EUROfusion

EC assisted breakdown modelling and validation

WPSA Planning Meeting (March 2020)

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Outline

EC heating system configuration during IC

ECH for:

- Pre-ionization and experimental validation
- Burn-through and absorption calculation

Coupling with magnetic analysis

Operational space

Conclusions

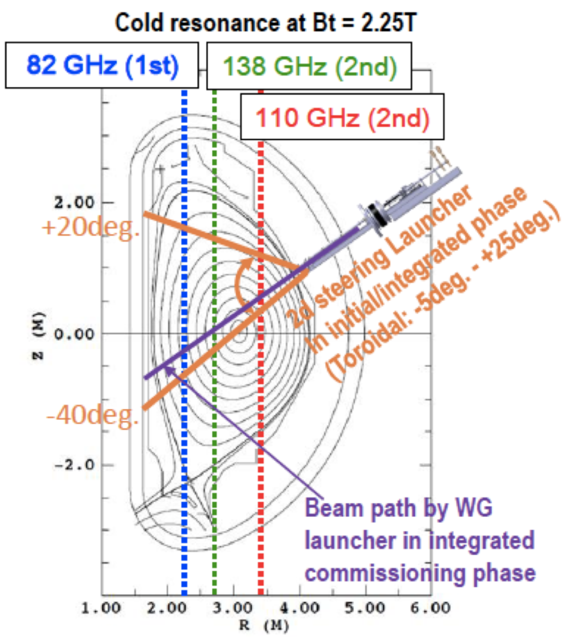
Workplan for IC

Integrated commissioning phase

Configuration of the machine: EC Heating system

	Integrated commissioning		
Number of Gyro. & TLs	1	1	
Frequency [GHz]	110	110 138	82
Gyrotron Power [MW]	1	1	
Max. Injection Power / Max. Pulse length	~1.5 MW/5 s (110 GHz) ~0.75 MW/5 s (138 GHz) ~0.6 MW/1 s (82 GHz)		
Polarization	any	any	TBC
WG Diameter [mm]	31.75	60.3	
Number of Miterbends	15	15	
Transmission Eff. [%]	~75	~75	~60
Max. Pulse Length [s]	5	5	1
Max. Duty Cycle*	TBD (similar to JT-60U)	~1/60	TBD (~3MJ/30min.)
Launcher	1 x Waveguide Launcher - 2 x 60.3 mm dia. WGs in parallel - Fixed angle parallel to port axis: 35.5° - No mirrors		

WG launcher
-> no steerable launcher
-> fixed angles (α = 35.5, β = 0)



[RCM7 - Kobayashi]

138GHz (1MW/100s)

- ECH/ECCD for B=2.25T

110GHz (1MW/100s)

- Edge ECH/ECCD for B=2.25T
- ECH/ECCD for B~1.7T

82GHz (1MW/1s)

- Plasma intiation & wall cleaning at B=2.25T by 1st harmonic

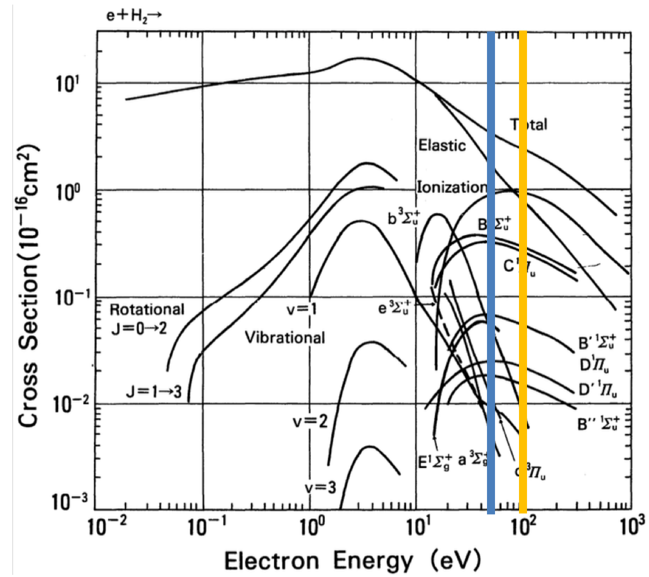
EC for pre-ionization

- Pre-ionization significantly increases the local ionization fraction near the ECH resonance.
- The maximun energy gained by electrons via nonlinear collisionless EC interaction in the early preionization stage is:

