Development of ECRH-based methods for assisted discharge recovery: experiment and simulation

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Motivation

EC assisted plasma initiation has been applied successfully on different tokamaks, providing additional heating during pre-ionization of the prefill gas and during burn-through, although the influence of EC is different on the two phases [Stober NF 2011]

In case of ITER First Plasma, burn-through modelling suggests that the power absorption is limited at the second harmonic, even in multi-pass configuration. [Ricci EPS 2016]

Clear research question: separate the effect, focusing on burn-through, and confirm predictions.

Experiments have been carried out on ASDEX Upgrade:

- ECH (X2) used after standard ohmic breakdown to limit the level of stray radiation
- injection of neon impurity during pre-fill phase to mimic non-favorable condition such as would be expected in case of impurity influx from the wall
- EC successfully sustains the burn-through of pre-filling gas with neon.

Data used for modelling.

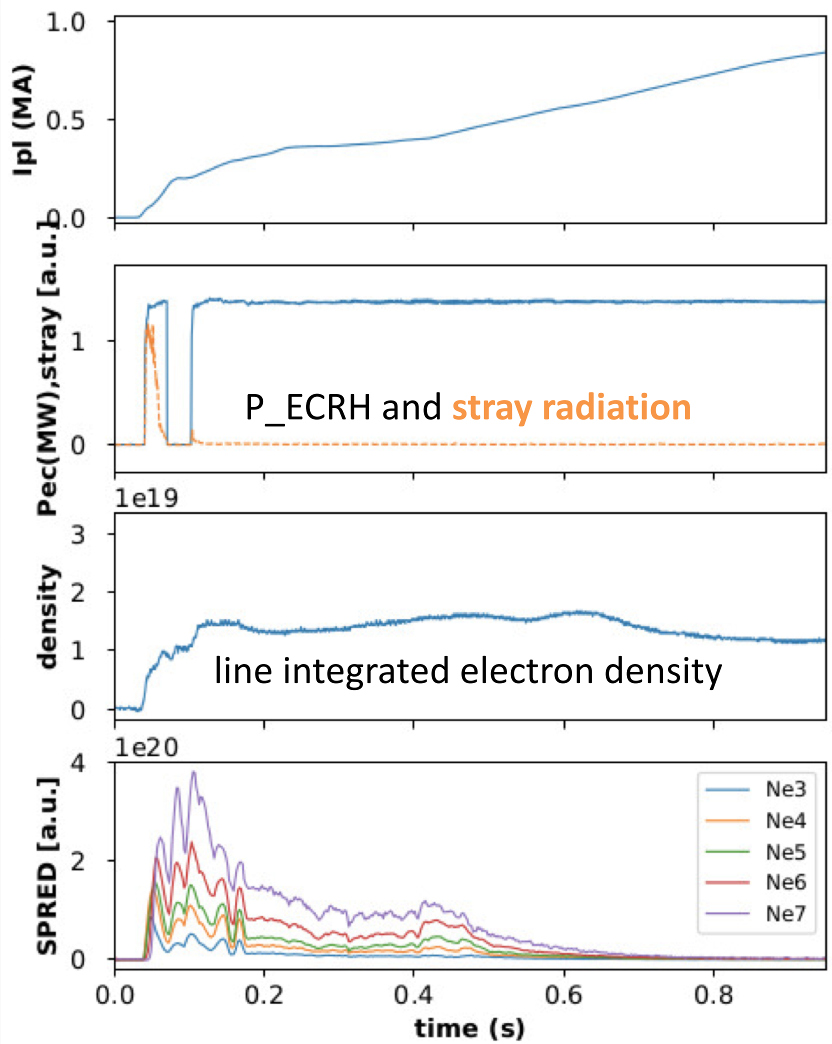
Outline

- Experimental strategy
- Role of EC key parameters
- Toroidal field flexibility
- Results

- Modelling

- Conclusion

AUG: Experimental strategy



- B0 = 2.4T and 140GHz X2 (0.7 and 1.4 MW)
- Glow discharge cleaning to avoid Ne accumulation and get reproducibility
- Parametric scan in Pec, Ne/D, toroidal field
- Effect of different parameters has been characterised mainly by SPRED

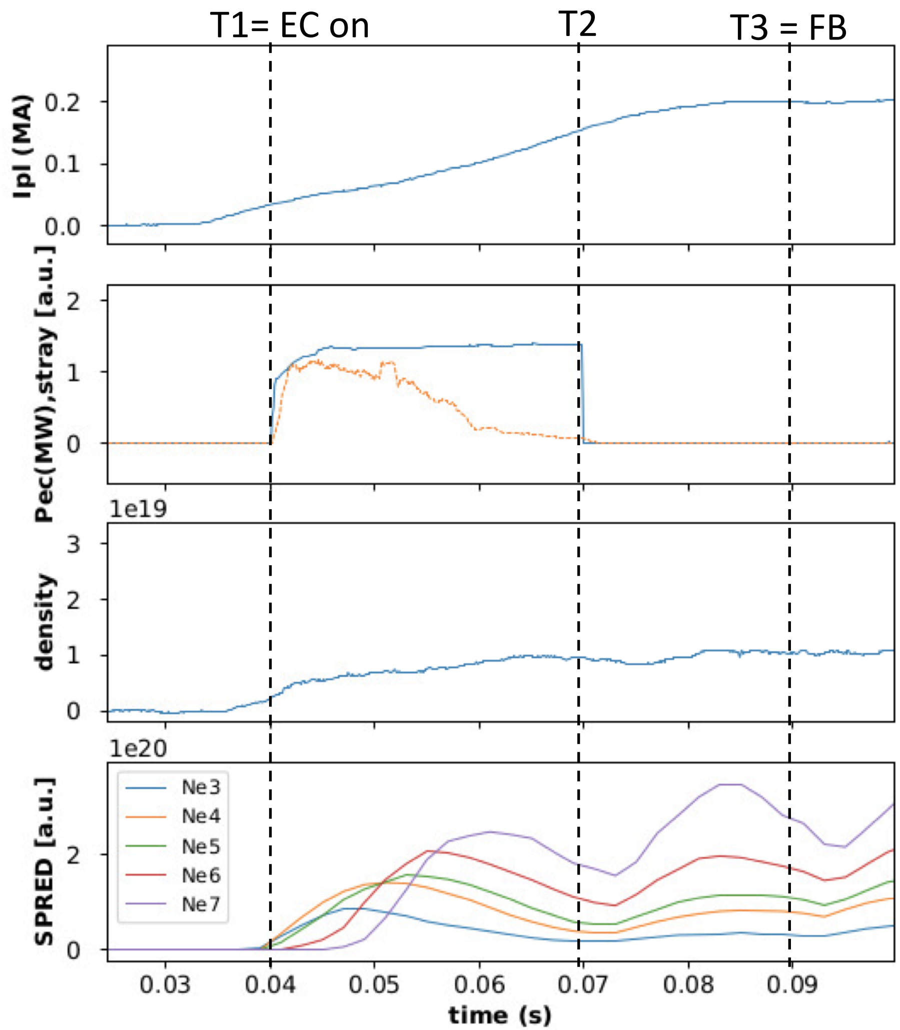
- Criterion for successful Ne burn-through:

Ne is completely burned in a time interval between 0.5-1 s depending on the initial concentration.

