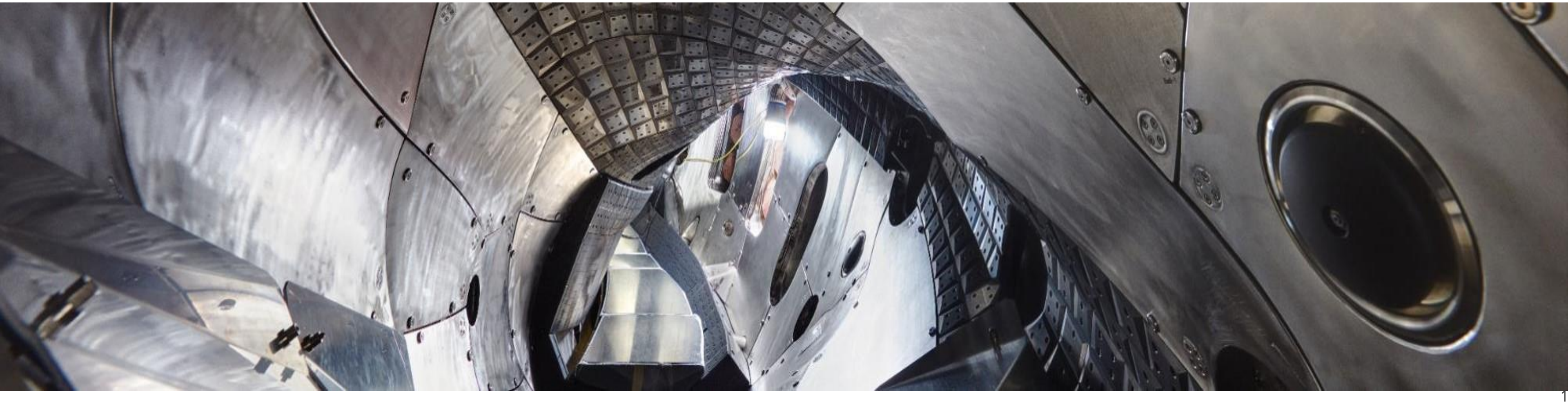
Joint Meeting of the Topical Groups “Heating” and “Fast Ions”
ICRF commissioning plans and operation in OP2.1
25/01/2022

D. Hartmann, Y. Kazakov, J. Ongena, S. Bozhenkov, K. Crombé



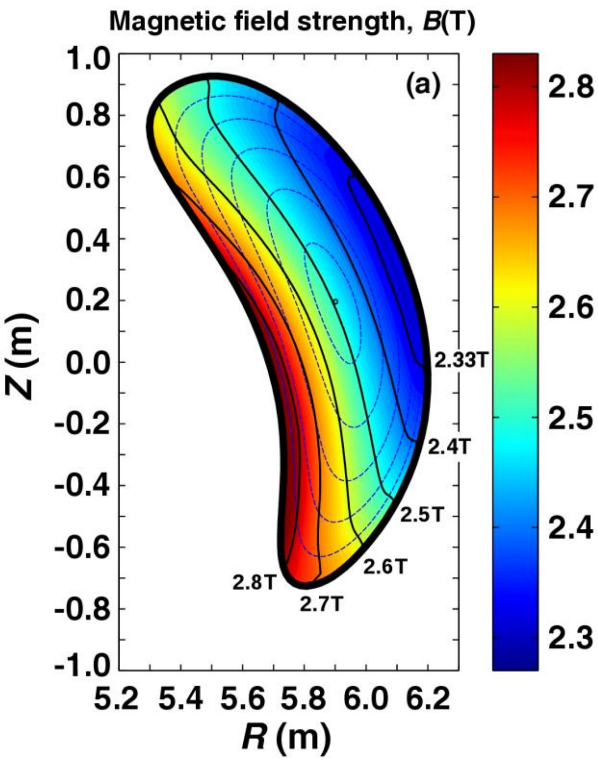
Outline

- OP2.1: ICRF system and operations summary
- ICRF planning during the plasma commissioning phase
- ICRF planning for the scientific program
- OP2.2: future planned ICRF studies (draft ideas)

