EUROfusion

Progress report on WPTE-RT03 experiments and implication for ITER

Joint WPTE-WPPrIO Meeting on Plasma breakdown/burn-through 03/09/2021

D. Ricci, T. Wauters

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RT03 overview and link to ITER

Objectives:

D1. Develop reliable ECRH and/or ICRH methods for RF assisted breakdown and produce prediction for ITER to determine the required RF power. **2021/2022**

D2. Optimize the ramp-up path (wrt impurity accumulation, MHD, flux saving) in metallic devices.

D3. Produce an integrated simulation of the breakdown and ramp-up phase for the first ITER plasmas.

D2 and D3 => Dedicated shots later

- Shots executed/planned in 2021

year	AUG	TCV	MAST-U	WEST
2021	20/20	0	0	0/15

RT03 overview and link to ITER

ITPA CC ITER Research Plan Workbook

EUROfusion proposals in RT03:

P1		Development of ECRH-based methods for assisted discharge recovery on AUG	Daria Ricci
P1		Quantification of X3 absorption for ITER modeling	Joerg Stober
P1(M)		Investigation of RF-assisted start-up in ITER	Kyriakos Hizanidis
P2(PB)		Parametric decay of ECRH waves	Asger S Jacobsen
P1		ICRF assisted breakdown at low loop voltage	Tom Wauters
P2	Dedicated shots later	Optimizing Core Radiation and MHD stability in the early phase of W devices (AUG and WEST)	Patrick Maget
P2	Dedicated shots later	Ramp-up optimization for W mitigation (AUG)	Fabien Jaulmes
P1(M)	Dedicated shots later	Iterative experimental methods for plasma start-up and ramp-up	Federico Felici

B.5.1 ECRH assisted plasma start-up (Cat 2)

B.11.6 Validation of models for ECH absorption in 3rd harm. operation at 5 MA / 1.8 T plasmas (Cat 2)

Proposed for RF assisted start-up at 1.8T in ITER (where EC assist does not work)

B.12.4 Optimization of current ramp-up to achieve target q profile for long pulse scenarios by feedback control (Cat 3)

B.5.4 Plasma transport in ramp-up phase (Cat 3)

Development of ECRH-based methods for assisted discharge recovery on AUG

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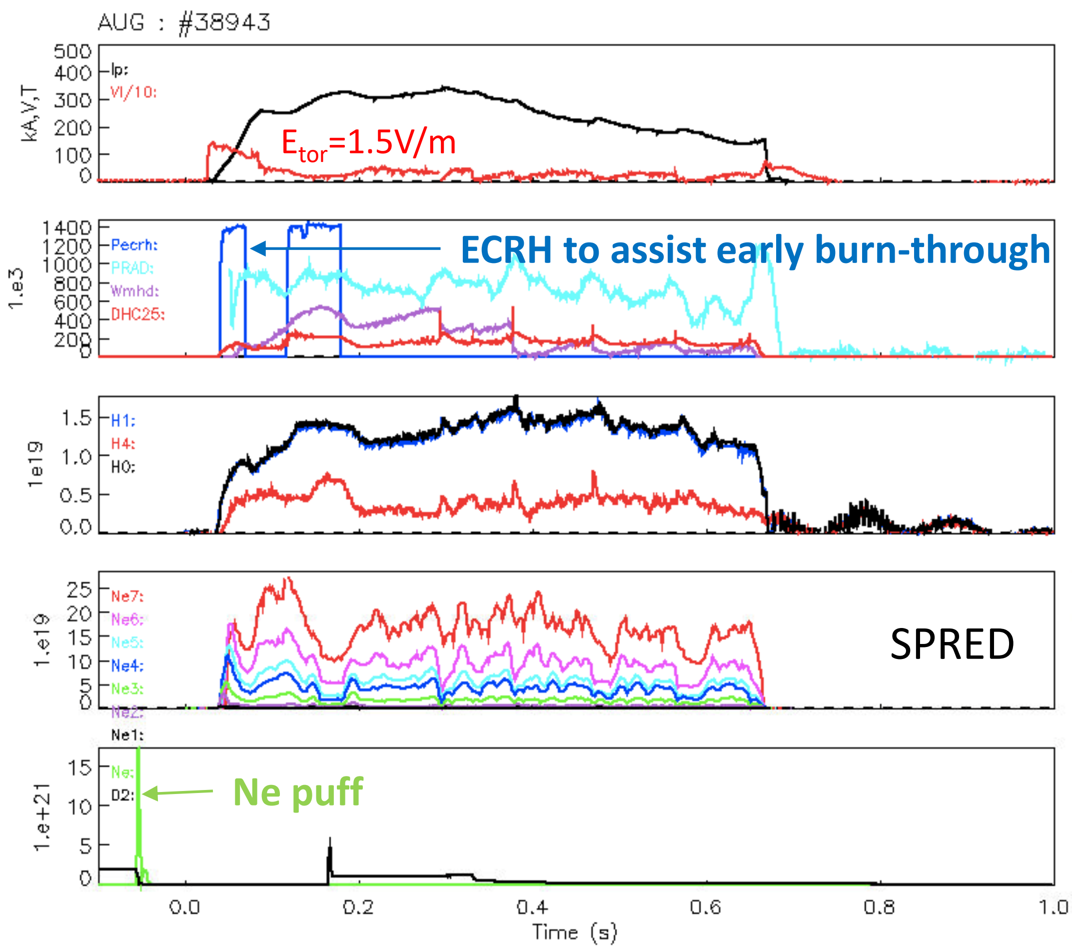
EC burn-though assist in presence of Neon