Different EC pulse length have been tested. In order to compare results from the entire database, the first 30 ms have been considered (first 70 ms of the discharge).

At 90 ms the fb control on Ip runs: time sufficiently accurate to define criterion for successful burn-through.

AUG: Experimental strategy



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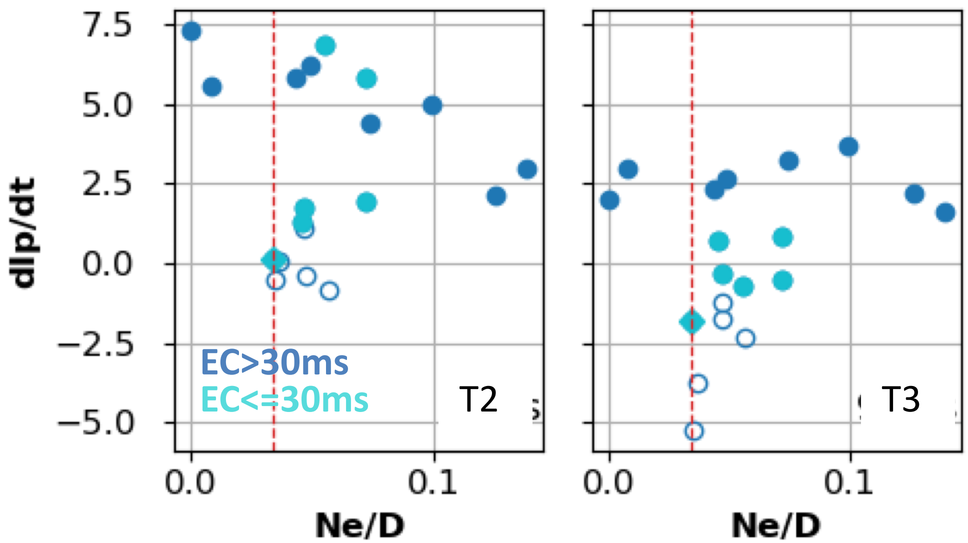
- Criterion for successful Ne burn-through:

Ip ~ 200kA at 90 ms



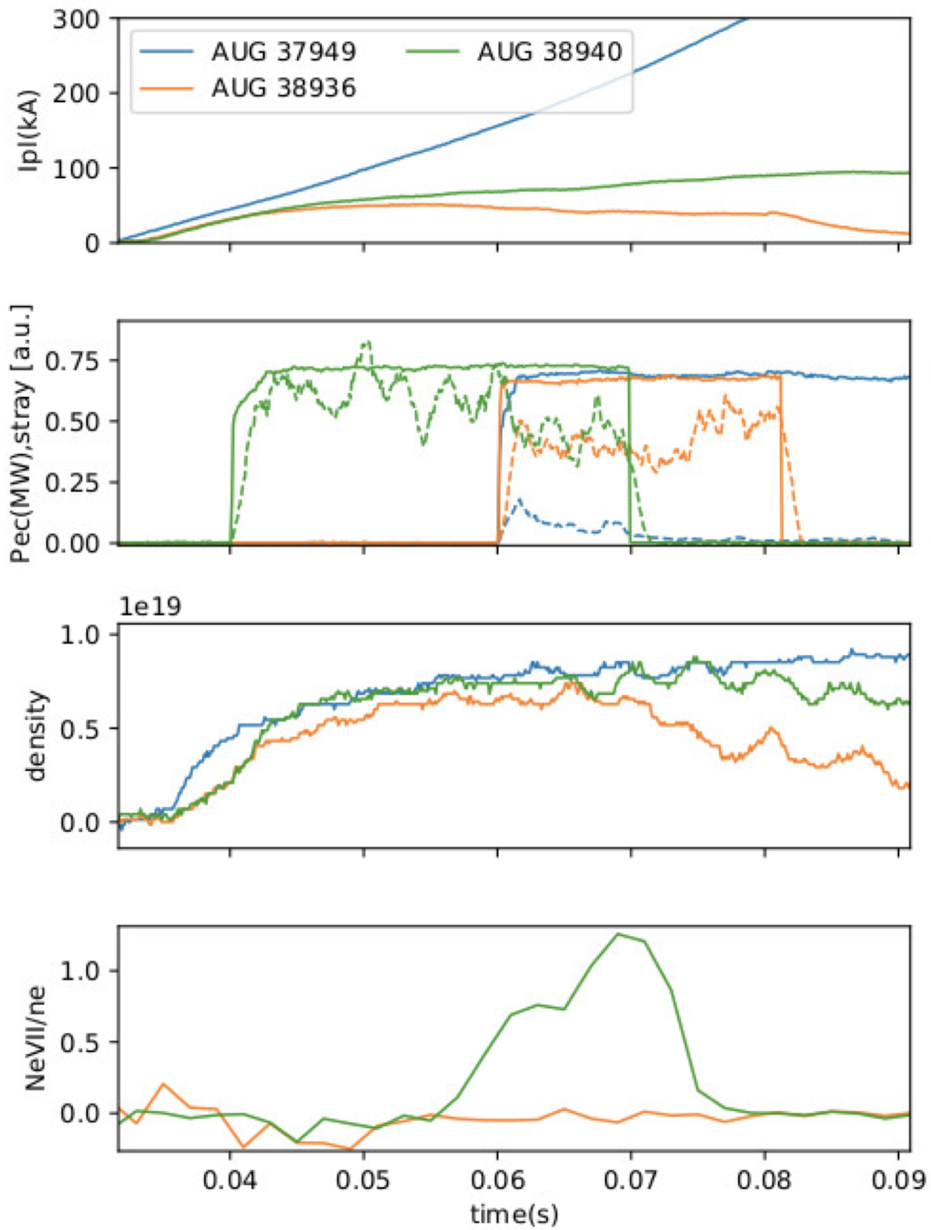
AUG: EC timing

Pulse	Pec (MW)	EC start(ms)	Ne/D
37949	0.75	60	0.0
38936	0.75	60	0.047
38940	0.75	40	0.045

