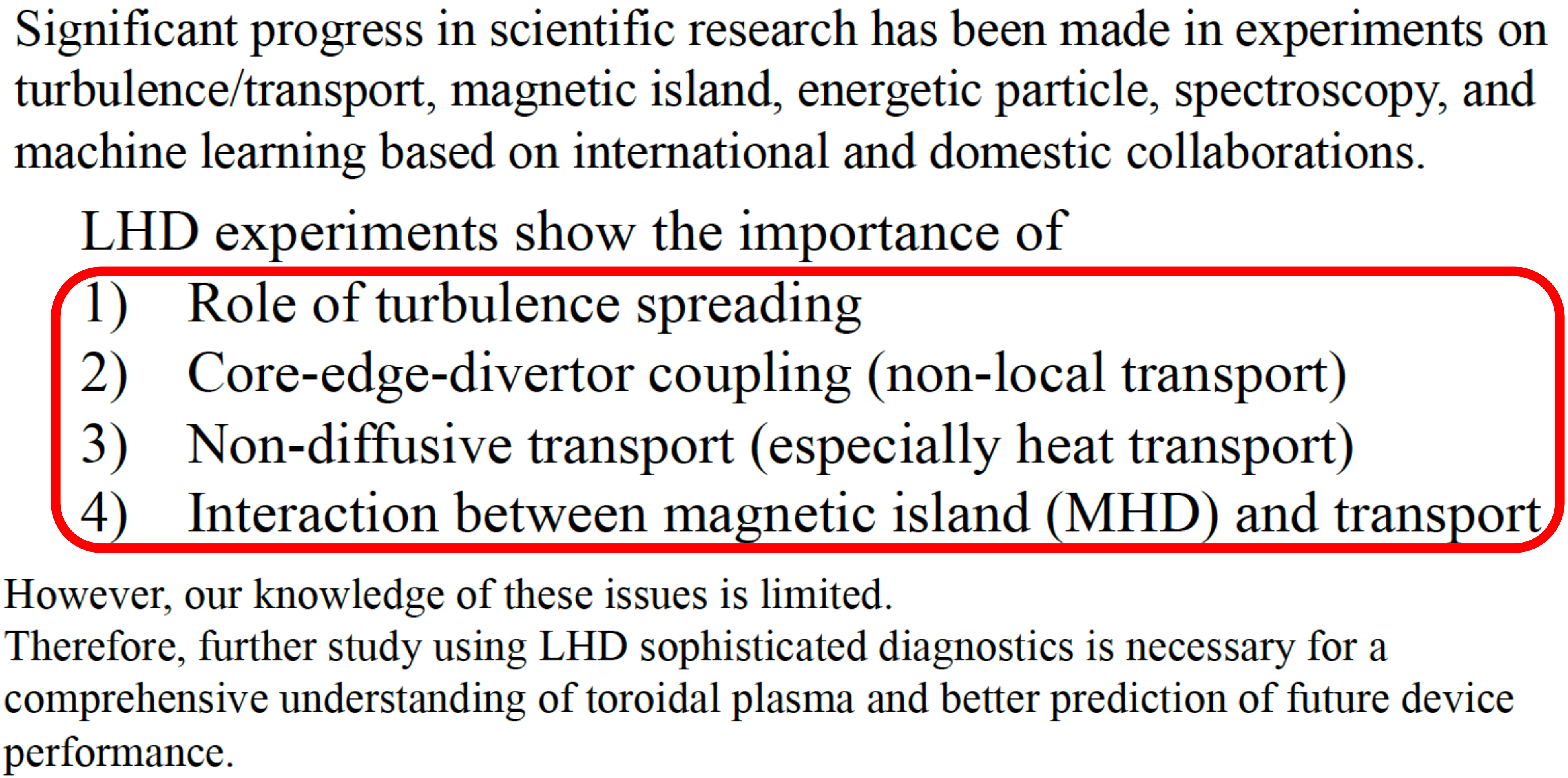


LHD Experiment Leadership for JFY2022

May 26, 2022

	Topical Group	Keywords	Leader	Domestic Adviser
			Deputy	International Adviser
1	Multi-ion plasma	● Mock test of sustainable burning ● Multi-ion transport in terms of core-edge-wall coupling	Naoki Tamura Masahiro Kobayashi	Kazuaki Hanada (Kyushu Univ.)
			Gen Motojima Hiroshi Kasahara	Andreas Dinklage (IPP) Oliver Schmitz (UW-Madison)
2	Turbulence	Interactions of turbulence in ● phase-space (e.g., coupling between high-k and low-k) ● real-space (e.g., turbulence spreading)	Tokihiko Tokuzawa	Shigeru Inagaki (Kyoto Univ.)
			Tatsuya Kobayashi Toru Tsujimura Motoki Nakata	Arturo Alonso (Ciemat) Carlos Hidalgo (Ciemat)
3	Spectroscopy	● Non-Maxwellian distribution / Anisotropy ● Collisional-radiative properties of molecules through high-Z ions	Motoshi Goto	Ryouhei Kano (NAOJ)
			Mikiro Yoshinuma Tetsutaro Oishi Tomoko Kawate	Sebastijan Brezinsek (FZJ) Joël Rosato (Aix-Marseille Univ.)
4	Instability	● Wave-Particle Interactions (e.g., Landau damping, TAE, ...) ● Abrupt events/Transitions	Yuki Takemura Kenichi Nagaoka	Yuto Katoh (Tohoku U.) Yasuhiro Suzuki (Hiroshima U.)
			Naoki Kenmochi Ryosuke Seki	William Heidbrink (UC-Irvine) Henning Thomsen (IPP)

Further study in LHD are still necessary
- From the FY2021 NIFS Research Project Results Review -



Significant progress in scientific research has been made in experiments on turbulence/transport, magnetic island, energetic particle, spectroscopy, and machine learning based on international and domestic collaborations.

LHD experiments show the importance of

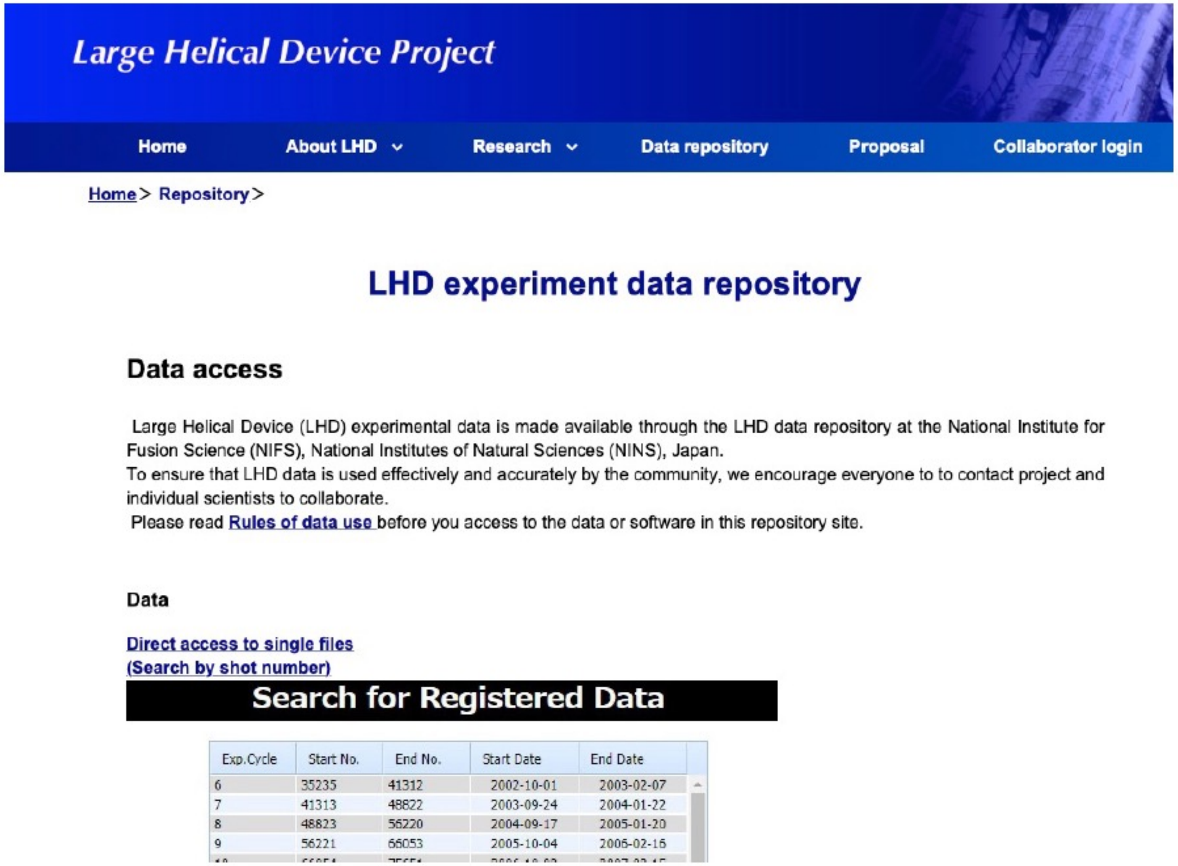
1) Role of turbulence spreading
2) Core-edge-divertor coupling (non-local transport)
3) Non-diffusive transport (especially heat transport)
4) Interaction between magnetic island (MHD) and transport