The recipe:

Ne injected at the end of D prefill

The amount of Ne (Ne/D < 0.1%) should be comparable to what remains in the machine after a killer gas pulse.

Glow discharge to avoid Ne accumulation and get reproducibility.

In 2020: Ohmic start-up in presence on Ne (MST1 campaign)

In 2021: ECRH switched on after break-down, to assist the early burn-through phase (@ 40 ms on AUG)

Overview

Goal:

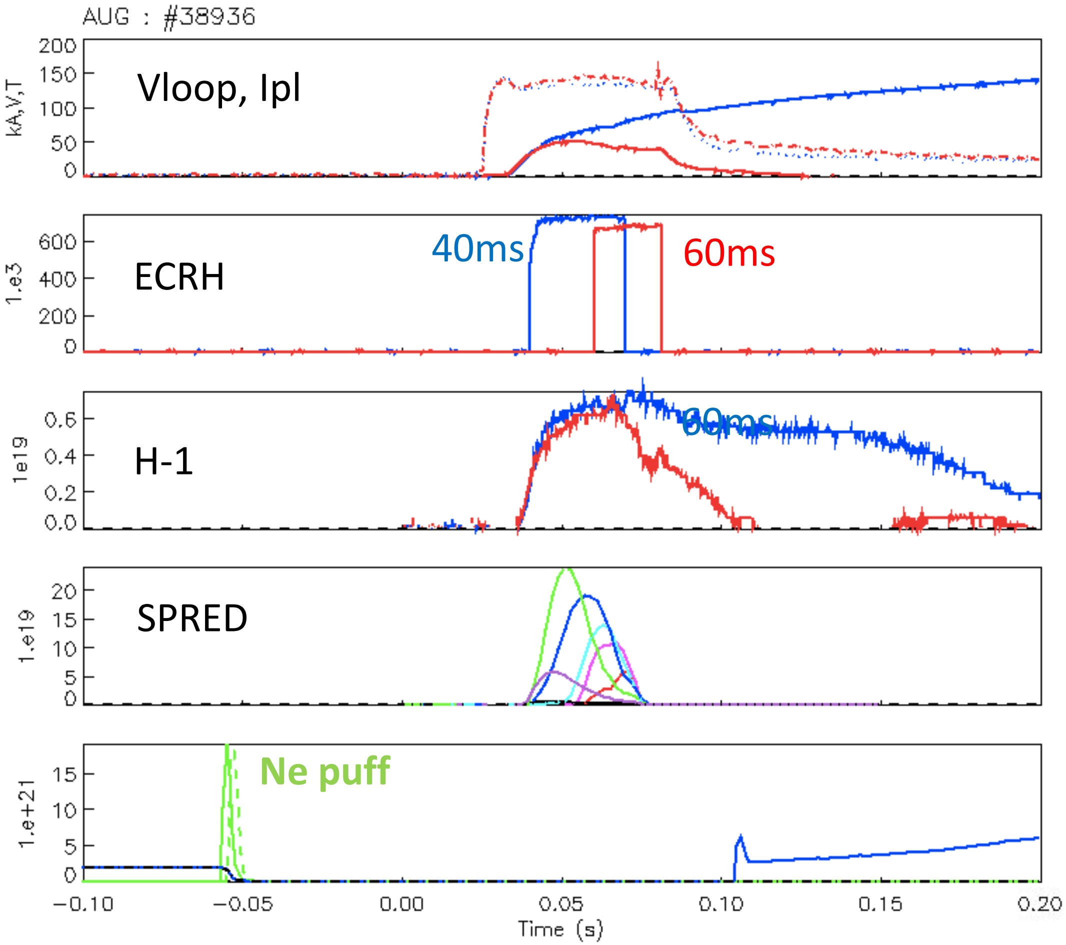
- Demonstrate and optimise the feasibility of discharge recovery by means of ECH in presence of impurity.
- EC power scan (3 levels) and Ne impurity scan (valve for 10, 20, 30 ms)
- Compare with BKD0 simulation
- Piggy-back observations of parametric decay during ECRH-based discharge recovery experiments.