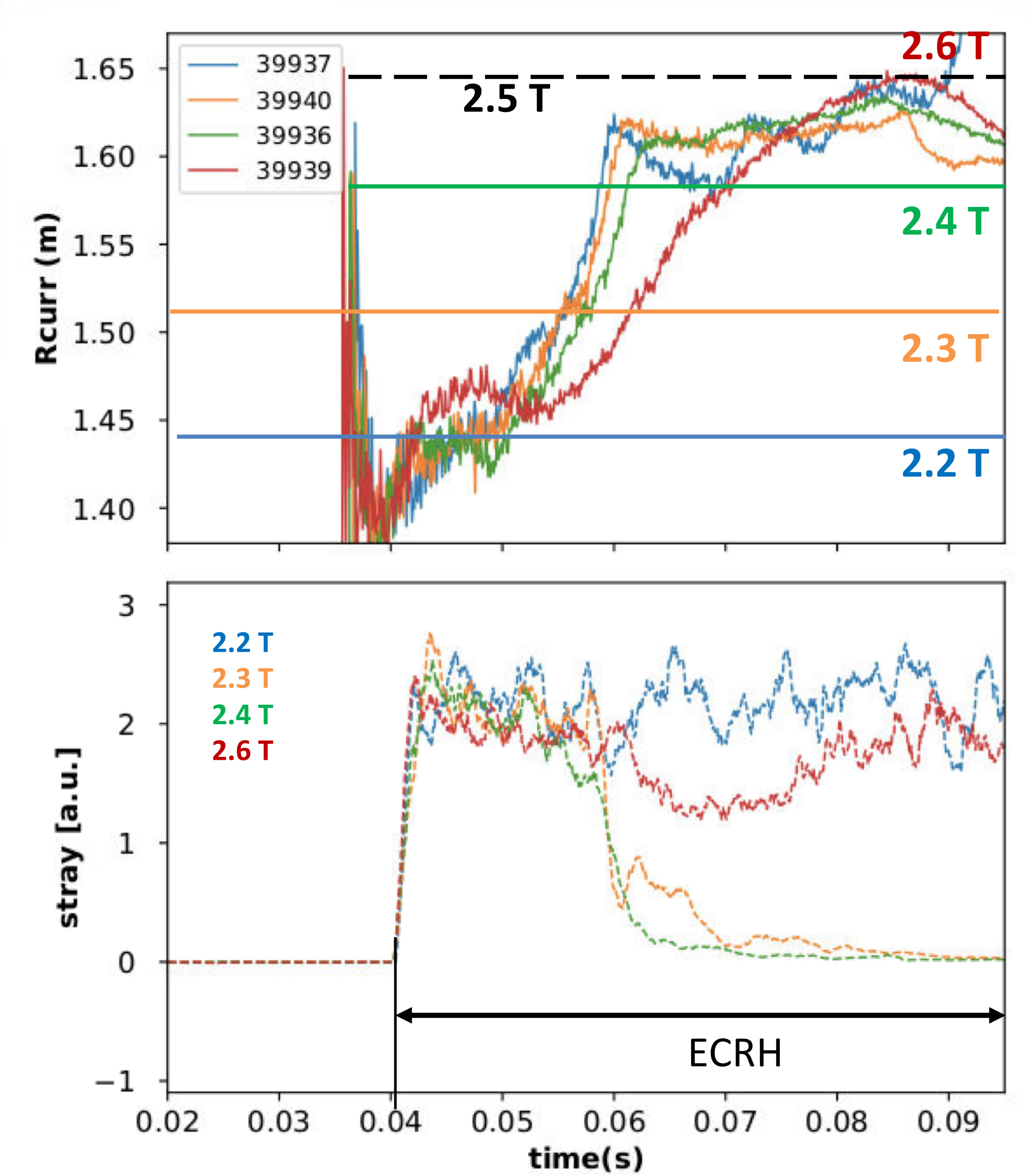
- 2 different **onset** for ECH has been tested: 40 and 60 ms in order to limit the stray radiation.

  => Only ton = 40 ms worked, the ton = 60 ms is too late

- **Pulse length**: if it is sufficiently long, it is possible to burn through high level of impurity => cleaning discharge



AUG: Variation of toroidal field



Pec = 1.4MW
Ne/D = 0.07

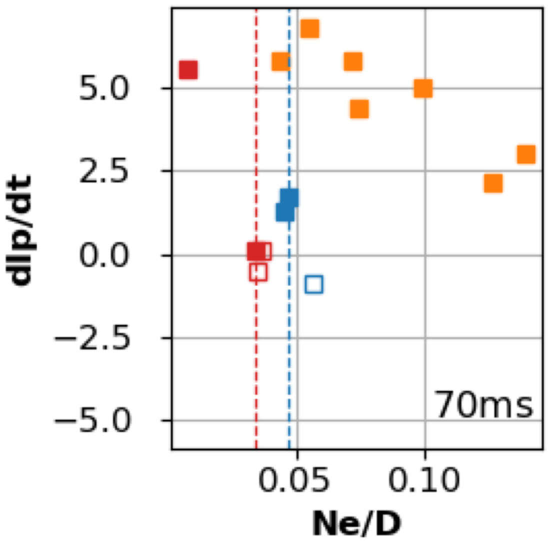
The toroidal field flexibility has been also documented, varying the cold resonance position up to ~13% of the major radius to match the ITER condition

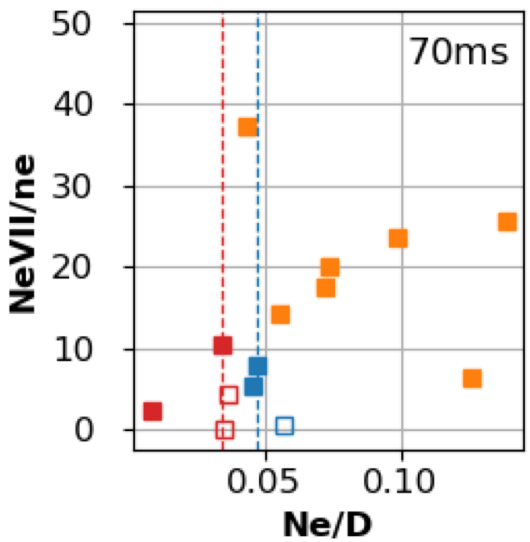
ITER (FP): Rec=5.4m, R0=6.2m

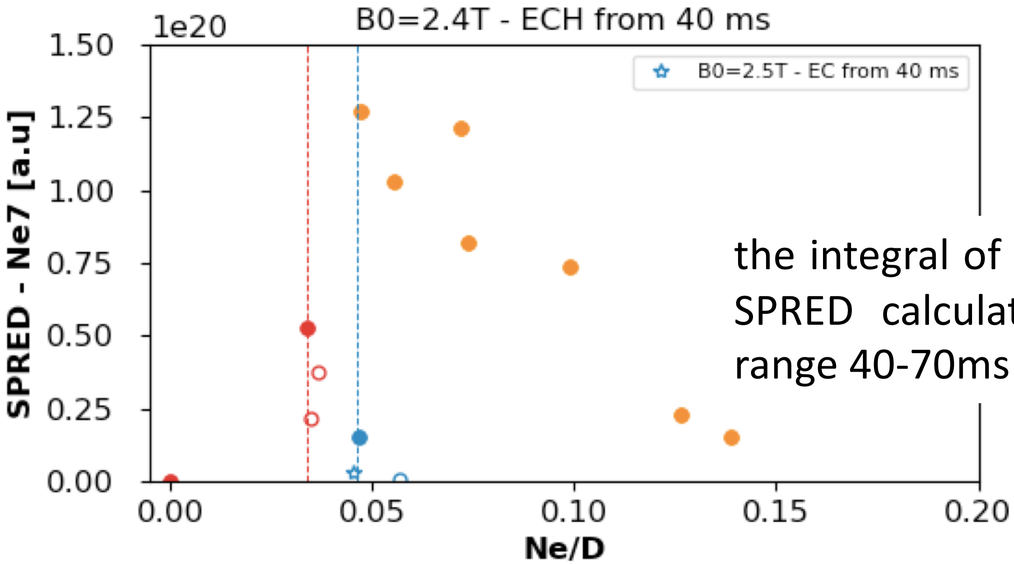
- Different Btor with identical poloidal field currents.
- For the first 20 ms of ECRH pulse, sniffer signals remains high and in the next 10 ms sharply drops except for case at **2.2T**.
- heating is more or less in the center of the current, as soon as variation of Rec is within 10%

=> Modification of the shape to improve 2.2T case.