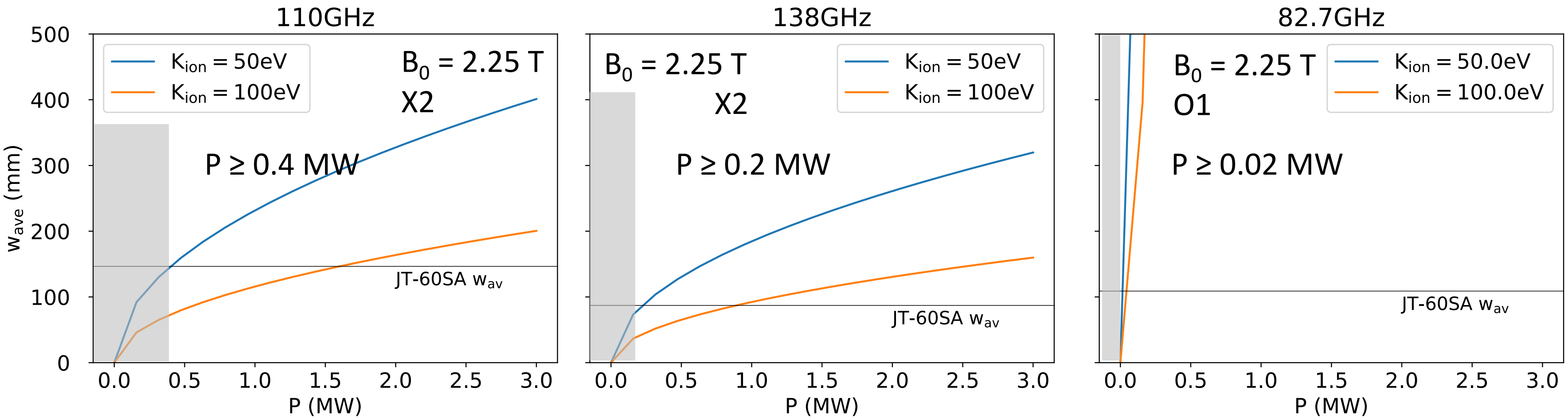
$W_{max,n=2} \cong 2.1\, P^{1/2}/\,(f\, w_{av})$ where $w_{av} = (w_y w_z)^{1/2}$

$W_{max,n=1} \cong 15.6\, P^{1/3}/\,(f\, w_{av})^{2/3}$. [KeV, MW, GHz, m]

[D. Farina, Nucl. Fusion 58 066012, 2018]



For one diverging beam, from open ended waveguide (no shaping), the spot size to access typical ionization energy:



EC for pre-ionization

The analytical estimates helps for the design of the experimental configuration of EC-assisted plasma breakdown

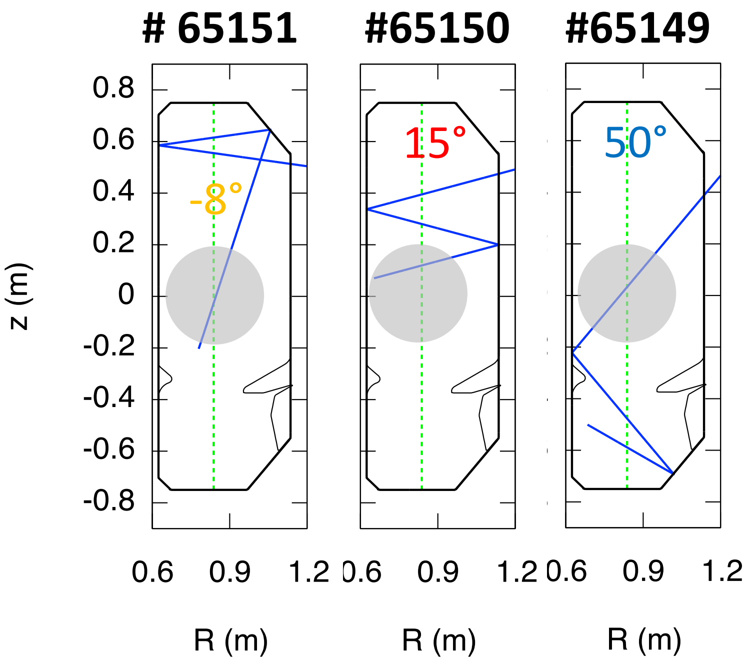
Particularly, **beam size at the resonance can be optimized when steerable launchers will be available,** knowing that energy gained by the electron and the number of electrons heated are proportional to the beam sizes in poloidal and toroidal directions ($N \propto (w_y/w_z)^{1/2}$)