Conclusions:

- **EC timing is crucial** for the burn-through to be sustained: ON when the current initially raises and Ne burn-through starts (at 40 ms on AUG)
- **Role of toroidal field (2.4T)** is not so clear: 5% of magnetic field is effective. It would be interesting to test the effect of using toroidal field of -2.3 and -2.6 T (we have already pulses at -2.4 and -2.5T with the same Ne): since ITER will not be able to vary Bt it seems important to document the flexibility.
- From SPRED clear indication of failure vs successful Ne burn-through
- Good data for comparison with BKD0 simulations, ongoing analysis
- Working at high Ne values, we notice from experiments that if we could run at 0.5/0.6 MA it would be much easier than run 1MA discharge.

Role of ECH timing on burn through

38940 vs 38936 – Bt = -2.4T



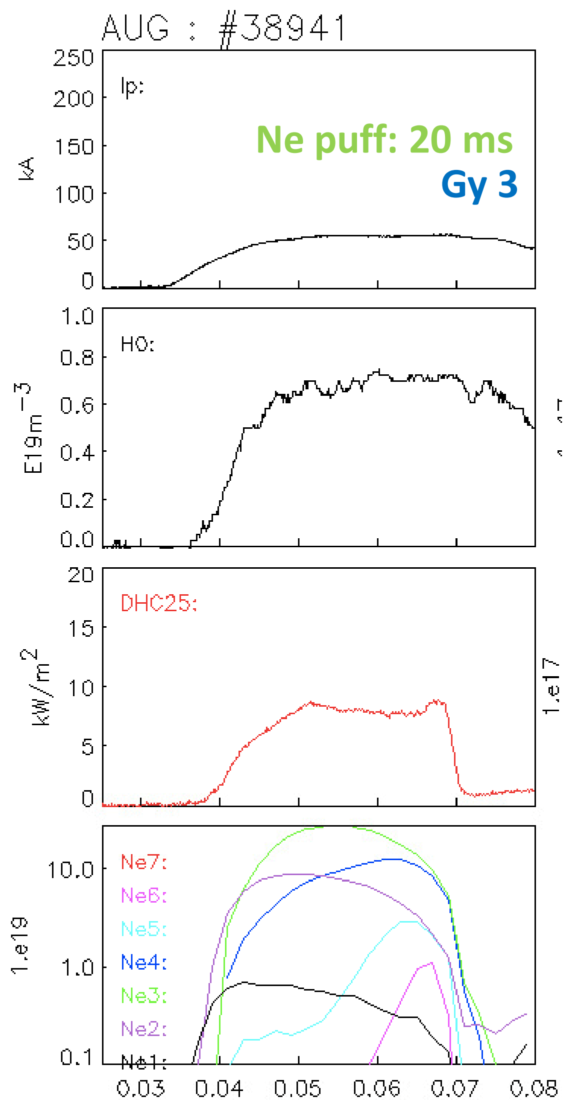
Identical experimental set-up except onset of EC

Longer EC pulse would not be useful, if EC starts at 60 ms

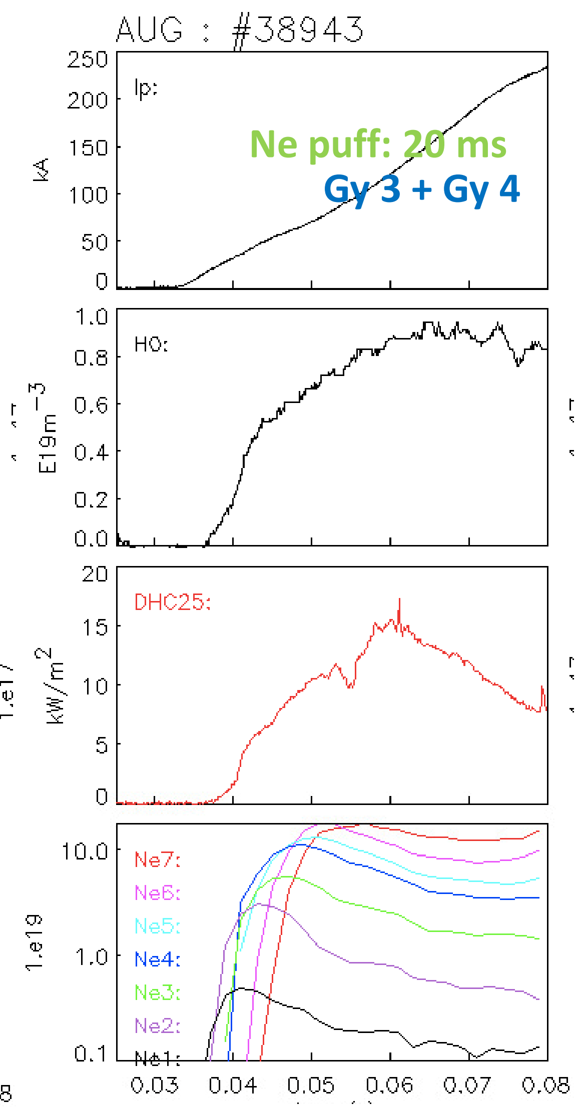
In general, when effective, longer pulse length can improve the burn-though