Results: Ne effect - first 30ms







the integral of NeVII from SPRED calculated in the range 40-70ms decreases

- B0 = 2.4T
- Different level of ECH power:

  0.0 MW, **0.7 MW** and **1.4 MW**.

- Ne level (from SPRED, line intensity of NeVII at 77.4nm normalized to the density) as a function of the total amount of Ne fraction in the prefill.

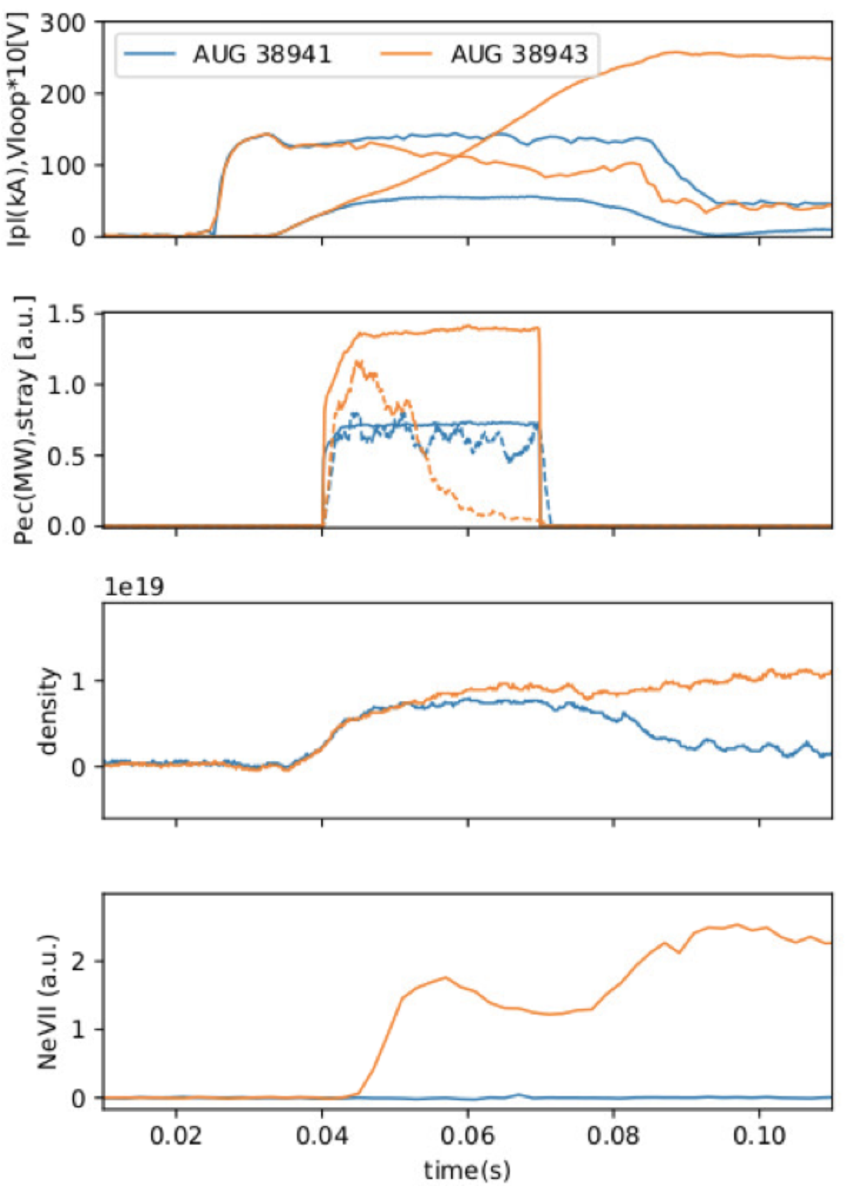
- Ne level at 70ms increases, the derivative of the plasma current decreases (keeping the temperature low) and the burn-through of NeVii line starts with increasing delay.