Project team:

- **LPP-ERM/KMS:** Jef Ongena, Bernd Schweer, Michel Vervier, Ivan Stepanov, Kristel Crombé, Pierre Dumortier, Yevgen Kazakov
- **FZJ:** Olaf Neubauer, Guido Offermanns, Klaus-Peter Hollfeld, David Castaño-Bardawil, Guruparan Satheeswaran, Dirk Nicolai, Andreas Krämer-Flecken, Rudi Caspers
- **IPP:** Dirk Hartmann, J. Peter Kallmeyer, R. Kairys, Matthias Stern, Andree Benndorf, Matthias Werner, Robert Wolf

ICRF system and operations in OP2.1: short summary



$$\omega = n\omega_{ci} + k_{\parallel}v_{\parallel}$$
$$(n = 1, 2, 3, \ldots)$$

- Two-strap antenna
- One RF generator and limited RF power
  (two RF generators in OP2.2)
- Two frequencies: f = 38MHz and 25MHz
- Two phasings: dipole and monopole
  (more phasings available in OP2.2)
- Focus: bringing the RF system into safe routine operation for its various applications in W7-X
  (fast-ion physics, T_i heating, MHD, turbulence studies, start-up, ICWC, etc.)
- Test and optimize the system for various magnetic configurations
  (antenna position, RF coupling, central magnetic field, etc.)
- ^{4}He plasmas: max. power operations, H minority scheme
- H majority plasmas: low-power operations (~100kW max.), primarily for start-up and ICWC explorations
- Test ICRF for start-up at 1.7-1.8T
- No ^{3}He ICRF in OP2.1

Main ICRF scenario in OP2.1: H minority in ^{4}He plasmas

- Well-established ICRF scenario
- Scenario optimization possible: H concentration, magnetic field (on- vs. off-axis), coupling, etc.
- Advantage: good ICRF absorption for a wide range of hydrogen concentrations, ~2-15%
- Recent theoretical insights for W7-X: ITG stabilization by ICRF-generated fast ions

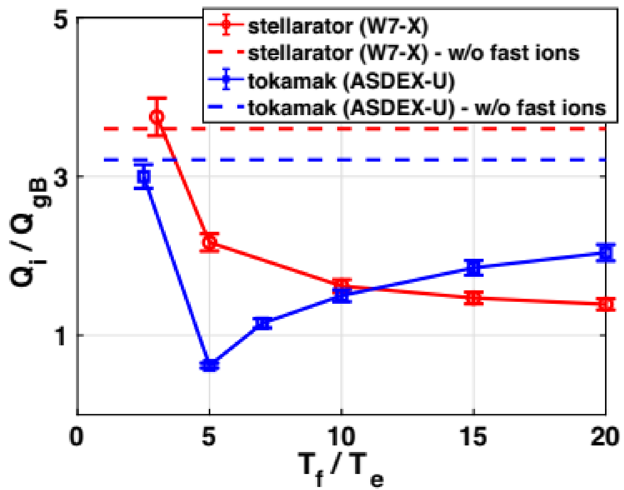


FIG. 1. Nonlinear main ion heat fluxes in GyroBohm (Q_{gB}) units for different energetic particle temperatures T_f/T_e. The horizontal dotted lines denote the fluxes obtained without fast ions (w/o denotes without).