Effect of ECH power on burn through

Failed -> no Ne7 signal



Successful



SPRED

Indication of failure vs sustained Ne burn-through

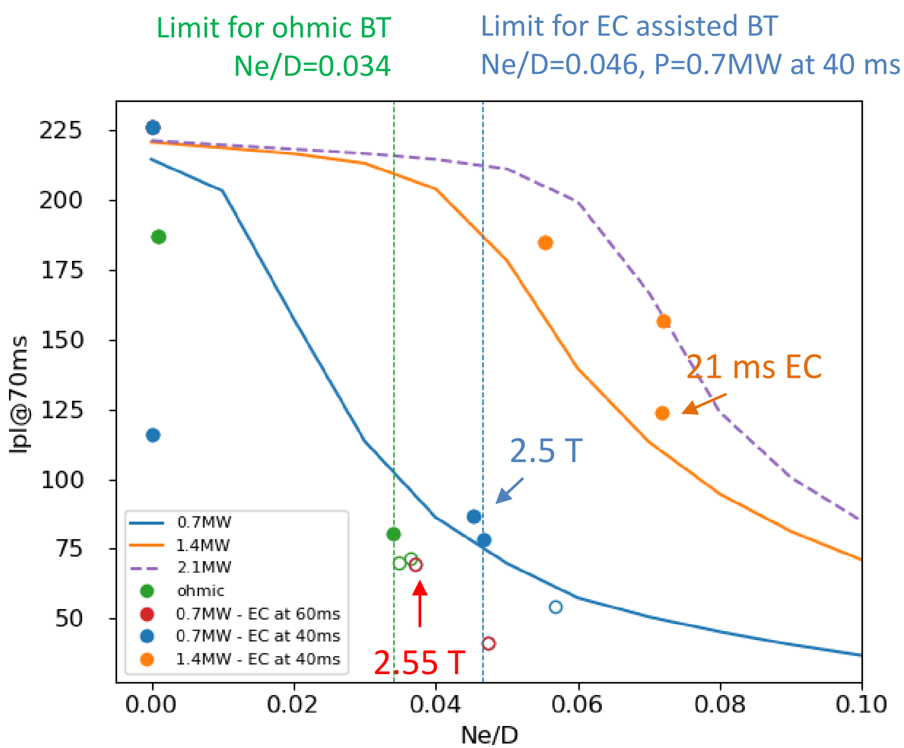
=> Used to reproduce the experimental threshold by simulations:

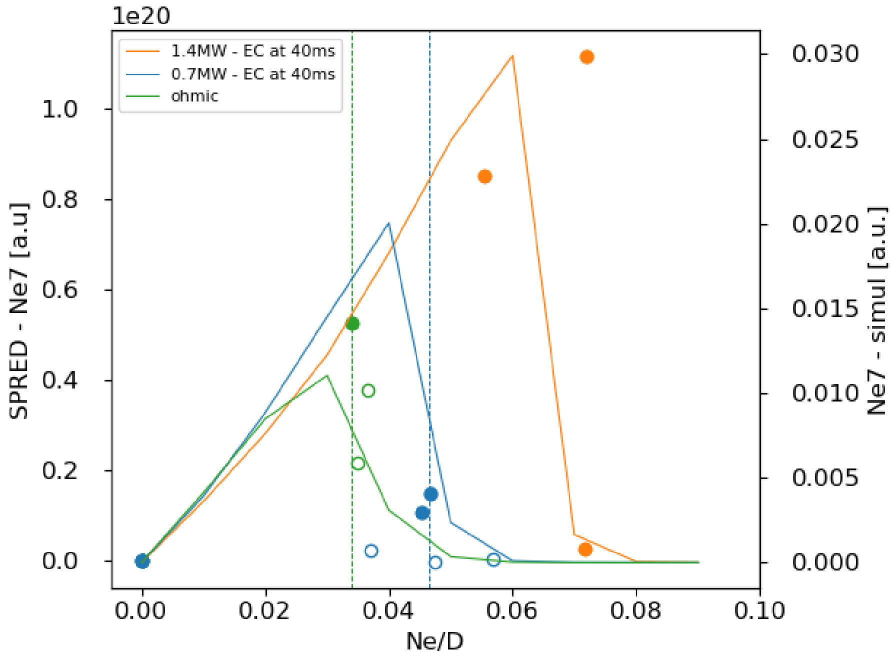
Ne/D ~ 0.034 for ohmic

Ne/D ~ 0. 046 for 0.7 MW

Ne/D ~ 0.075 for 1.4 MW (estimated)