Ohmic: Ne < 3.5%

EC 0.7 MW: Ne < 4.7&

EC 1.4 MW: Ne up to 14%

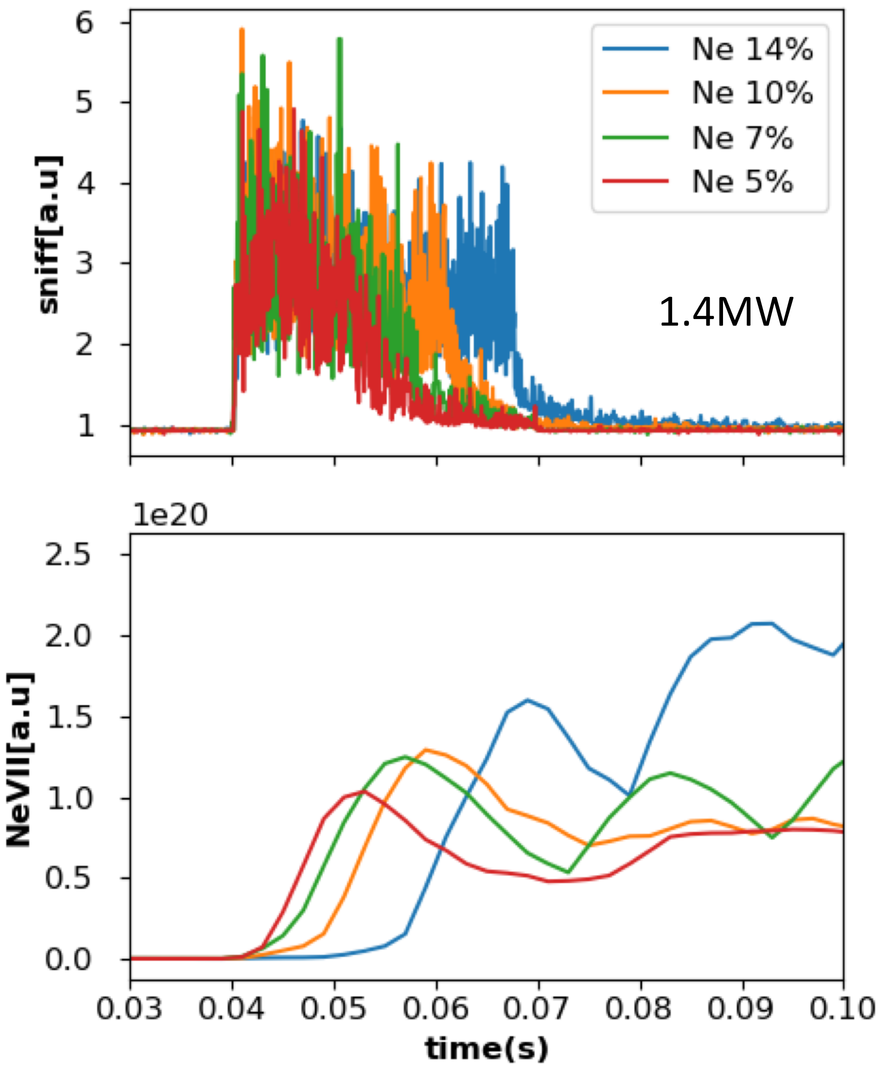
Results: EC power effect - first 30ms



Effect of the power

Pulse	Pec (MW)	Ne/D
38941	0.75	0.056
38936	1.4	0.055

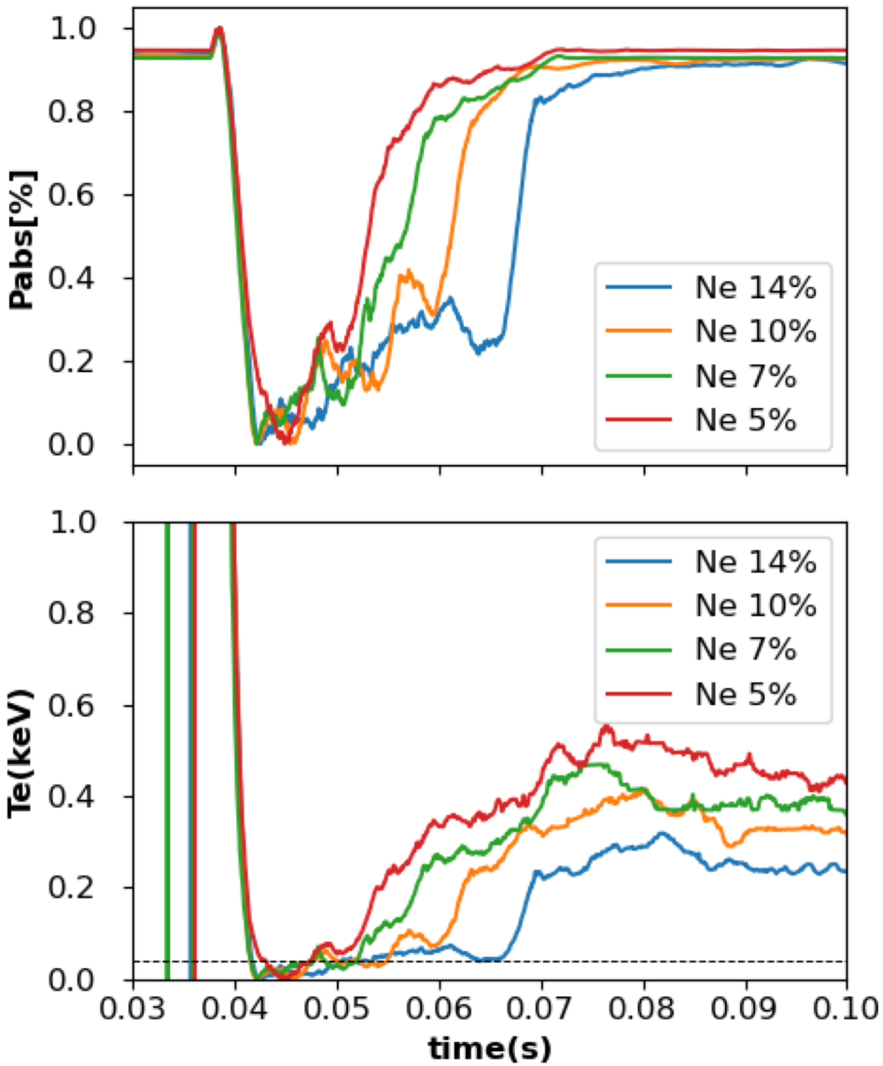
AUG: EC stray radiation at 1.4 MW



Sniffer probes show similar time behaviour:
Stray radiation increases with increasing Ne/D

From SPRED, NeVii lines start with increasing delay.

AUG: EC Absorption



Signals used to interpolate between zero and full single pass absorption, that scales as the electron pressure (simplified model)

Absorption from ~ few % to 30% and then rises up

Temperature: absorption from sniffer probe + line integrated density: $\tau \sim n_e T_e$

=> Upper limit of Te with assumption of flat density profile.

=> A peaked density profile would reduce Te (local electron pressure at the cold resonance)

BKD0+GRAY

A correct evaluation of the EC wave absorption is important in case of EC assisted start-up. Absorption is a function of n_e and T_e, which are low in the early stage of the discharge, leading to few percentages of injected power to be deposited at the resonance layer considering single or multi-pass configuration.

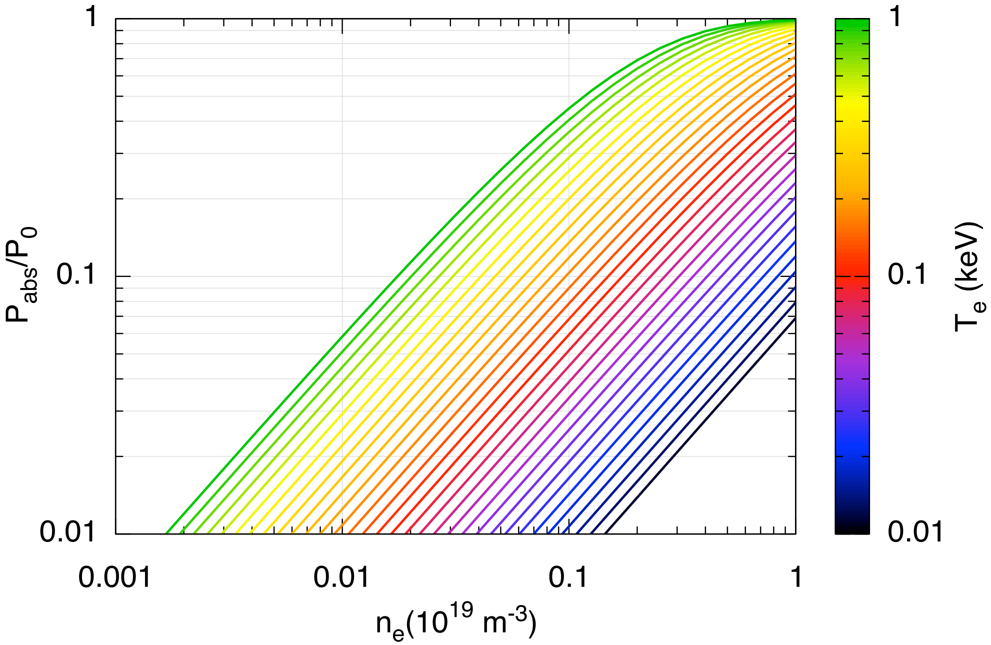
A predictive model has been developed by means of a two-step analysis :