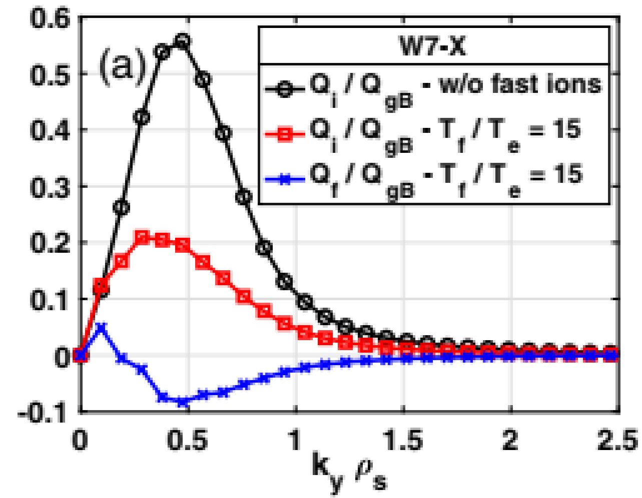


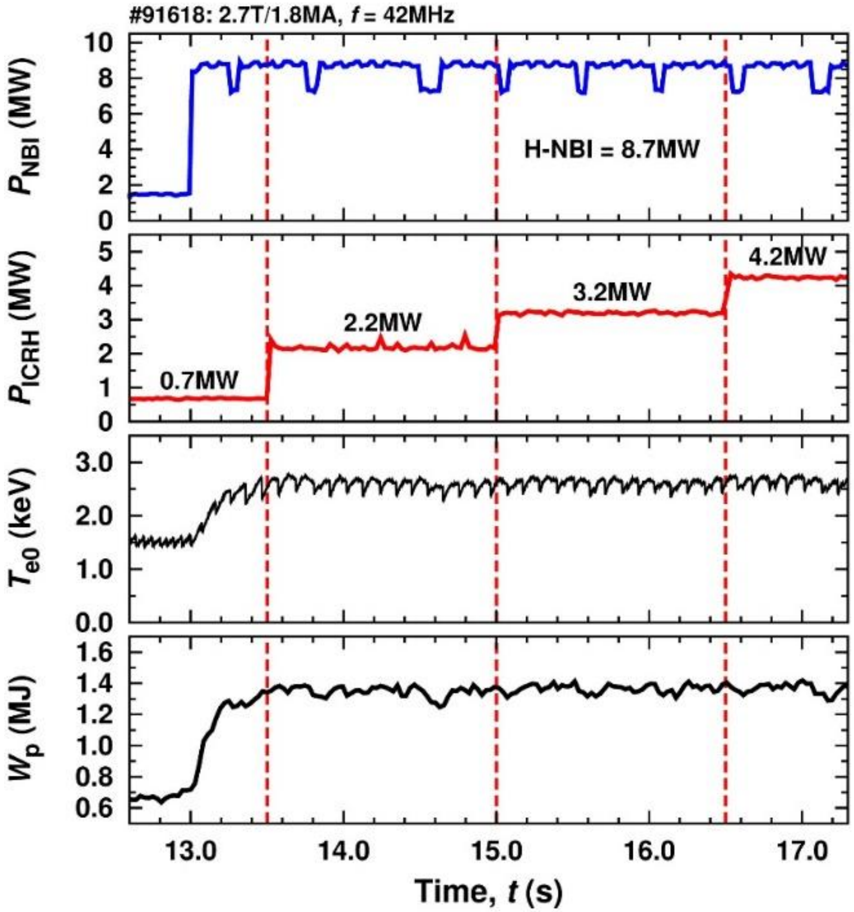
FIG. 2. Nonlinear saturated (a) main and energetic ion heat flux spectra and (b) velocity space structure of Q_f/Q_{gB} averaged over k_x, k_y, and z at $T_f/T_e = 15$ (w/o denotes without). The black

More details: A. Di Siena et al., *Phys. Rev. Lett.* (2020)

Assumed conditions: $n(\mathrm{H})/n_e$ = 6%, T_{fast}/T_e **= 15**

These studies require full-power ICRF with 2 generators available (OP2.2)

ICRF in hydrogen majority plasmas in OP2.1 (without ^3He): only low-power operations (~100kW max.)