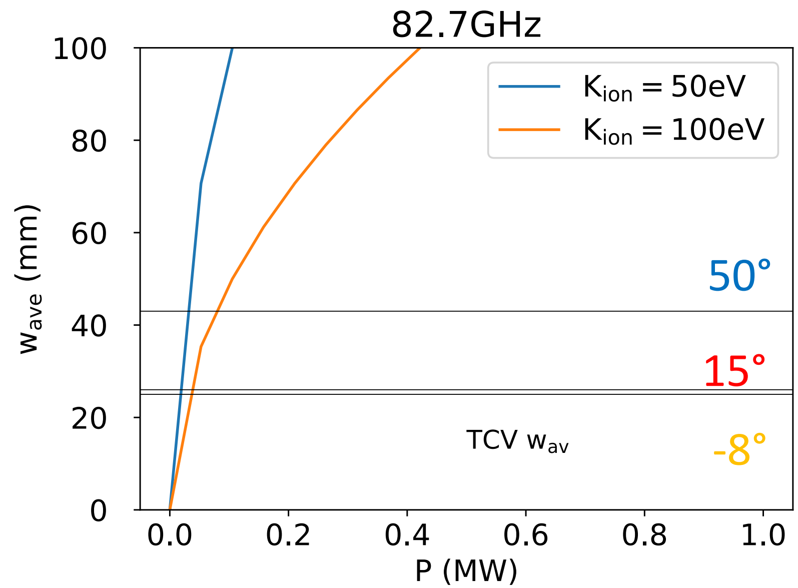
82 GHz (OM1) is quite efficient for Pin >20 kW

138GHz (XM2) can be used successfully for Pin >200 kW

Collisionless heating is not sufficient to guarantee the success of the full start-up process (to complete pre-ionization and burn-through)

Comparison with experiment: MST1-X01@TCV





Resonance on-axis

EC power at different resonance position => spot size changes in vertical direction

Poloidal scan: -8°, 15, 50°

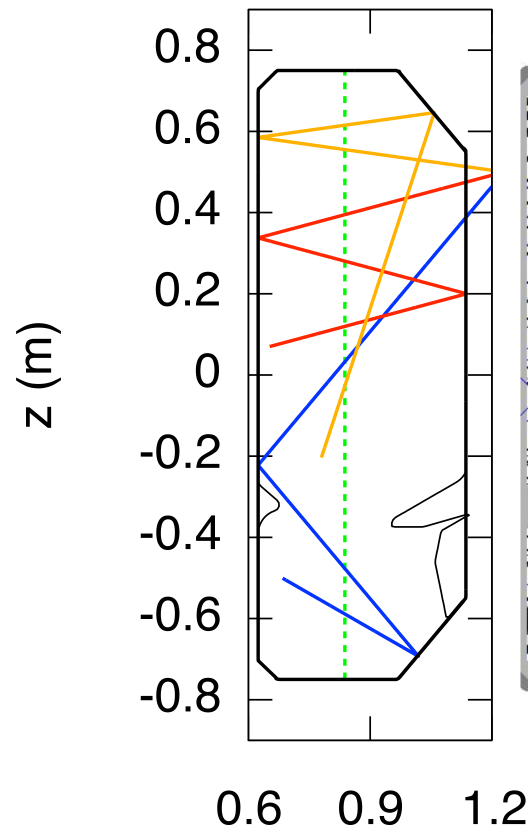
Ray tracing calculation by GRAY

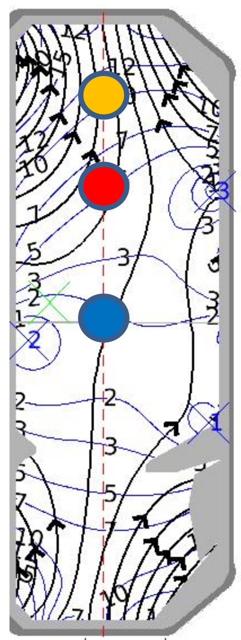
R/a_0: 0.88/0.25 m TCV

Energy gained by electron via collisionless heating is enough to pre-ionize (it depends on beam sizes in poloidal and toroidal directions).