- 0D simulation of time evolution of main plasma parameters (BKD0 code) [Granucci, NF2015]
  - Energy balance equations for electrons and ions
  - Particle balance equations for electrons, ions and neutrals (D_2 and impurities)
  - Electric circuit equation
- coupled with the self-consistent calculation of the EC power absorption, including EC localization, polarization effects and wall bouncing effect (GRAY code). [Farina, FST 2007]

$$\frac{3}{2}\frac{d(n_e T_e)}{dt} = P_{oh} + \boxed{P_{EC,abs}} - P_{equi} - (P_{iz,H} + P_{rad,H}) - (P_{iz,imp} + P_{rad,imp}) - P_{e,conv}$$

GRAY

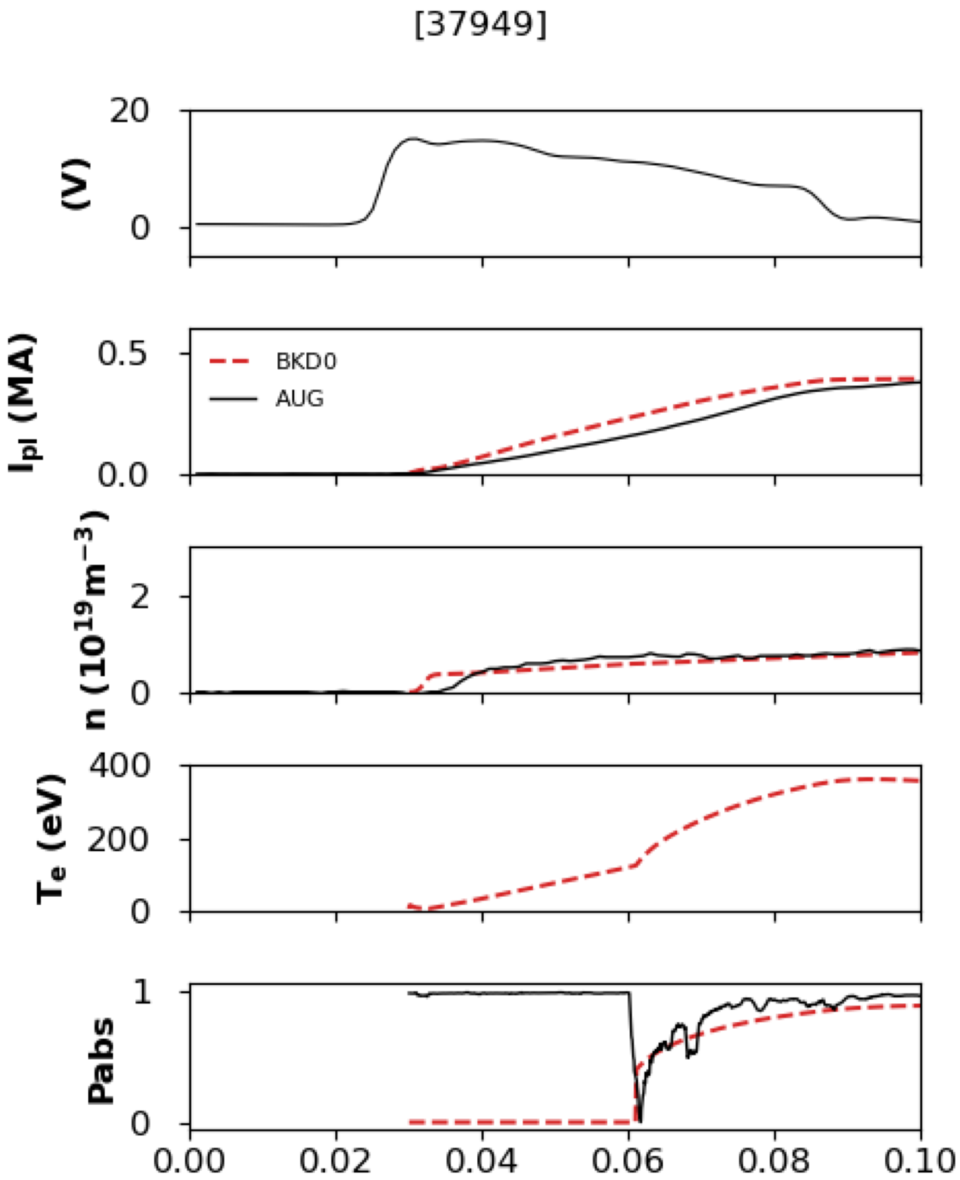
GRAY



Absorption calculated by GRAY

A model for wave reflection at the plasma facing walls is included, which is relevant for optically thin plasma scenarios when the EC beam may cross the plasma multiple times before being completely absorbed.