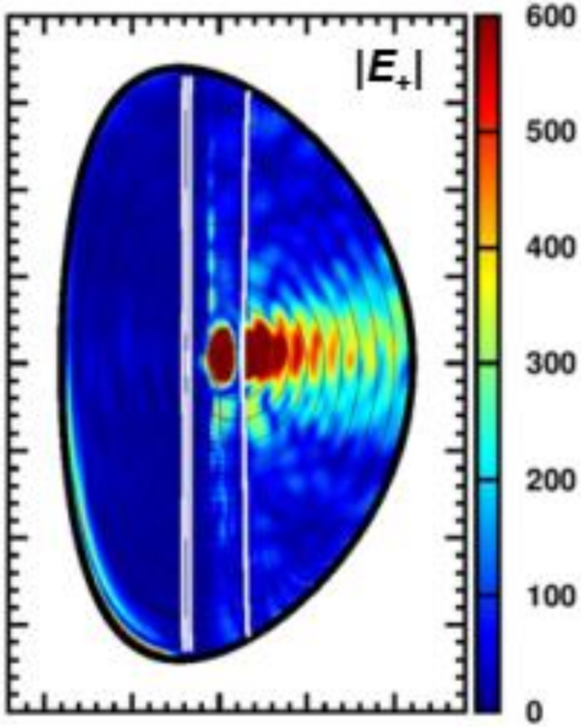


JET-ILW example: P_{ICRF} = 1-4MW, in combination with NBI, no RF absorption

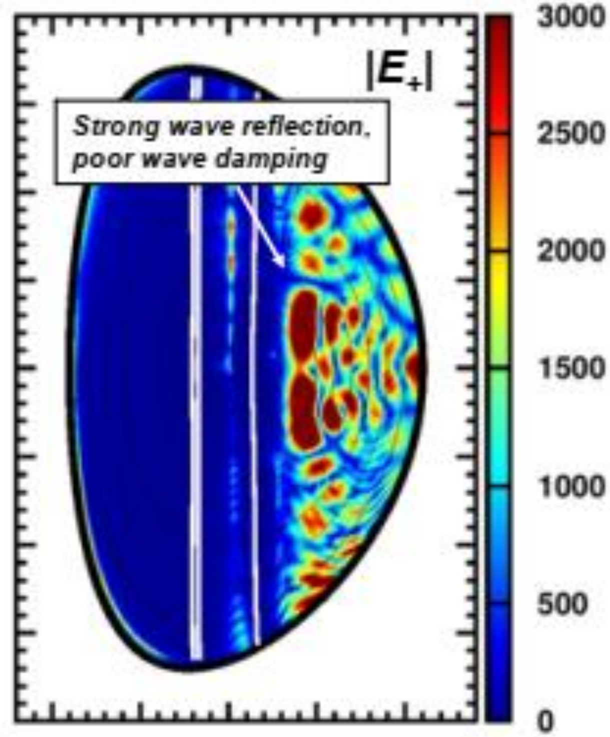
- Poor ICRF absorption
- Only low-power operations (~100kW max.) allowed: primarily for start-up and ICWC explorations

ICRF operations with ^3He: only starting in OP2.2

^3He ~ 1%: good absorption
(three-ion ICRF scheme)



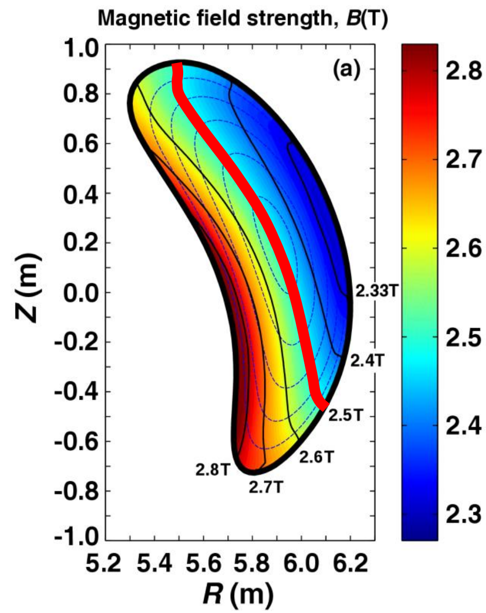
^3He >~ 3%: poor absorption,
strong wave reflections