MST1-X01@TCV : Fast camera data

Poloidal scan: -8°, 15, 50°
Plasma programmed in z=0 m



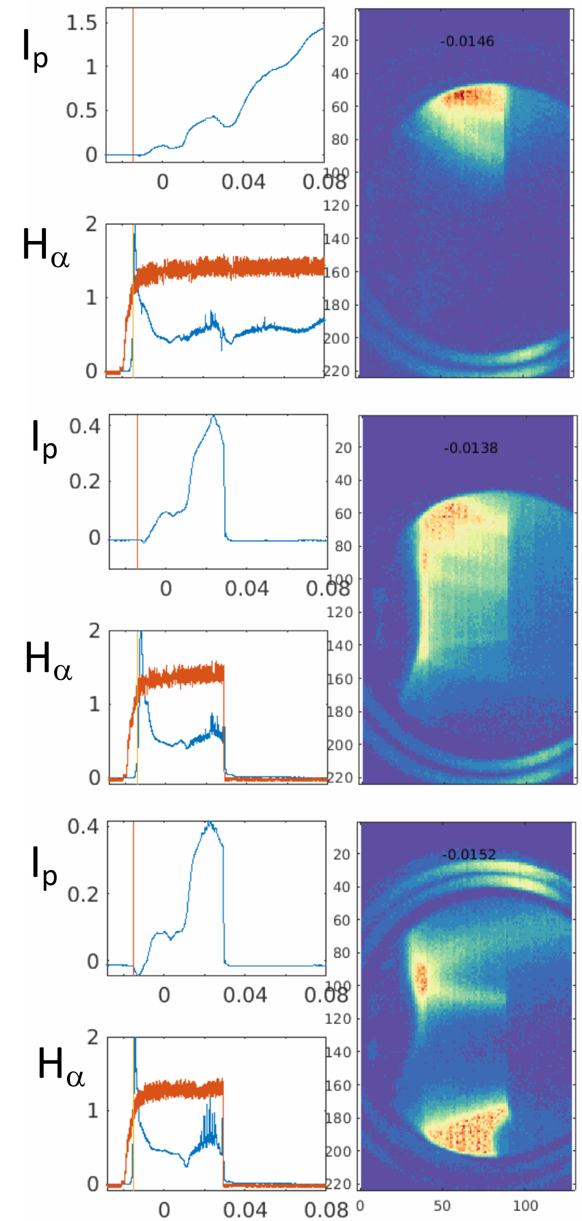


First pass

z = 0.55m

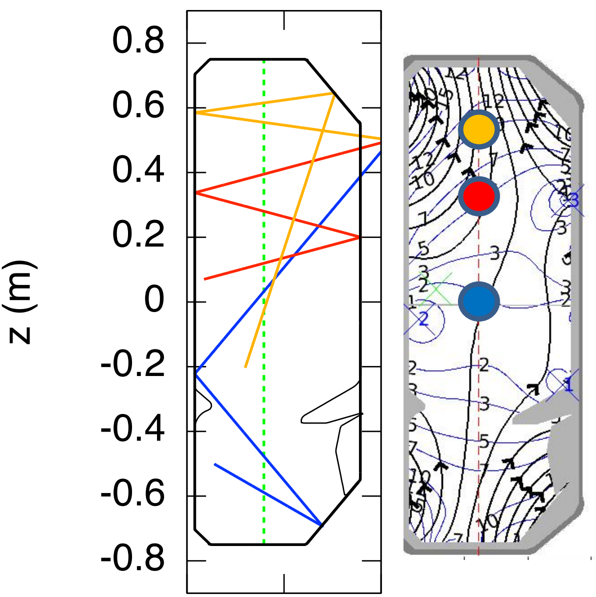
z = 0.39m

z = 0.03m



Plasma starts at different z positions, depending on the poloidal launching angle

MST1-X01@TCV : PD (H_α)



First pass

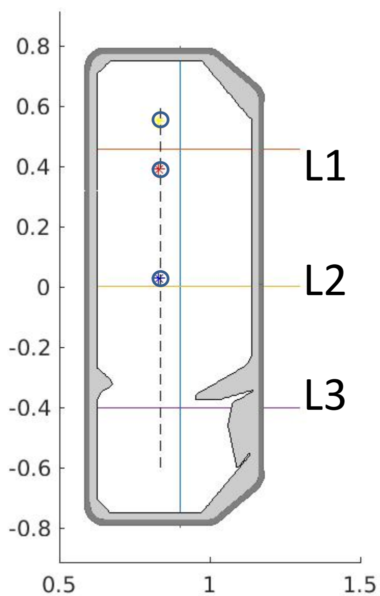
z = 0.55m

z = 0.39m

z = 0.03m

Pre-ionization occurs at the intersection between resonance and beam first pass.

From PD, horizontal line of sights (L1,L2,L3):



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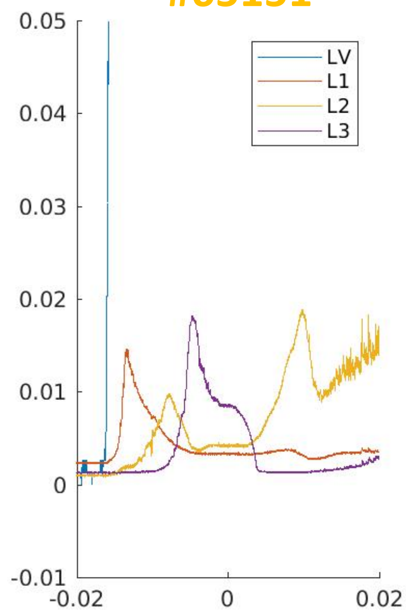