However, our knowledge of these issues is limited.
Therefore, further study using LHD sophisticated diagnostics is necessary for a comprehensive understanding of toroidal plasma and better prediction of future device performance.

From the "Conclusion" of Prof. Ida summary talk

Now LHD experiment data is open to the world!

The LHD data can be accessed from the LHD data repository at https://www-lhd.nifs.ac.jp/pub/Repository_en.html.



Large Helical Device Project

LHD experiment data repository

Data access

Large Helical Device (LHD) experimental data is made available through the LHD data repository at the National Institute for Fusion Science (NIFS), National Institutes of Natural Sciences (NINS), Japan.
To ensure that LHD data is used effectively and accurately by the community, we encourage everyone to to contact project and individual scientists to collaborate.
Please read Rules of data use before you access to the data or software in this repository site.

Data

Direct access to single files
(Search by shot number)

Search for Registered Data

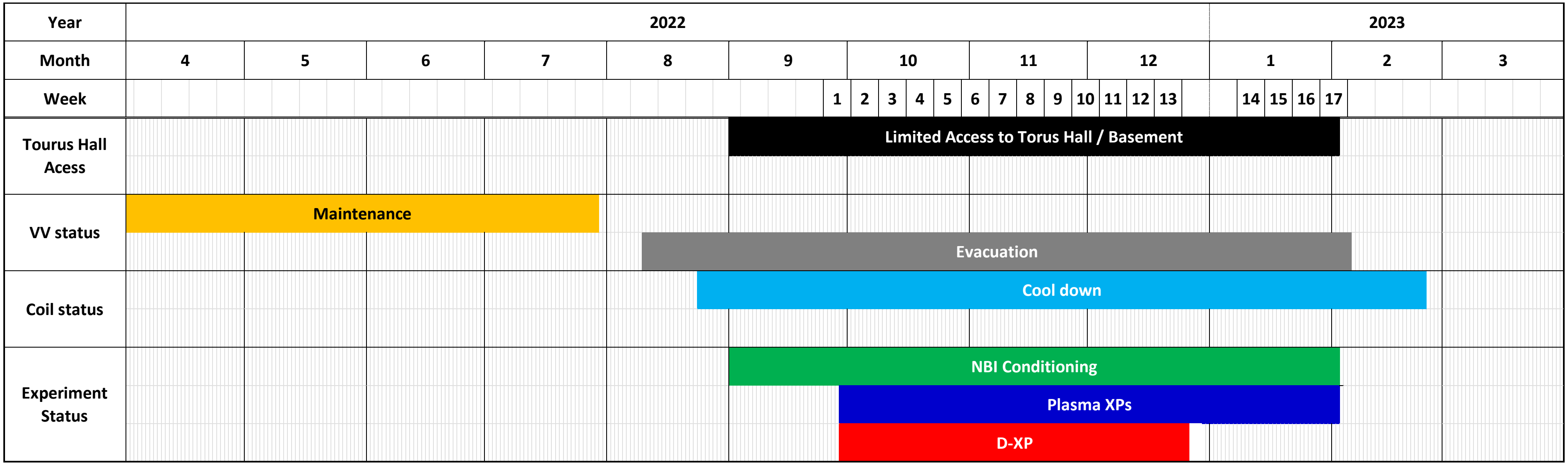
Exp.Cycle	Start No.	End No.	Start Date	End Date
6	35235	41312	2002-10-01	2003-02-07
7	41313	48822	2003-09-24	2004-01-22
8	48823	56220	2004-09-17	2005-01-20
9	56221	66053	2005-10-04	2006-02-16

77 TB LHD data is now open to the community without any restriction

Open Science started in Nuclear Fusion Community for the first time.

Schedule for 24th LHD experiment campaign

Schedule for 24th campaign (tentative)