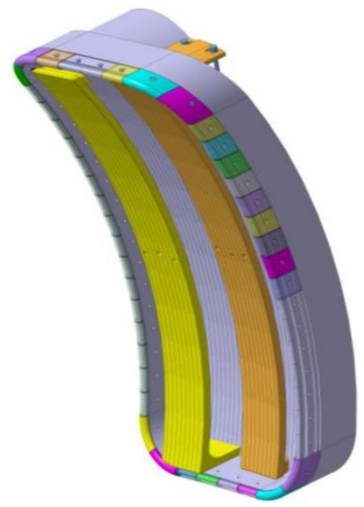


- New ICRF system: *'first climb-up the mountain, then pick the Edelweiss'*
- No ^3He ICRF in OP2.1

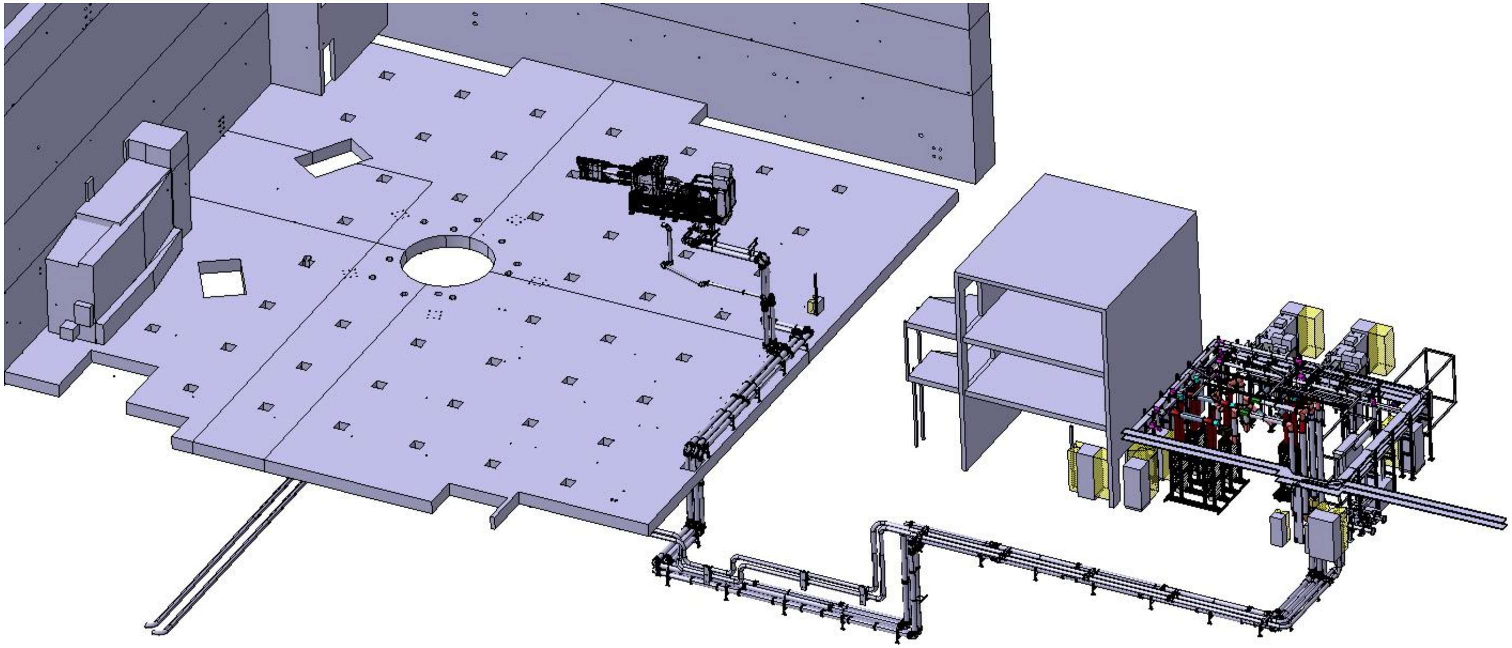
Technical setup of the ICRH system

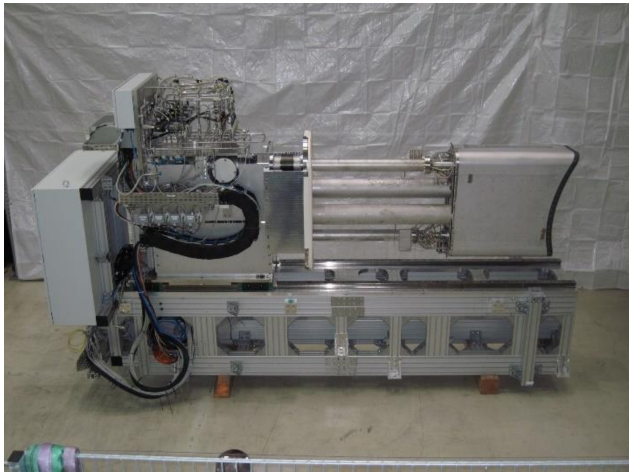
- **1 (2) radio-frequency (RF) generators**
  - 1,5 MW, 10 sec, 3 minute duty cycle
  - 25 MHz – 38 MHz
- **ICRH 2 poloidal strap antenna,**
  - 2 poloidal straps to $k_{parallel}$ shaping of excited FM wave via RF-magnetic coupli
  - geometrically fitted to standard magnetic config.
  - radially movable
  - equipped with gas inlet
  - actively water cooled and equipped with thermo couples
  - imbedded reflectometer
  - pre-matching with internal capacitors
- **RF transmission line (TL) + matching system**
  - match antenna impedance to generator impedance
  - set the phase between straps, thus $k_{parallel}$ spektrum