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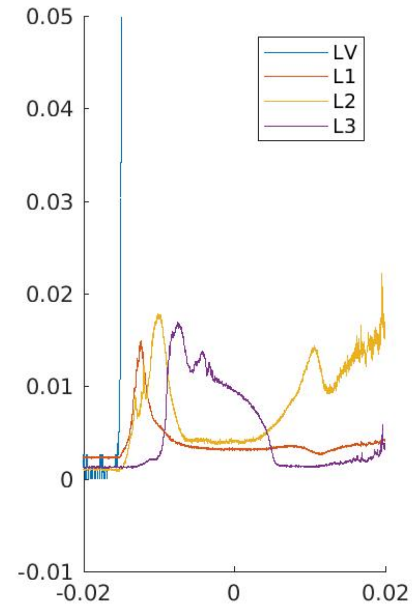

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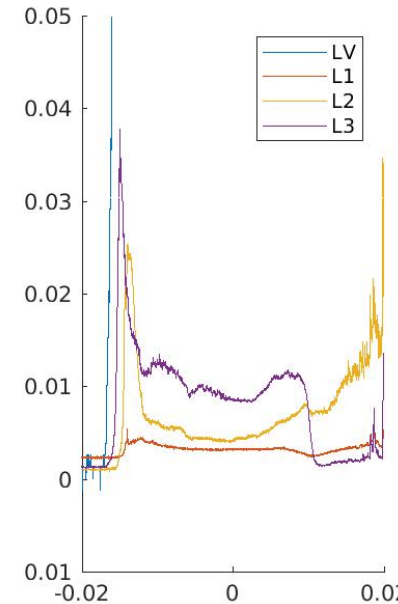


Remark

Possible diagnostic:

- Camera
- H_α monitor
- Stray radiation

EC for Burn-through

Pre-ionization ad burn-through processes impose different requirements (on the ECH system) and the impact on the plasma initiation can be different.

ECH waves can be absorbed by the free electrons in the plasma, providing additional heating and thus support burn-through.

GRAY code for the analysis of EC absorption:

- consider only first and second pass
- optimization of the launching condition, given ECRH system specification

0D model (**BKD0**) has been developed and coupled with **GRAY** to make a consistent **evaluation of the EC absorbed power.**

Dedicated MST1-X01 @ AUG experiment foreseen in April: injection of EC only during burn-through.

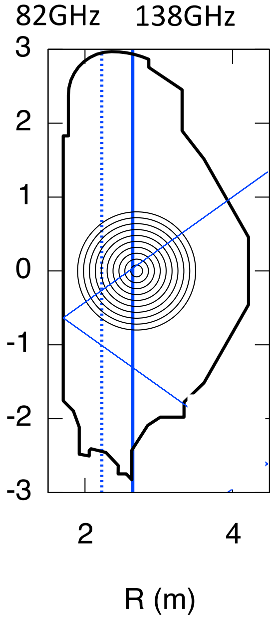
Advantage : not mixing up different physics issues. Earlier EC can modify the Townsend avalanche.

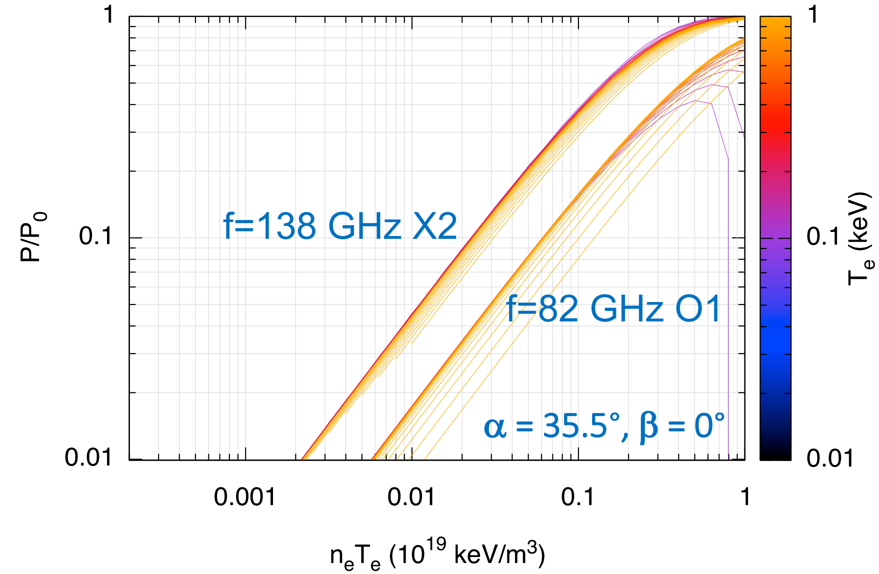
JT-60SA: absorption with GRAY

O1- and X2- schemes

α = 35.5°, β = 0°
(WG launcher)
Single pass

At n_eT_e typical of start-up, absorption is less than 5%
Factor ~ 2 between X2 and O1