Simulations results: burn-through





Comparison between measured and simulated Ipl @ 70 ms, end of EC for most of the pulses

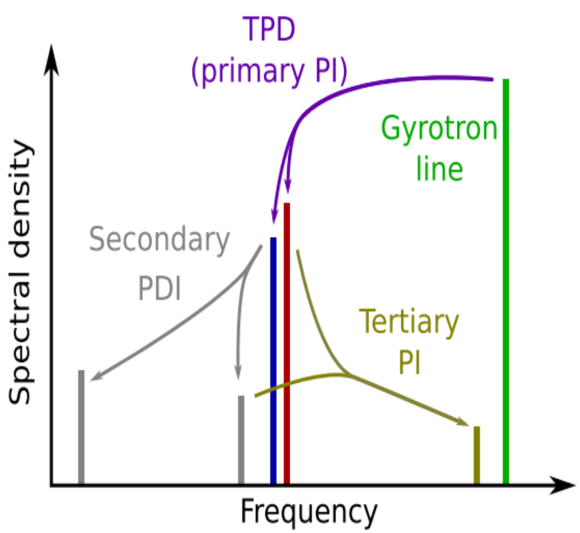
Experimental limit for ohmic and EC assisted burn-through at 0.7 MW was found

Ne/D: nominal value of the calibrated Ne and D fluxes, used as simulation input.

Ne threshold: an increase of ~30% of Ne in prefill, requires ~0.7 MW of EC more for successful burn-through

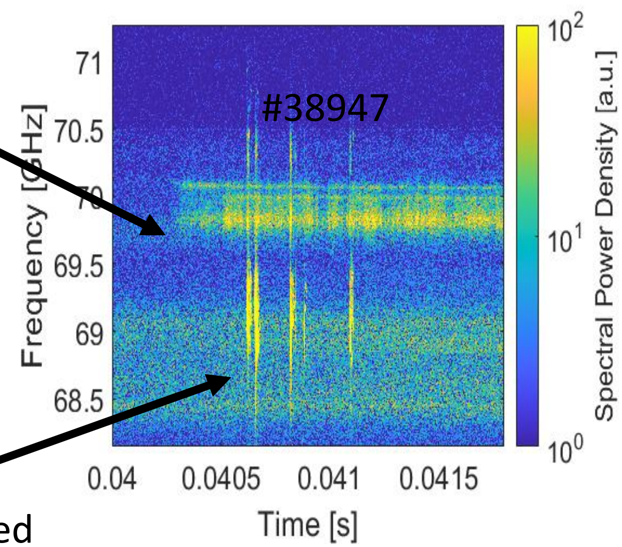
Piggy-back observations of parametric decay during ECRH-based discharge recovery experiments at 140GHz.

- CTS reciever detected parametric decay during the start-up phase every time the gyrotrons were turned on, even though the detector is in sector 5 and gyrotrons used are in sector 14.
- Signals at half the gyrotron frequency observed.
- 1 shot reached flat top phase. Correlation between mode activity and parametric decay observed during flattop phase.



Parametric decay appearing as soon as gyrotrons turn on

Additional broadband bursts observed



Quantification of X3 absorption for ITER modeling

Quantification of X3 absorption for ITER modeling

TFLs: E.Joffrin, B. Labit **SCs:** T. Wauters, D. Ricci

Device: AUG

Pulses objective	Status	Pulse #
X3 Optical depth scan	☺	39747-39751
ECRH control	☺	39747-39751
Variation of Bt (inconsistent ECE)	😐	39747-39751