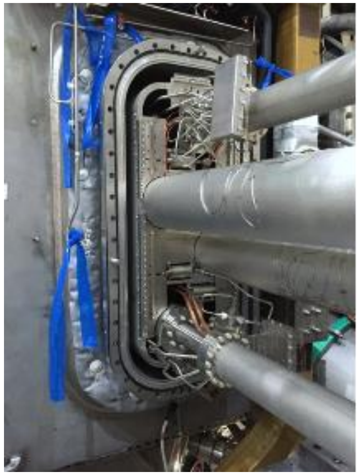




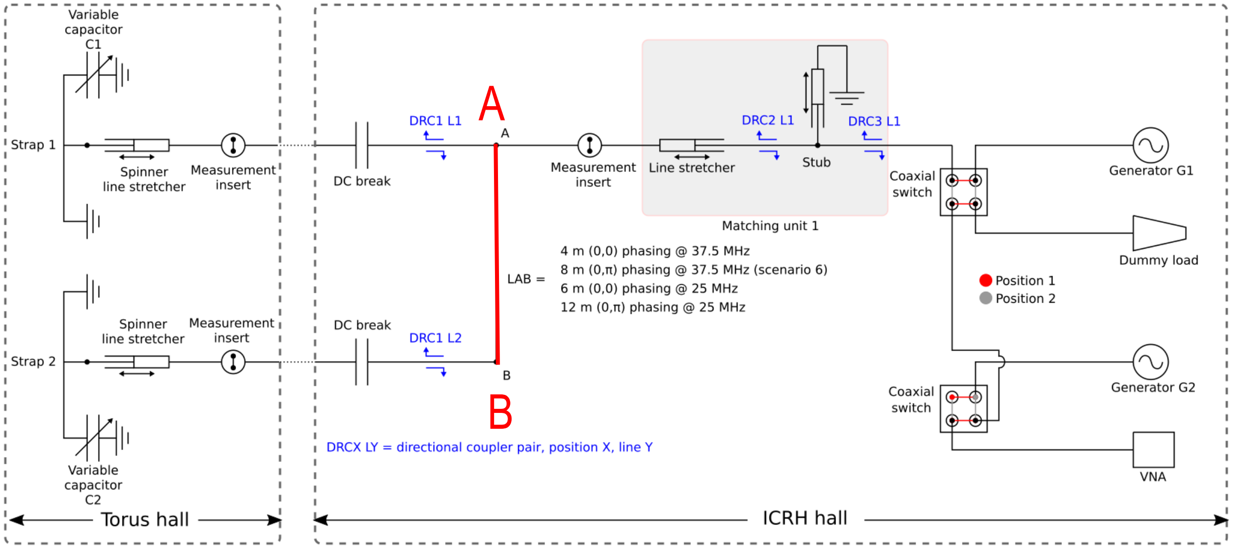
ICRH hardware







ICRH system in OP2.1



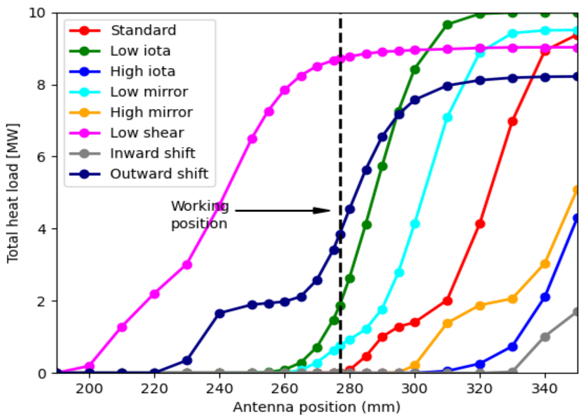
Kallmeyer 1-CCC-T0056.2

In OP2.2 extension to arbitrary phase with 2 generators

Section AB

Challenges of the ICRH System

I. Stepanov, 1-CCD31-T0019.0



- **Requirements for strong excitation of Fast Wave**
  - antenna close to plasma density of 2 $10^{18} m^{-3}$ along the poloidal straps
  - antenna sufficiently far from LCFS to avoid plasma damage
  - antenna impedance matching possible
  - sufficiently high voltage stand-off in antenna and TL system
- **Technical commissioning (April – August 2022)**
  - RF generator operation onto RF calorimeter for 38 MHz and 25 MHz
  - determine vacuum matching of the antenna for operation frequencies and phasing
  - antenna conditioning to increase voltage standoff in antenna and transmission lines.
  - Check for RF leaks
- **Plasma commissioning (September – Oktober 2022)**
  - Operation principles for OP2.1
    - RF generator power <= 100 kW without absorption mechanism in the plasma
    - Generator operation only by ERM-KMS personnel
    - No He3 operation
  - For each magnetic configuration
    - determine operation position of the antenna
    - determine impedance matching
    - Increase power and duration to about 1 sec and about 500 kW (?)
  - For each antenna frequency or phasing
    - Determine impedance matching