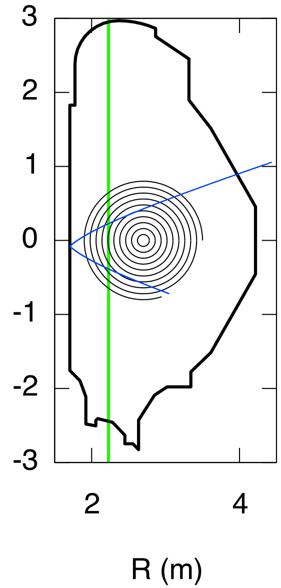


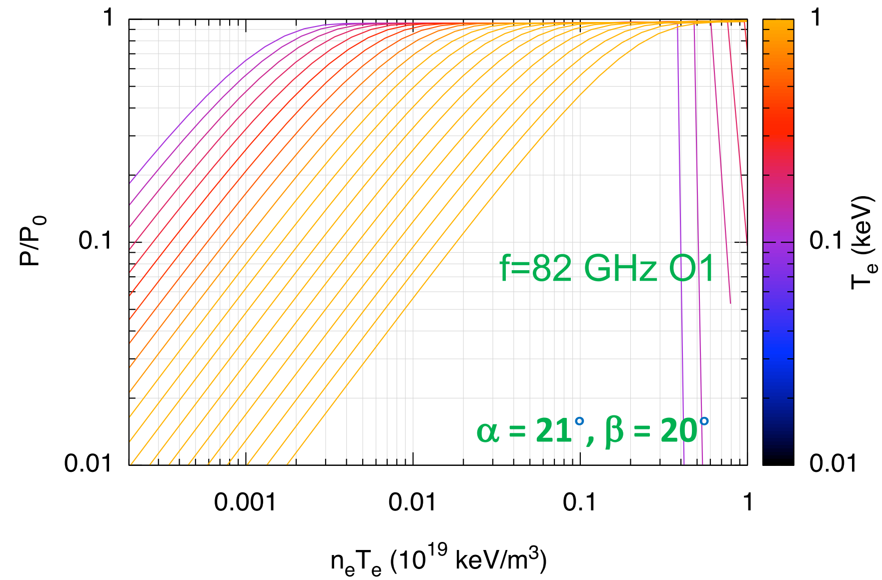


IC

O1-scheme

α, β optimized
(Steerable launcher)
Second pass after wall reflection





Wall reflection allows to optimize absorption via conversion of the residual power from O1 to X1 mode

Remark

From the analysis of EC burn-through for JT-60SA during IC, ECH system configuration at 138 GHz (X2) can assist the full start-up phase.

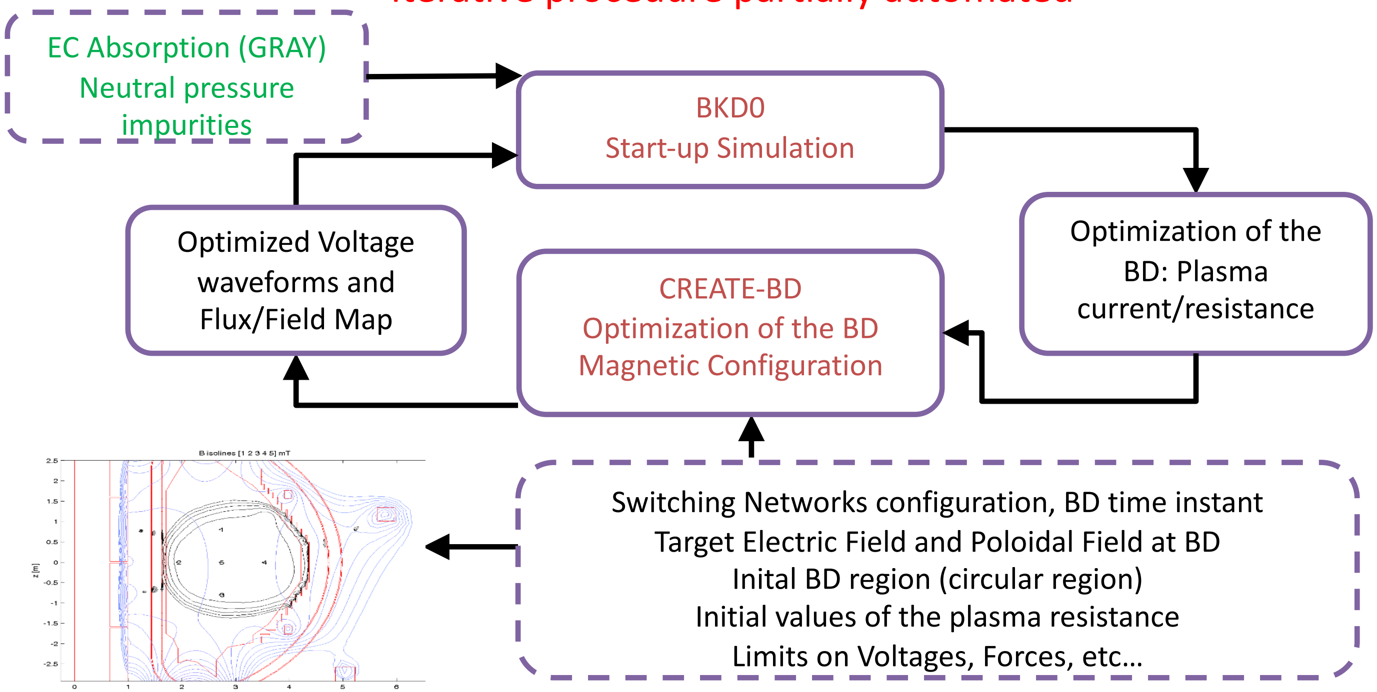
Remark on stray radiation:

- protection issue
- direct proof of absorbed power

JT-60SA magnetic model

An iterative procedure which couples BKD0 with the CREATE-BD magnetic model for JT-60SA, integrating and optimizing the active circuit currents and considering eddy currents in the passive structures for developing the initial plasma scenario

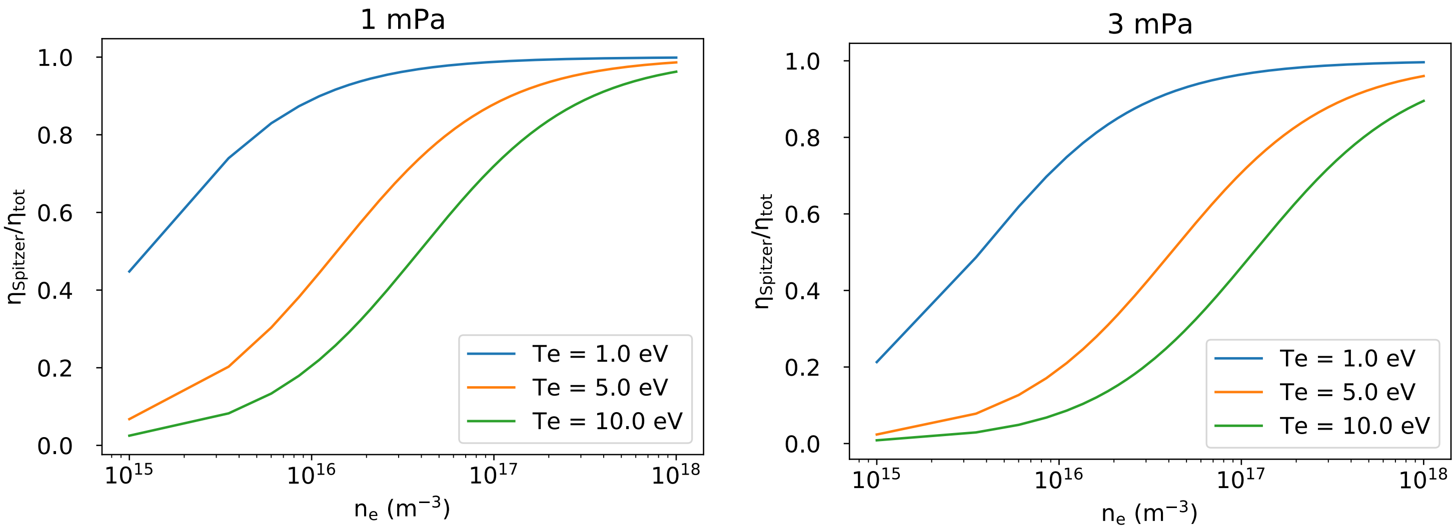
Coupling between BKD0, GRAY and CREATE-BD
Iterative procedure partially automated



IC magnetic configuration :
50% of the CS current
Without stabilizing plates

[De Tommasi G et al. 2018 27th IAEA Fusion Energy Conf. EX/P3-26]

Resistivity



In BKD0, plasma resistance during early ramp up stage is estimated by introduction of avalance resistivity:

$f = n_e/n_0$ if $0.01 < f < 0.1$

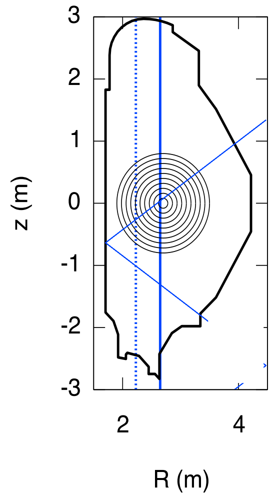
$\eta_{tot} = \eta_{Spitzer} + \eta_{ava}$