Main deficiencies

- ❑ Inconsistent ? ECE at two highest powers for 1.6 T

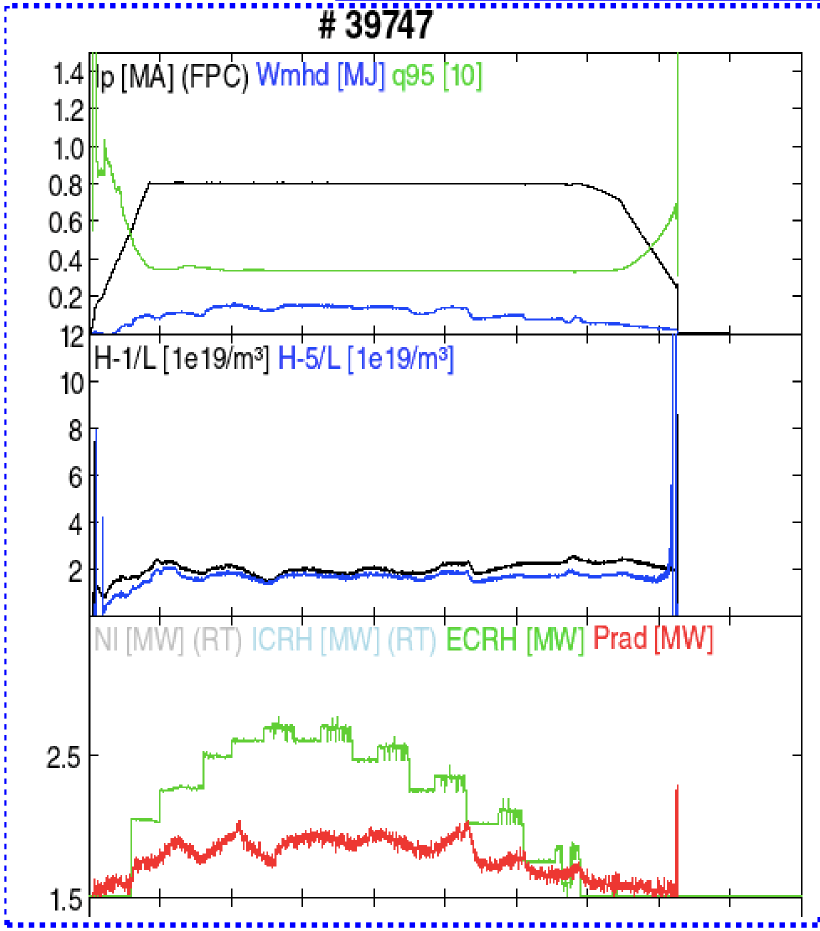
Main scientific results achieved

- ❑ 800 kA discharges heated by X2 at 105 GHz with up to 5 Gyrotrons. The heating power is ramped down such that 6 levels of core electron temperature can be set covering an interesting range of optical thickness.
- ❑ ECE ok at 1.7 T, 4 gy possible -> high Te case

Objectives for the next step:

Analysis to be done:

- ❑ IDA from ECE and TS (done)
- ❑ Non-absorbed power fraction from Thermocouples.
- ❑ Comparison with Torbeam predictions.



RT03 pulses executed so far	20
Total allocation	20
Contingency request?	no

ICRF assisted breakdown at low loop voltage

ICRF assisted breakdown at low loop voltage

- Motivation
  - Provide IC breakdown assist at 1.8T where EC assist does not work
    - 1.8T is planned to achieve H-mode more easily → commission plasma control during H-mode and test ELM mitigation techniques
    - Ohmic breakdown is more difficult to achieve at lower field due to shorter connection lengths of the open magnetic field lines.
  - Even at half and full B-field, ohmic plasma initiation in ITER may only succeed for a narrow prefill pressure range and at low values [IDM 3XV5XS]
    - Consequentially the density during breakdown and burn-through will be low, which is known to increase the likelihood of the formation of supra-thermal electron or runaway discharges.
    - Techniques to widen the operations space are welcomed
  - Unabsorbed EC power during the several seconds of low ne-Te plasma and potential consequences of parametric decay may narrow the application EC to burn-through assist

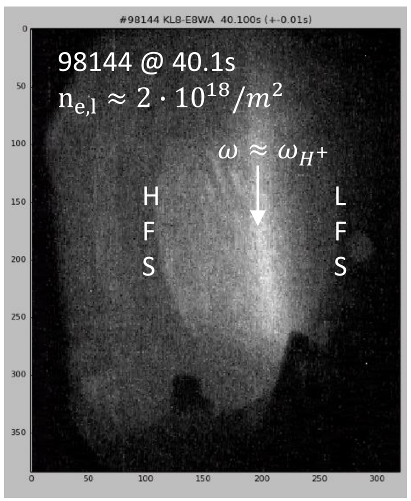
JET experience on IC assisted breakdown

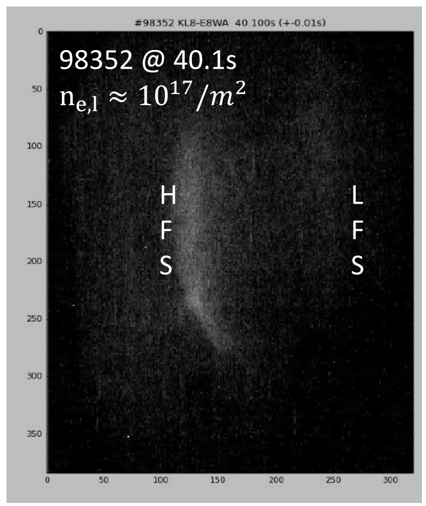
Development of IC assisted mode-B breakdown in **D(H)** and **H** @ 33MHz, 2.3T, starting from proven ICRF plasma production scenarios (ref. ICWC)

- Pre-ionisation before loop voltage (t < 40.45s)