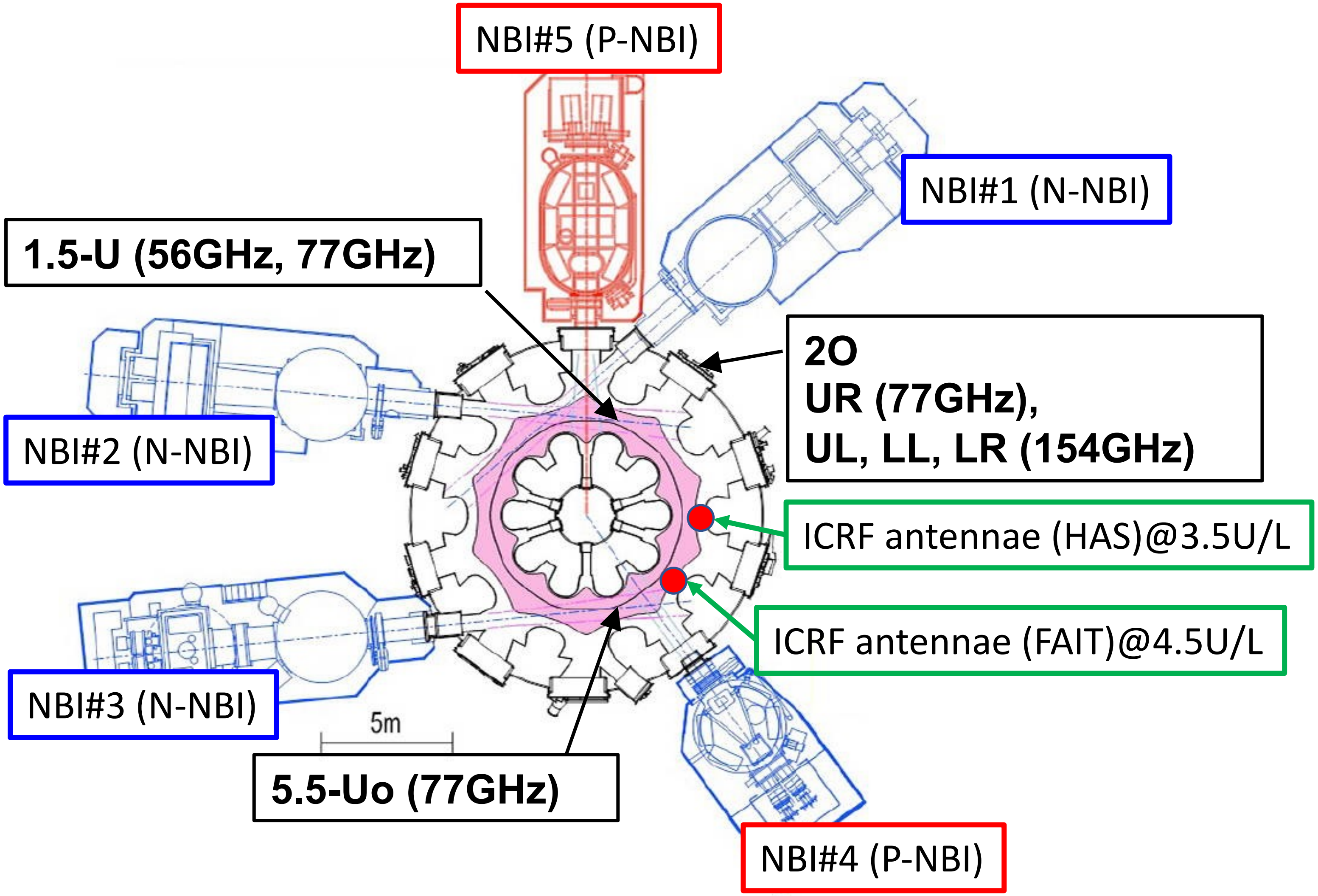


- Experiment Proposal Submission: **by June 30 (Next Thursday), 2022**
- FY2022 LHD Research Forum: **July 11 - 15 2022**
- Plasma Experiments: **End of Sep 2022 ~ Beginning of Feb 2023**
(Deuterium operation: **End of Sep 2022 ~ End of Dec 2022**)
  - ✓ VV: ~ End of July 2022(maintenance), Mid. of Aug 2020 ~ Beginning of Feb 2023 (in vaccum)
  - ✓ Cooldown of SC-coil: End of Aug 2022 ~ End of Feb 2023
  - ✓ NBI conditioning (Strict Access Control for TH): Beginning of Sep 2022 ~ Beginning of Feb 2023

This campaign is the LAST campaign for the D-experiment

Heating devices

Heating devices on LHD



NBI#5 (P-NBI)

NBI#1 (N-NBI)

1.5-U (56GHz, 77GHz)

2O
UR (77GHz),
UL, LL, LR (154GHz)

NBI#2 (N-NBI)

ICRF antennae (HAS)@3.5U/L

ICRF antennae (FAIT)@4.5U/L

NBI#3 (N-NBI)

5.5-Uo (77GHz)

NBI#4 (P-NBI)

Summary of Heating Devices for 24th Campaign

➢NBI

- N-NBI (NBI#1-#3) : 4-5MW/injector (H), ~2MW/injector (D)
  - ✓ **Challenge to extend the injection power in D-operation** and overcome the isotope effect of negative-ion production/extraction.

    ⇒EP confinement Studies, N-NBI development for ITER/DEMO
- P-NBI(NBI#4-#5): ~5MW/injector (H), ~9MW/injector (D)
  - ✓ NBI#4: Intermittent injection as a diag.-NBI at long pulse (>10s) discharge
  - ✓ NBI#5: He-beam injection is possible to investigate He-ash behavior in high-temperature plasmas.

➢ECH

- 77GHz (~0.8MW) x2, 154GHz (~1MW) x2, 154GHz (1MW)/116GHz (0.5MW) x1, 56GHz (0.4MW)
  - ✓ Improvement of center-focused ECH from high-field side injection using a 77GHz Gyro.
  - ✓ A dual frequency gyrotron successfully started its operation in 23rd campaign.
  - ✓ Challenge to establish a new heating scheme using **optical vortex**.

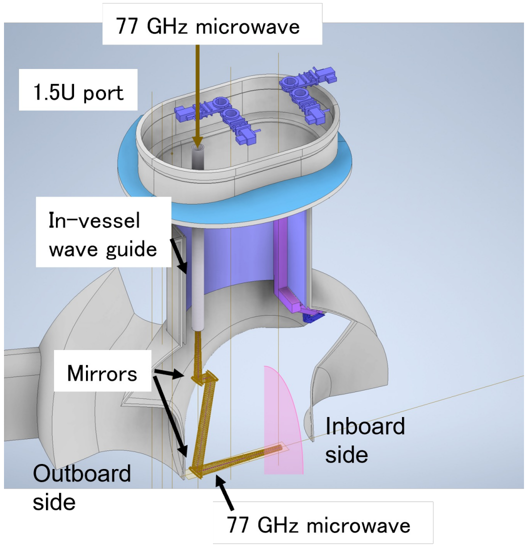
    ⇒**A new heating scheme over the cut-off density** becomes possible.

➢ICH

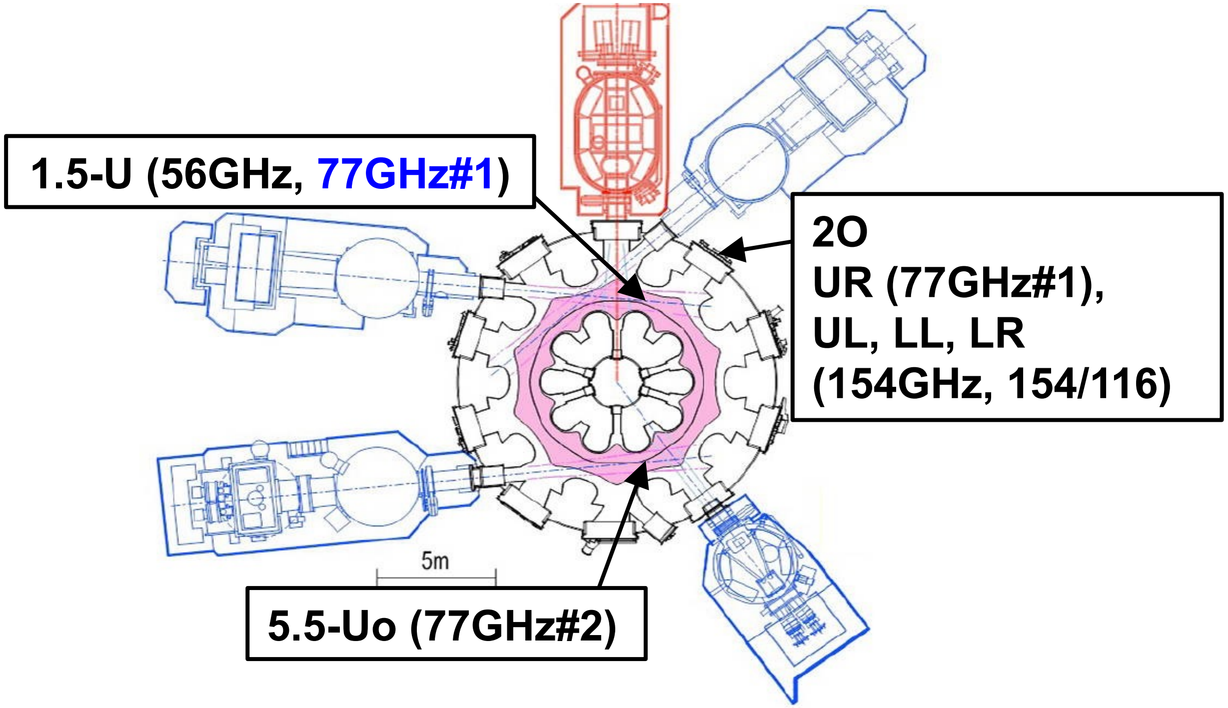
- 2 pairs of antennae optimized for 38.47MHz available.
  - ✓ HAS Antenna (3.5U&L port) : 2.2MW(short pulse), 1.2MW (long pulse)
  - ✓ FAIT Antenna (4.5U&L port) :1.9MW(short pulse), 1.4MW (long pulse)