BKD0 and GRAY



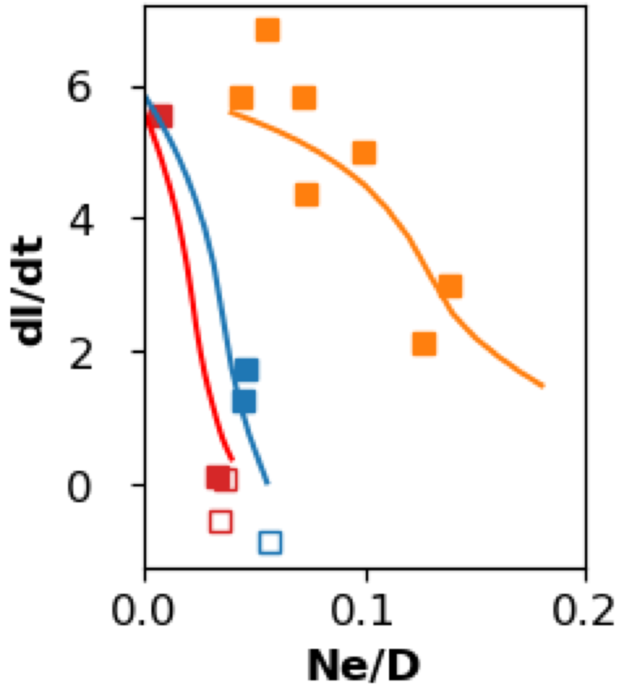
0.7 MW

t_{ON} =60 ms

No impurity

BKD0-GRAY simulation of #37947 used to setup the experiments

Simulation/AUG

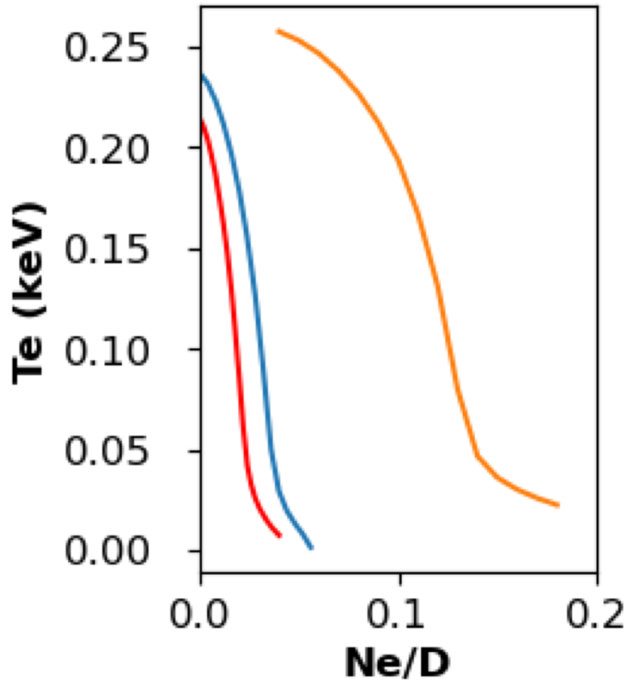


0.0 MW, **0.7 MW** and **1.4 MW**

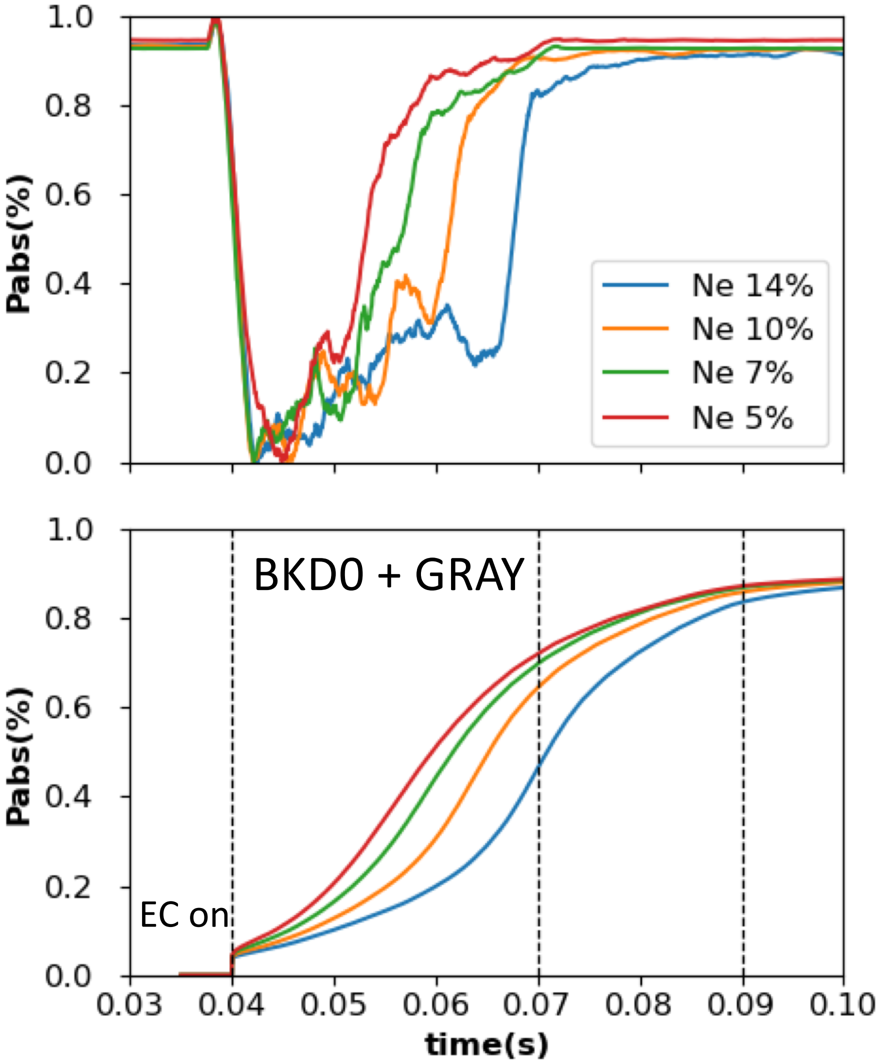
Simulations reproduce experimental results

- for EC pulse duration of 30 ms
- different results for EC onset (40/60 ms)
- find the threshold for successful burn-through condition
- Predict more then 20% of Ne

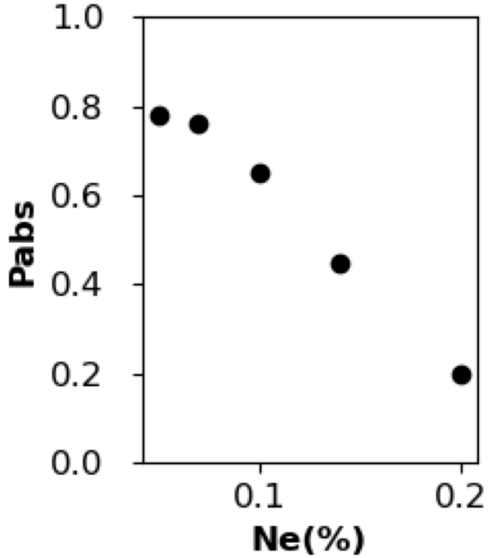
Simulated electron Te



Simulation/EC Absorption



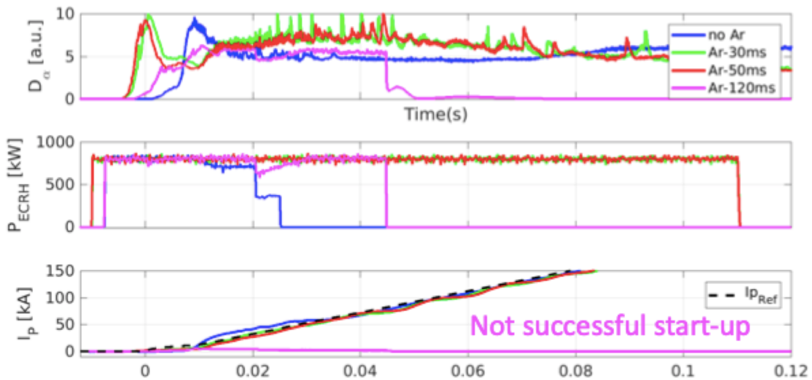
- The results of the simulation are compared with the experimental data from sniffer probe showing good agreement



Calculated Pabs after 30 ms of EC

$P_{EC,in}$ = 1.4 MW

Simulation/TCV



D2 (3e20 mol/s) +Ar
Ar valve not calibrated
(@ t=-1s 1.5 V - 30, 50, 120 ms)

no GDC
t_{BD} anticipated
EC input power increased

Adding Ar as impurity leads to an increased power threshold for a sustained startup

Direct comparison not possible:

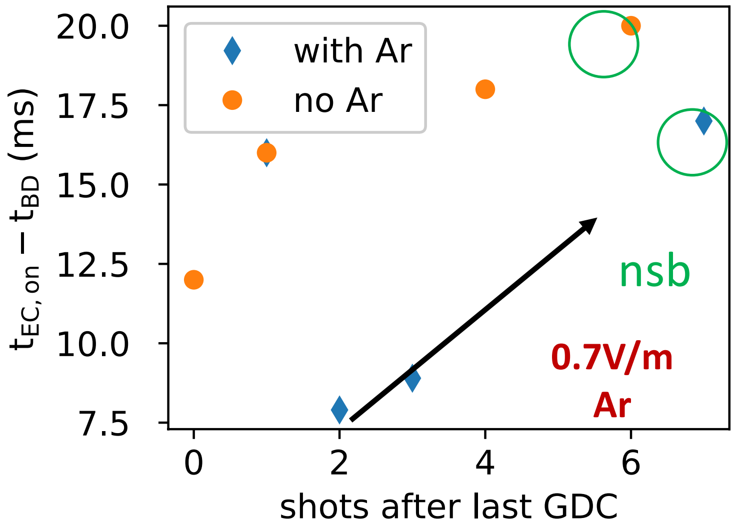
- low loop voltage conditions
- EC also for pre-ionization
- EC actively controlled trying to reduce the required power (dI_p/dt constant) => results depend on wall condition

Up to 2% of Ar sustained with 0.7MW

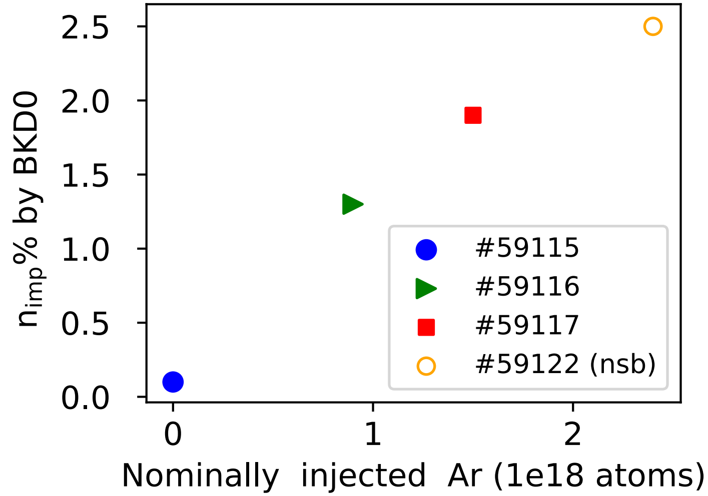
For Ne less power required (0.6 MW)

⇒ For 0.7 MW on TCV (R0 = 0.88m) <2.5 % of impurity

TCV: Sequence of successive pulses (X2)



t_{BD} = max of D_α emission

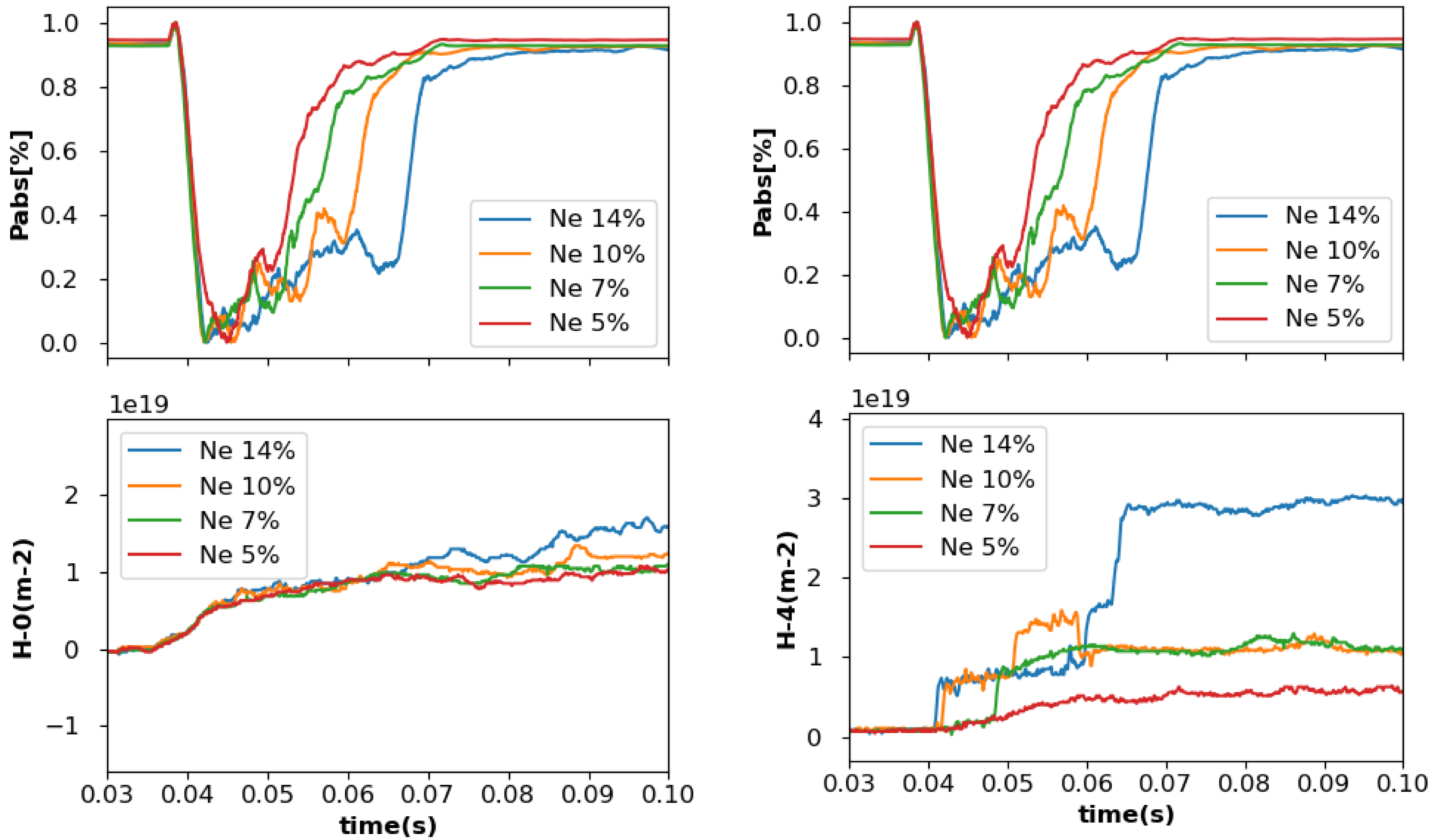


Conclusions

- Key parameters that strongly affect early impurity burn-through are onset and duration of EC pulse
- Variation more than 10% of the cold resonance position can be improved by modification of currents
- EC Power threshold as a function of Ne/D has been found

- Simulations successfully predict the power threshold and reproduced quite successfully experimental outputs
- Absorption is in good agreement with sniffer probes

Thank you



Line integrated density at different z location