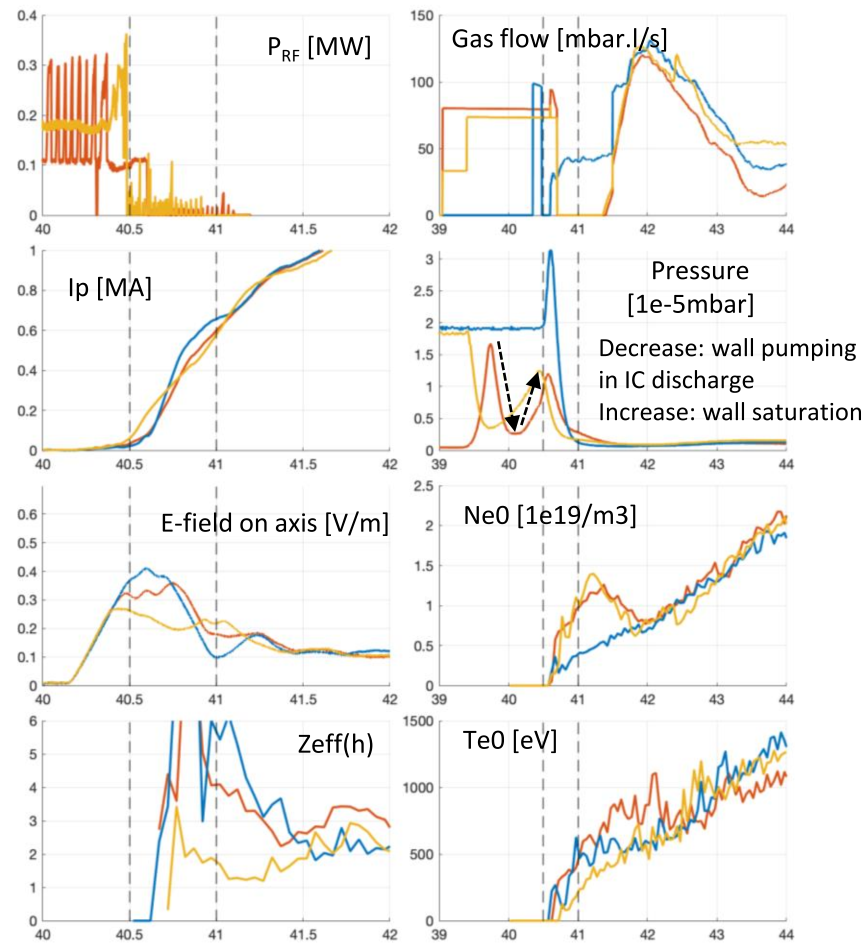
D(H) → 98144

Majority H → 98352





Comparison to ohmic mode-B → 98342 (H)



- IC plasma density << $1e19/m^2$
- Low pressure while high gas influx due to IC plasma at breakdown
- IC antenna mismatch at limiter plasma formation
- Higher density in IC scenario vs ohmic scenario
- Similar temperature, marginal in 98352 at lowest E-field

JET experience on IC assisted breakdown

- 1 session in D with 5%H, 33MHz, 2.3T → D(H)

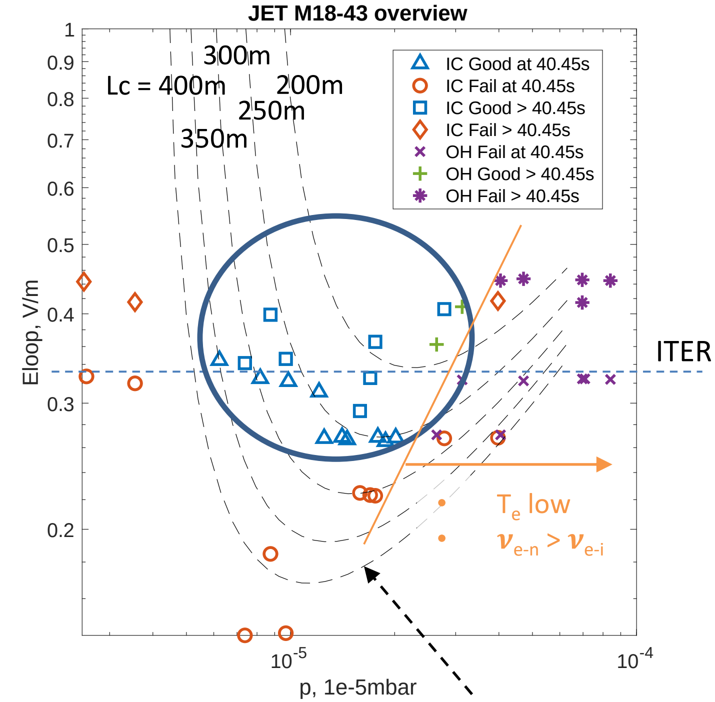
Good IC assist	IC assist delayed	Failed IC assist	Good ohmic	Ohmic delayed	Failed ohmic
6	~3 (out of 6)	2	/	/	1