Operation of ECH

- Available Gyrotrons (77GHz x2, 154GHz x2, 154/116GHz x1, 56GHz)
  - ✓ 77GHz#1 @ 5.5-Uo/1.5-Uo(high-field side injection) ~0.7MW
  - ✓ 77GHz#2 @ 2-OUR ~0.8MW
  - ✓ 154GHz#4 @ 2-OLL ~1MW
  - ✓ 154GHz#5 @ 2-OUL ~0.9MW
  - ✓ 154/116GHz#7 @ 2-OLR ~1MW(154GHz) / 0.5MW (116GHz)
  - ✓ 56GHz @ 1.5-U ~0.4MW



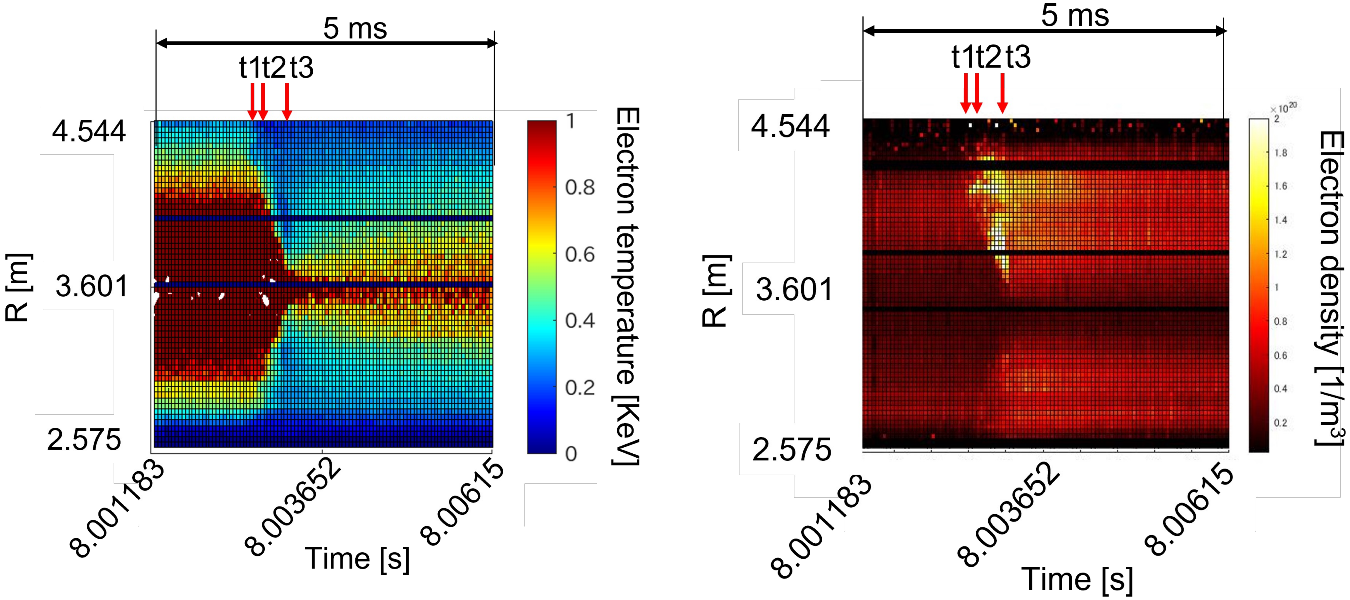
Antennae alignment of the high-field side injection at 1.5-Uo



Diagnostics upgraded

Thomson (TS) diagnostic

- Fast TS (50μs/5ms) diagnostic reveals various interesting phenomena, i.e., pellet abration, minor collapse of eITB, and etc.
- **Real time operation of TS (78-84 pts)** is planned for long pulse discharge. This may provide a new feedback scheme for steady state operation.

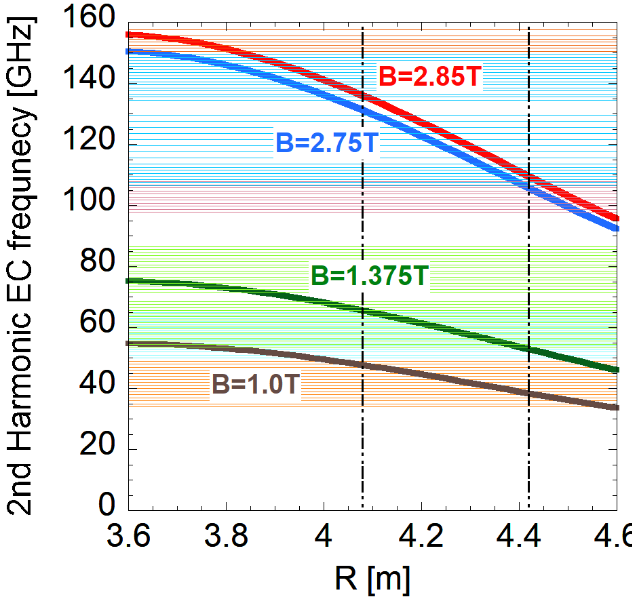


Temporal evolution of T_e and ne profiles after ICE pellets injection

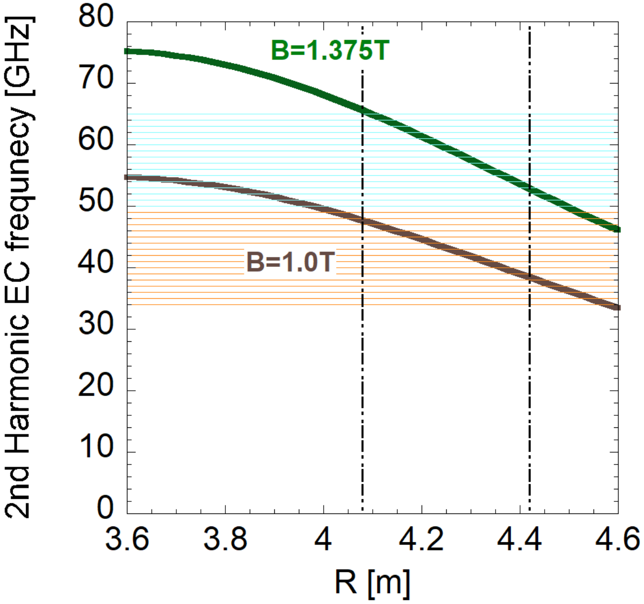
ECE diagnostics

- ECE
  - ✓ Bt=2.85T ~ 1T : Radiometers are available to use almost experiment condition.
  - ✓ Advanced systems, i.e., CECE and grad-Te ECE, are planned.
- ECEI
  - ✓ target Bt= 1.0 ~ 1.375T
  - ✓ Upgrade to 3 modules (from 2) in 24cycle