ICRH plasma commissioning

#	Purpose	ICRH System Modification	Mgn. Conf.	B36 [T]	Freq [MHz]	Phasing	working gas	Absorption	max. RF power [kW]	target plasma	Required session [session]	Duration mechancial work [day]
1	antenna position		std.	2,5	38	pi	He	He (H)	0	ECRH	1	0
2	**plasma operation**		std.	2,5	38	pi	He	He (H)	500	ECRH	1	0
3	antenna position and operation		**high mirror**	2,5	38	pi	He	He (H)	500	ECRH	1-2	0
4	**antenna gas inlet**		high mirror	2,5	38	pi	He	He (H)	500	ECRH	1	0
5	**plasma startup**		tbd, but known	2,5	38	pi	He	He (H)	500	ECRH	1	0
		pi phasing, 25 MHz			25							1
6	plasma operation		tbd, but known	2,5	25	pi	He	**none**	100	ECRH	1	0
7	plasma startup		tbd, but known	**1,8**	25	pi	He	He (H)	500	none	1	0
8	plasma startup		tbd, but known	1,8	25	pi	**Hydrogen**	**none**	100	none	1	0
		0 phasing, 25 MHz										2
9	plasma startup		tbd, but known	1,8	25	0	He	He (H)	500	none	1	0
10	plasma startup		tbd, but known	1,8	25	0	Hydrogen	none	100	none	1	0
		0 phasing, 38 MHz										2
11	plasma operation		tbd, but known	2,5	38	0	Helium	poor He (H)	100	none	1	0
12	plasma startup		tbd, but known	1,8	38	0	Helium	none	100	none	1	0
13	plasma startup		tbd, but known	1,8	38	0	Hydrogen	none	100	none	1	0
		pi phasing, 38 MHz										2
14	plasma operation		new confg.	2,5	38	pi	He	He (H)	500	ECRH	1	0

Planned ICRF capabilities at the start of the scientific programm of OP2.1

- **ICRF system commissioned**
  - Launched RF power from the antenna known
  - Safe operation for certain magnetic configurations
  - Reliable prediction of the antenna matching based on measurements
- **Plasma heating experiments**
  - Hydrogen minority in helium plasmas at B=2.5 T
    - Generation of fast hydrogen and possibly fast helium (fast = over thermal)
    - Standard configuration, high mirror magnetic configuration
    - „P_{RF} 500 kW, 1 sec“
    - Antenna phasing 180°
  - Possibly hydrogen heating in helium plasmas at B=1.8 T
- **Plasma startup**
  - Startup in helium or hydrogen at 2.5 T and 1.8 T

ICRF-related proposals for OP2.1

- **All planned topics (see slide 11) that were not performed in the plasma commissioning**
- **Further goals**
  - Coupling studies: max. RF power including antenna gas inlet
  - Test ICRF antenna gas inlet with various gases (H and ^{4}He)
  - Hydrogen concentration scan
  - B_0-scan to change the ICRF position: on-axis vs. off-axis deposition
  - Preparation of the scenario for future dedicated fast-ion studies (incl. ECRF and NBI power scan)
  - Test ICRF operations in the presence of pellet fuelling
  - Test the modulation of ICRF power
  - ICWC
  - Start-up
  - Characterization of plasma edge in the presence of ICRH
  - Preparation of ICRF for future dedicated turbulence, MHD studies, etc.:
- **Diagnostics**
  - Edge ne and Te profiles (endoscopes in sectors 3 and 5)
  - Fast-ion detection
  - Wall observation
  - Impurity observation
  - Hydrogen concentration
  - ICE

Proposals: D. Hartmann, J. Ongena

Proposals: Y. Kazakov, S. Bozhenkov

Proposals: J. Ongena, D. Hartmann

Proposals: K. Crombé, A. Goriaev

Collaboration with other TG's: planned use of ICRF needs to involve the ICRF team

Dedicated meeting on the plasma start-up at 1.7T: next Tuesday, 01/02/2022, **14:00**

Outlook of ICRF operations for OP2.2

- H minority heating: maximize ICRF power with two generators (dipole phasing)
- Extend the system for additional antenna phasings (e.g., current drive phasing)
- Start using ^{3}He and three-ion ICRF scenarios
- ICRF heating in the presence of pellet fuelling

Future dedicated fast-ion, scenario, turbulence, MHD studies, etc. involving ICRF

- Collaboration with the corresponding TG‘s
- The discussion should involve the ICRF team