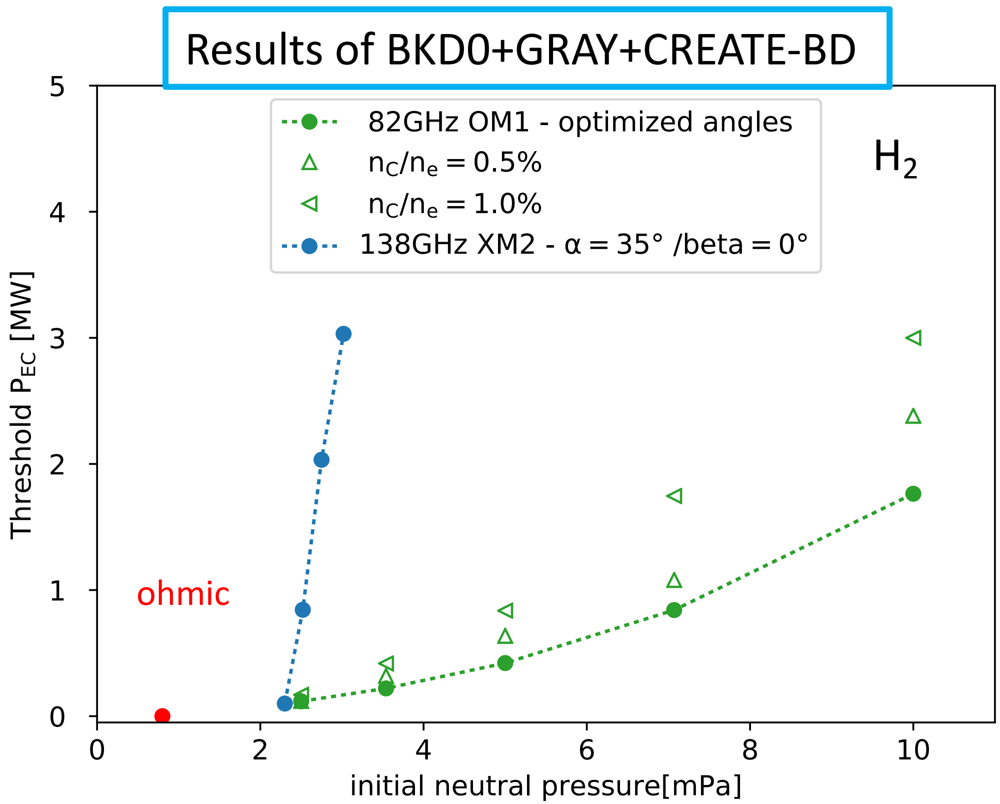
$\eta_{Spitzer} = 5.2\ 10^{-5}\ Z_{eff} \ln\Lambda\ T_e^{\ -1.5}$ [NRL]

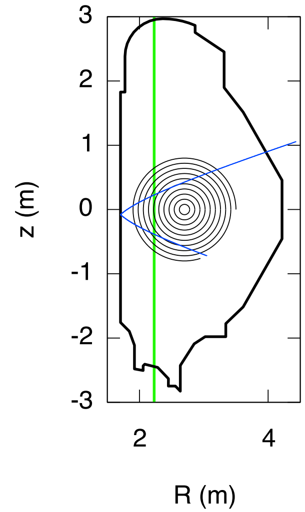
$\eta_{ava} = (4.5\ 10^5\ f)^{-1}$ (E=0.5V/m)

JT-60SA operational window

EC power threshold as a function of the initial neutral H_2 pressure for the α = 35.5, β = 0 (single pass) and the α = 21, β = 20 (second pass after wall reflection), at different initial C content and n_O/n_e=0.1%







In case of second pass after wall reflection, the mode conversion from OM to XM widens the operational window for the 82 GHz case with optimized angles.

Conclusions

- EC for Pre-ionization for IC: analytical estimates can give hints for the design of the experimental configuration of EC-assisted plasma breakdown and to set experimental parameter.
- Power threshold:

  82 GHz (O1) is quite efficient for P_{in} >20 kW

  138GHz (X2) can be used successfully for P_{in} >200 kW

- EC for Burn-through for IC: ECH system configuration at

  138 GHz (X2) p~ 2.5 mPa at 750 kW

Workplan for IC

On-site from second half of September

- Work with M.Mattei on waveform optimization
- Experimental test
- Participation to EC assisted start-up experiment
- Data analysis and BKD0 simulation

Off-site:

- Strong interest in remote participation to ECWC phase
- Participation to EC assisted start-up experiment
- Data Analysis

Alternative strategy in case of travel limitation (e.g. coronavirus)

If remote data access available, data analysis, simulations and optimization processes are still possible.