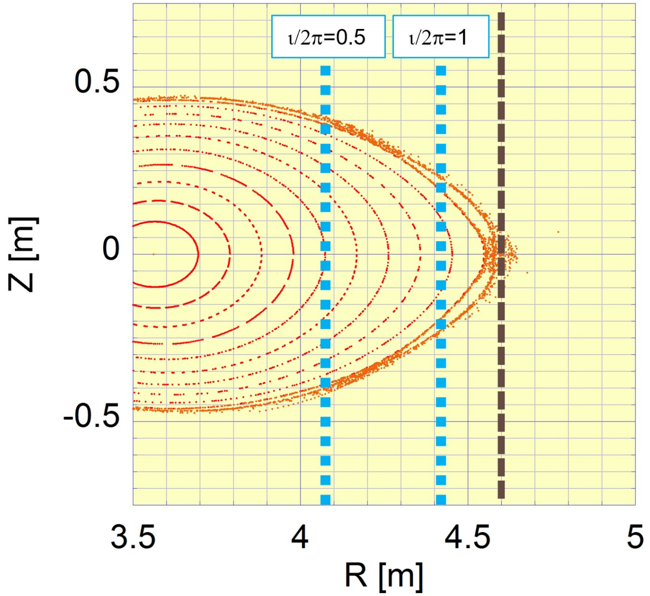
ECE @8-O



ECE @9-O



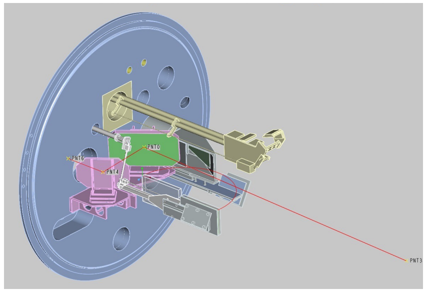
Rax=3.60m

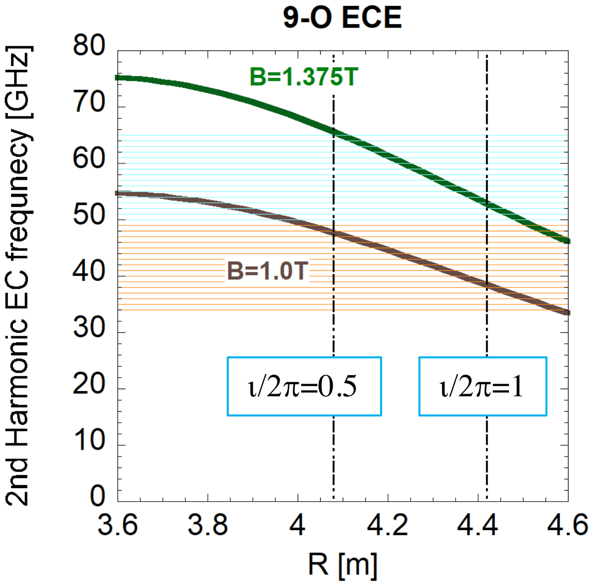


There is a limit to the available density range, please contact to T.Tokuzawa(tokuzawa@nifs.ac.jp).

RAD-Q
(New ECE radiometer for low magnetic field strength experiment)

- 32 channels in V- / Q-band (34-65GHz)
(which frequencies are lower than conventional ECE radiometer such as RADL)

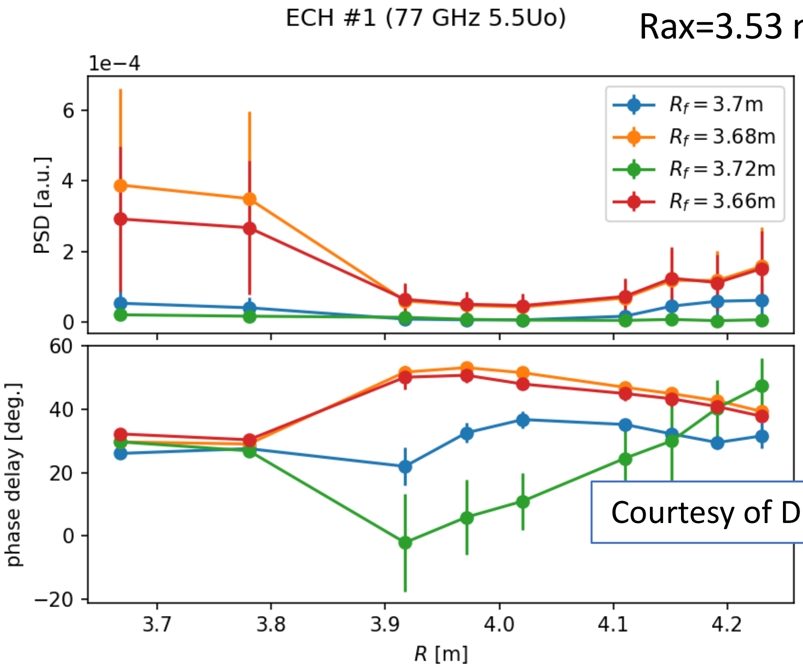




✓ Most of the radial range is covered in Bt=1T

✓ Utilized for the heat deposition analysis of 3rd harmonic ECH

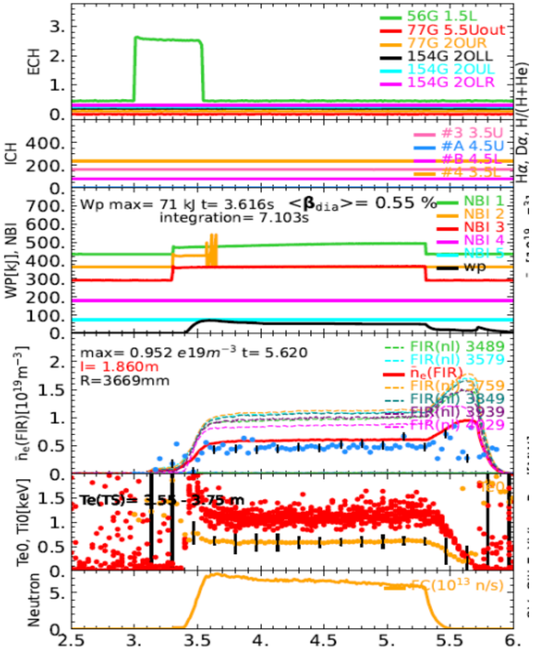
Rax=3.53 m, Bt=-0.975T



Courtesy of Dr. Yanai

ECE Imaging
for 2D Te fluctuation profile measurement

#163518 Rax=3.60, Bt=-1.0T

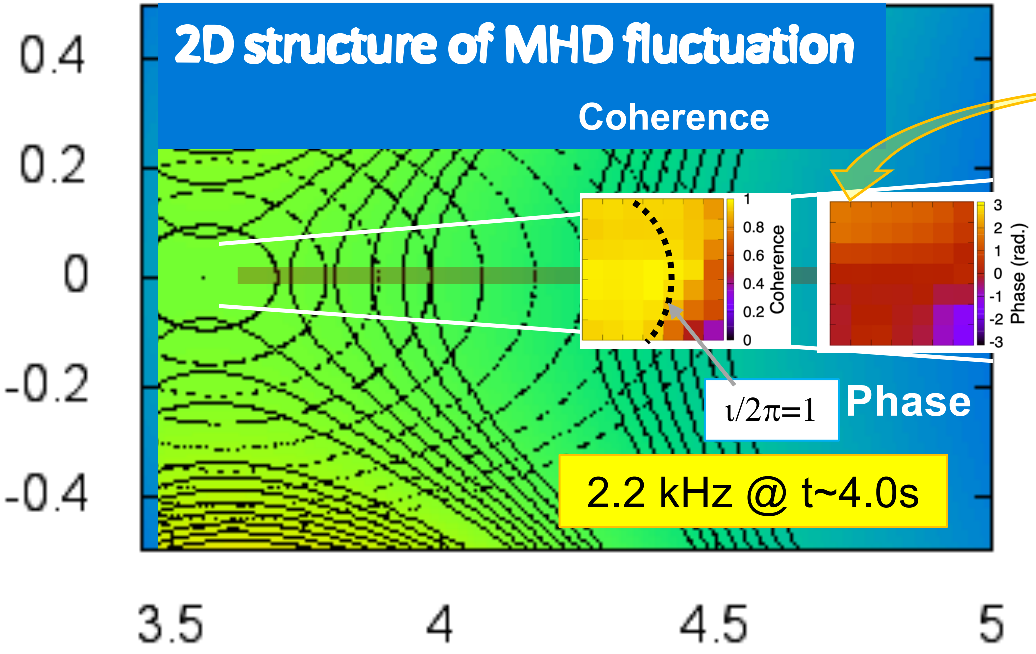


Q-band ECEI is upgraded from

22c: 8ch x 8antenna(vertical) => 64ch : 35-42GHz for 1T (ι=~1)

➔23c: add 1 module = >128ch : 54-61GHz for 1.375T (ι=~1)

➔24c: add 1 module => 192 ch : 62-69GHz for 1.375T (ι=~0.5)



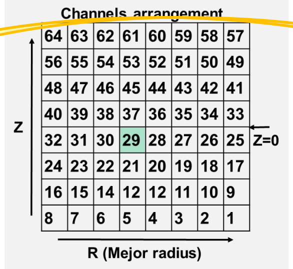
2D structure of MHD fluctuation

Coherence

Phase

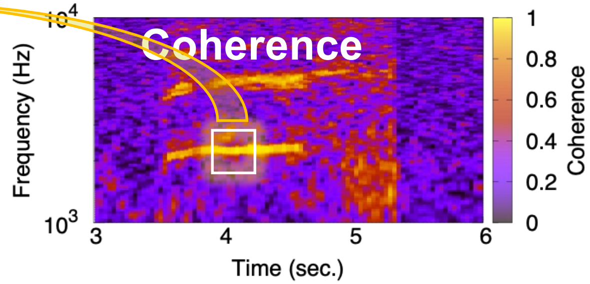
ι/2π=1

2.2 kHz @ t~4.0s



Channels arrangement

64	63	62	61	60	59	58	57
56	55	54	53	52	51	50	49
48	47	46	45	44	43	42	41
40	39	38	37	36	35	34	33
32	31	30	29	28	27	26	25
24	23	22	21	20	19	18	17
16	15	14	12	12	11	10	9
8	7	6	5	4	3	2	1



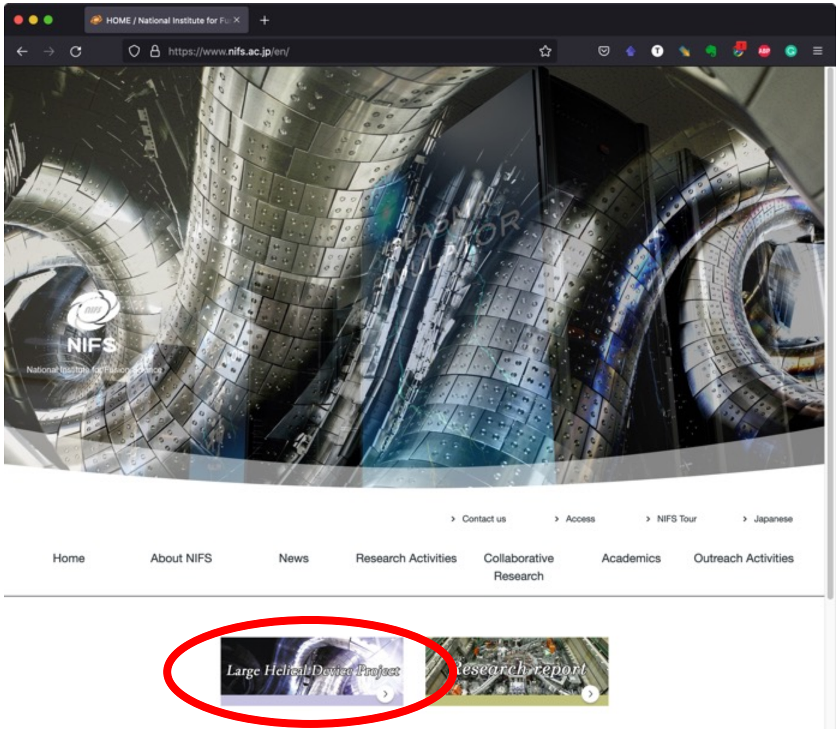
- ✓ ALL channels are well working even during 56GHz ECH.
- ✓ 2D profile of low-*n* MHD oscillation structure has been obtained.

How to submit proposals for the LHD experiment

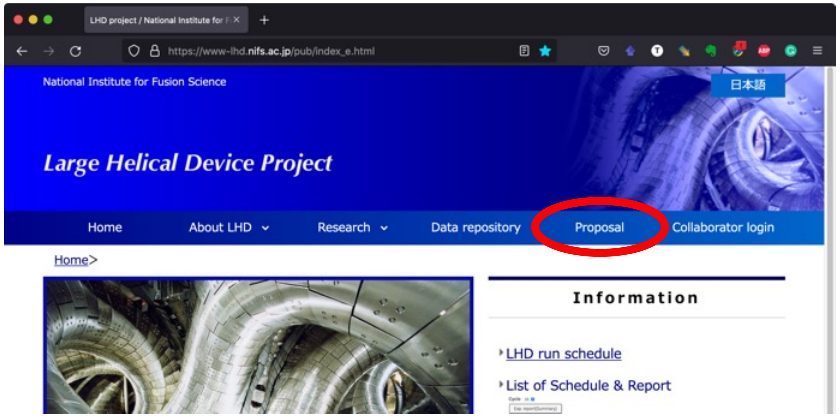
Route to the proposal submission website

1. Please go to the NIFS website, https://www.nifs.ac.jp/en/index.html

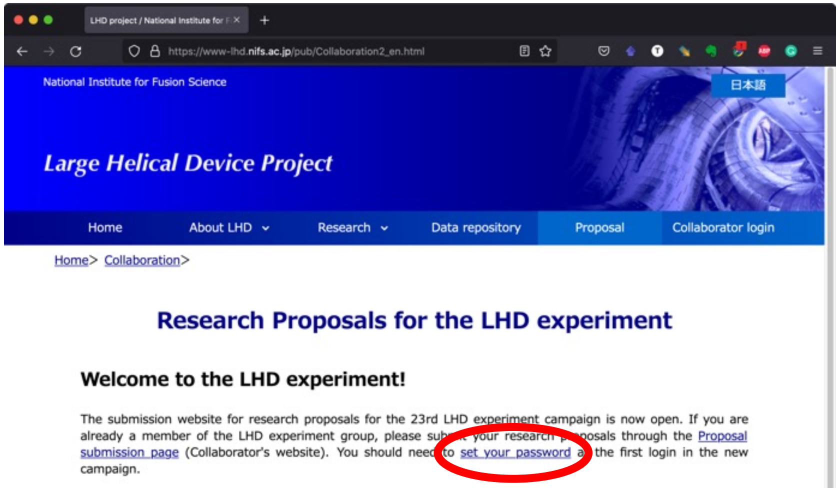
2. Click “Large Helical Device Project” in the middle of the NIFS website.



3. Click “Proposal” in the top banner.



4. Click “set your password” if you are logging to the “LHD collaborator’s website” including the “Proposal submission page” for the first time after April 2022.



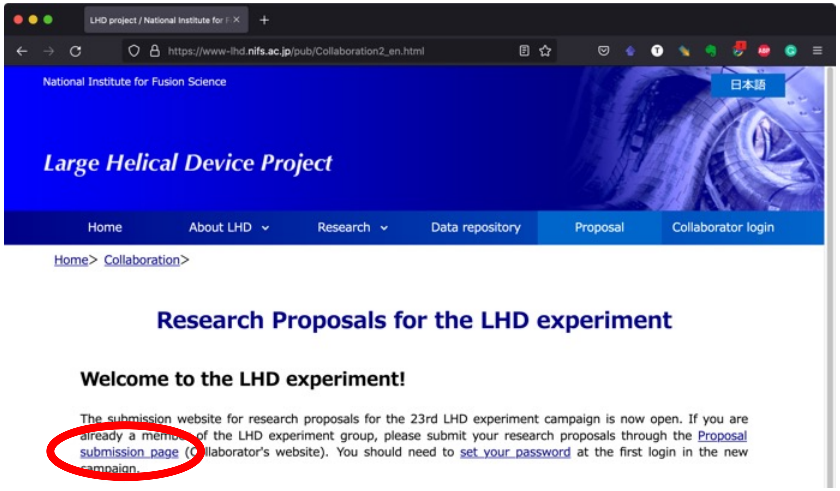
Research Proposals for the LHD experiment

Welcome to the LHD experiment!

The submission website for research proposals for the 23rd LHD experiment campaign is now open. If you are already a member of the LHD experiment group, please submit your research proposals through the Proposal submission page (Collaborator's website). You should need to set your password at the first login in the new campaign.

Route to the proposal submission website (cont'd)

5. After renewing your password, please click the "Proposal submission page."



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- Submitting a proposal through the submission website requires **LHD collaborators' credentials**.
- If you are not an "LHD collaborator" or are not sure if you are an LHD collaborator, please input the necessary information into the "Registration information" form on the "Proposal" web page of "Large Helical Device Project" website.

Further study in LHD are still necessary
- From the FY2021 NIFS Research Project Results Review -

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LHD experiments show the importance of

1) Role of turbulence spreading
2) Core-edge-divertor coupling (non-local transport)
3) Non-diffusive transport (especially heat transport)
4) Interaction between magnetic island (MHD) and transport

However, our knowledge of these issues is limited.
Therefore, further study using LHD sophisticated diagnostics is necessary for a comprehensive understanding of toroidal plasma and better prediction of future device performance.

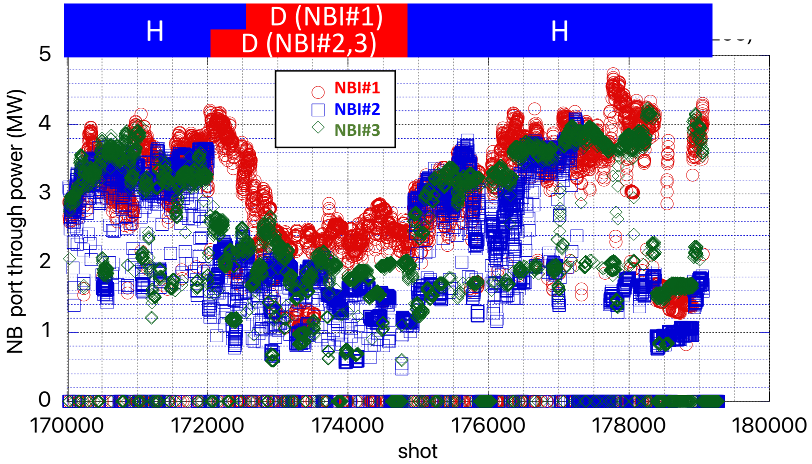
Especially in deuterium plasmas!

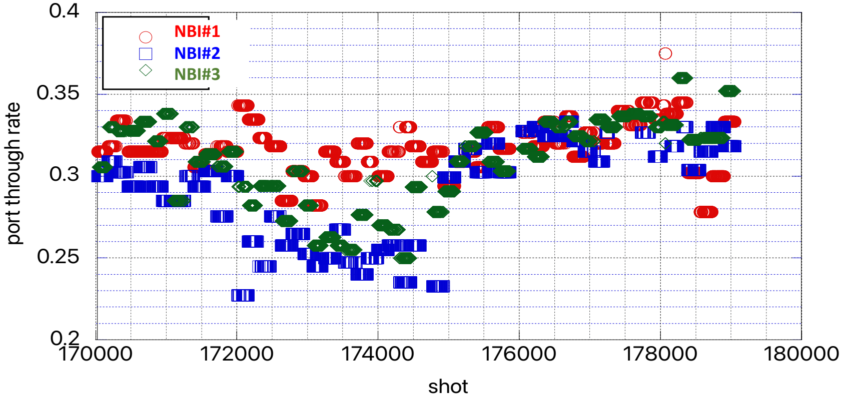
From the "Conclusion" of Prof. Ida summary talk

Backup slides

Operation of Negative-ion based NBI (N-NBI)

The injection power N-NBI was degraded in D-operation due to (1) the isotope effect in negative-ion production and to (2) the mismatch of beam steering system in D-operation.





NBI#1 P_{max}=4.73MW

Port-through rate recovered to H-operation level by the installation of Electron Fence (EF), which reduces the isotope effect in negative-ion production, on the surface of plasma grids.

NBI#2 P_{max}=4.08MW

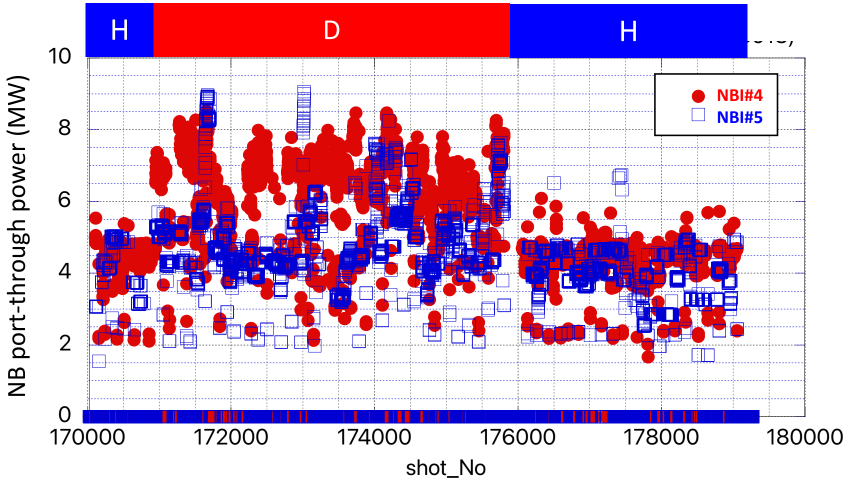
Port-through rate was degraded even in H-operation after slot-type Grounded Grids (GGs). Replacing GGs from slot-type to multi-hole type, the Port-through rate recovered in H-operation. At the end of campaign, one of the ion sources (IS2B) could not be operated due to a water leak trouble in a GG. **The leaked GG was replaced with a spare grid.** **In order to overcome the isotope effect in negative-ion production, EF will be installed**.

NBI#3 P_{max}=4.24MW

A new beam steering system, which does not have mass dependence, was applied for one Ion-Source (IS3A). It worked fine at the initial H-operation but needed to be revised for D-operation.
The steering system is revised for 24th campaign. The revised system will also be applied for IS3B.

Operation of Positive-ion based NBI (P-NBI)

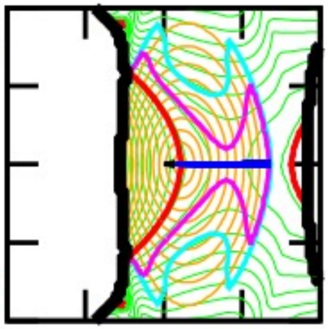
- ➢ The injection powers are 8 - 9 MW in D-operation and ~5MW in H-operation.
- ➢ During long pulse discharge over 10 sec, NBI#4 can be used as a diagnostic NB with intermittent NB injections using the electricity from commercial power line.
- ➢ He beam injection was realized with NB#5.
  - ✓ The number of operational ISs is limited to unity because the pumping speed of the vacuum pump is very small for He.
  - ✓ IS operation with He needs several recovery discharges with Ar to remove the W-fuzz layer formed on W-filaments of IS. This produces W-film layers on the IS grids and cause break-down.
  - ✓ In order to perform recovery discharge with Ar, a remote control gas feeding system is necessary to switch the gas species from He to Ar. Only one ion-sources out of four is equipped with this system. We are trying to apply this system for other three ISs in 24th campaign, but the world wide shortage of semi-conductor components may cause a delay.

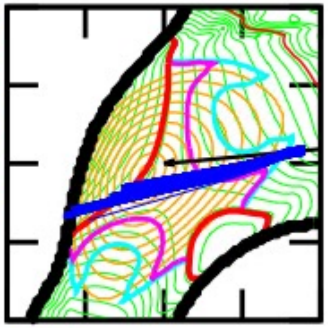


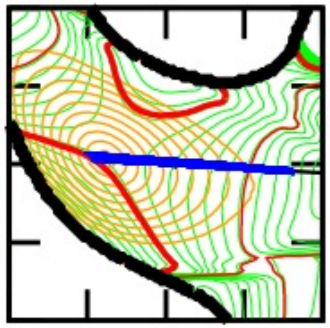
Because of difficulty caused by He-operation, we would like to limit the operation period of He-beam.

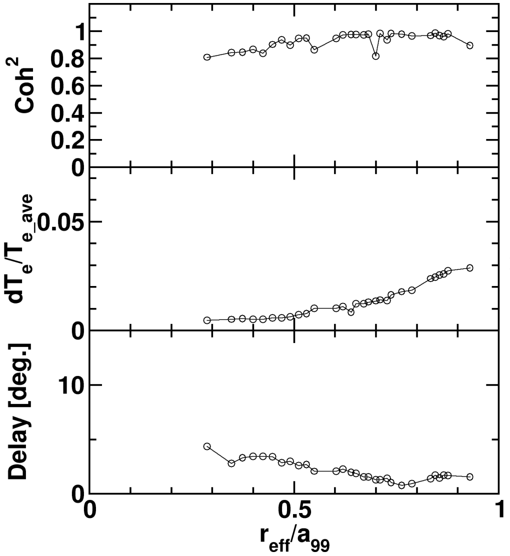
Operation of ECH

- New antenna for 77GHz gyrotron at 1.5Uo for high-field side injection was installed and successfully demonstrated well focused ECH at center.
  - ✓ The reflected microwave at the counter wall seems to limit the operational power of gyrotron. Due to this effect, the injection power is limited to 0.3MW.
  - ✓ Injection angle is revised to prevent the reflected wave not to enter the transmission line
- A new dual frequency (154/116 GHz) gyrotron started its operation successfully. Flexible experimental scenarios become possible
  - ✓ A new peripheral ECH scheme at Bt= 2.75T in addition oblique injection of 154/77GHz.
  - ✓ higher harmonic ECH by 3rd harm. 116GHz at 1.375T with 2nd harm. 77GHz
  - ✓ Plasma startup or core ECH at ~2T

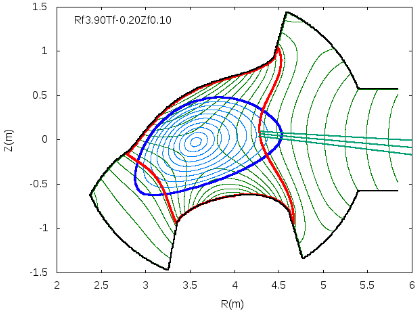

1.5-Uo
77GHz


2-OUR
77GHz


2-OLL
154GHz



Modulated Te profile by 116GHz microwave.



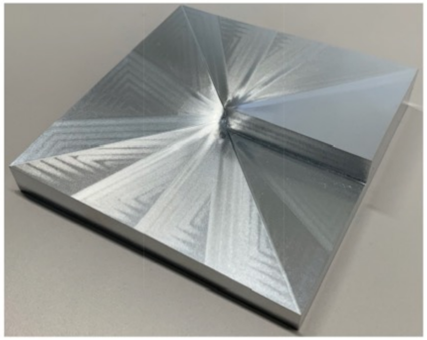
A new peripheral ECH by 116GHz

Trial/demostration of optical vortex ECH

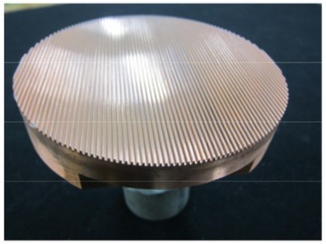
- **Optical vortex ECH has a potential of heating plasmas over the cut-off density** [1].
- A spiral phased mirror with bi-pass microwave line are installed on the existing transmission [2].
- The over dense plasma heating by optical vortex ECH will be demonstrated and its related physics will be explored.

[1] T. I. Tsujimura and S. Kubo, Phys. Plasmas 28, 012502 (2021)
[2] T. I. Tsujimura et al., Rev. Sci. Instrum. 93, 043507 (2022)

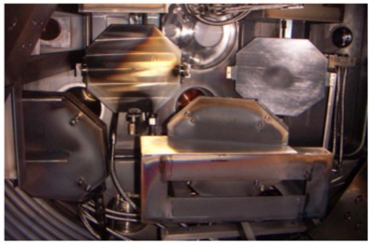
Microwave transmission line



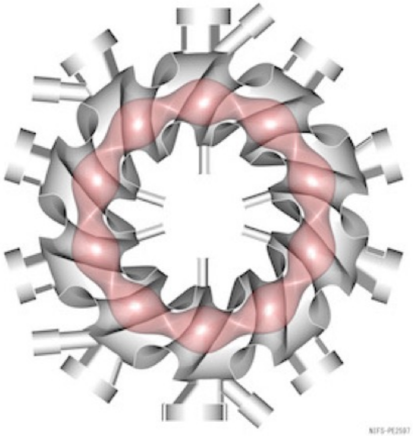
Spiral phased mirror



Polarizer

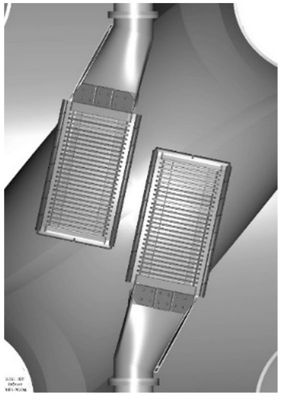


Injection antenna

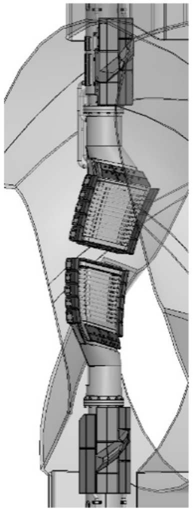


LHD plasma

Operation of ICRF heating



HAS antenna



FAIT antenna

- Two ICRF antennae for ICRF heating (38.47MHz)
  - HAS Antenna (3.5U&L port) ($k_{||}$ = 5.82 m^{-1}:dipole)
    1.1MWx2(short), 0.6MWx2(long)
  - FAIT Antenna (4.5U&L port) ($k_{||}$ = 0 m^{-1}:monopole)
    1.3MW+0.6MW (short), 0.8MW+0.6MW (long)
- The transmission line connected to the 3.5L port had a trouble of arcing. The arcing points are under investigation to repair.
- Heating scheme:
  - Minority heating: He(H), D(H), D(H,F) @2.75T
  - Second harmonic heating: D,He@2.75T , H@1.375T
  - High harmonic fast wave heating B <1.375T using H, D and He
  - Ion Bernstein and Ion Cyclotron Wave heating
- New Challenge
  Realtime control of ICRF heated plasmas using neutron emission rate (Sn) is planned
  ⇒Realtime control of ion temperature