- 2 sessions in H, 33MHz, 2.3T → majority H

Good IC assist	IC assist delayed	Failed IC assist	Good ohmic	Ohmic delayed	Failed ohmic
11	~4 (out of 11)	3	2	1 (out of 2)	4

  - Good = successful transition from breakdown to position, current and density control.
  - Delayed = current awaits an increase of Vloop
  - Failed = failed burn through (Ne) or too little/much gas

ICRH Antennas A2: A+B+D with monopole toroidal phasing



Pressure in Townsend avalanche curves corrected for gas temperature (200ºC)

Other findings:

- **No evidence of increased impurities** in current ramp-up due to ICRH (RF-sheath effects, Ni from ICRH antennas.)
- **IC pre-ionization is possible at any Ne-content** while additional heating is needed for sustained breakdown and burn-through at higher Ne concentrations
- **Breakdown scenario affects later current development** (>42s). Flat or hollow current profiles after IC assisted breakdown confirmed by METIS simulations

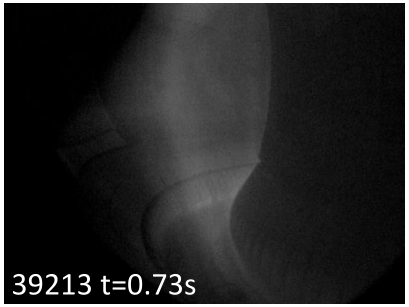
RT-03 AUG: IC assisted breakdown

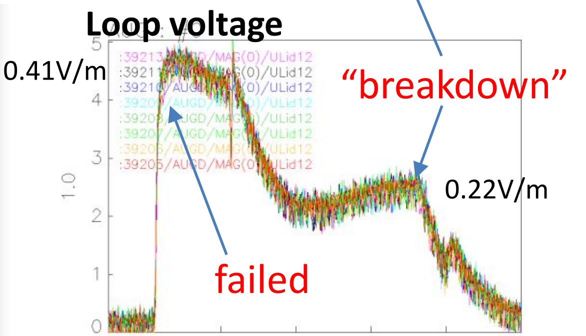
- AUG breakdown relies on rapid discharge of the SC ("ohmic switch")
  - This scenario cannot be brought to low loop voltage < 1.1V/m
  - 7 pulses with performed as such with E-field >= 1.1V/m
  - 6 successful = significant given the sensitive operational window for bkdn in AUG

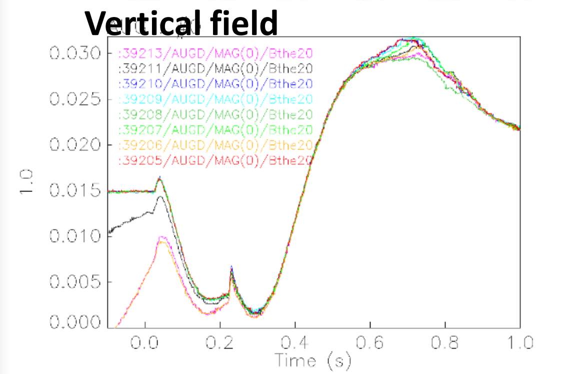
- Breakdown scenario "without OH switch" → lower E-field
  - No working ohmic reference pulse available
  - 9 pulses with IC assist at low E-field ~ 0.41V/m
    - Gas pressure scan & two Bias Bv waveforms
    - Max Ip : 2kA (39213) & 1kA (39209)

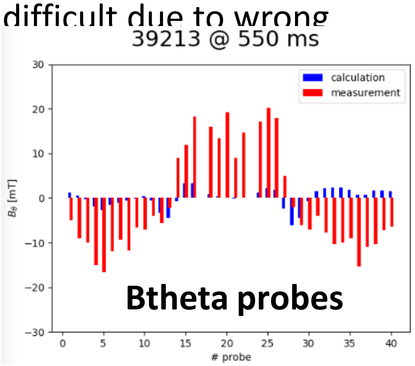
  → More development time needed

- Ohmic bkdn at 0.22V/m and Bv by OH induced vessel currents only
  - Optimisation of poloidal field wave form difficult due to wrong measurements = time consuming









Follow-up experiments 2021/2022

- RT03 ASDEX upgrade → May 2021
  - Low loop voltage achieved by switch-less operation, nonstandard
  - 9(+7) pulses dedicated to develop scenario → more time was needed

- JET planned in C42
  - Explore lower Bt = 2.3T → 1.7T → 1.4T at 33MHz relevant to breakdown assist at 1.8T in ITER
  - Avoid IC power loss due to mismatch (different phasing or additional antenna via real time control)
  - Determine the minimum electric field / pressure for ohmic vs RF assisted mode-B
  - Assess robustness of low voltage breakdown scenario to influx of impurities, addition of stray B fields and antenna phasing (C42)
  - Benchmark simulations codes for ITER prediction.

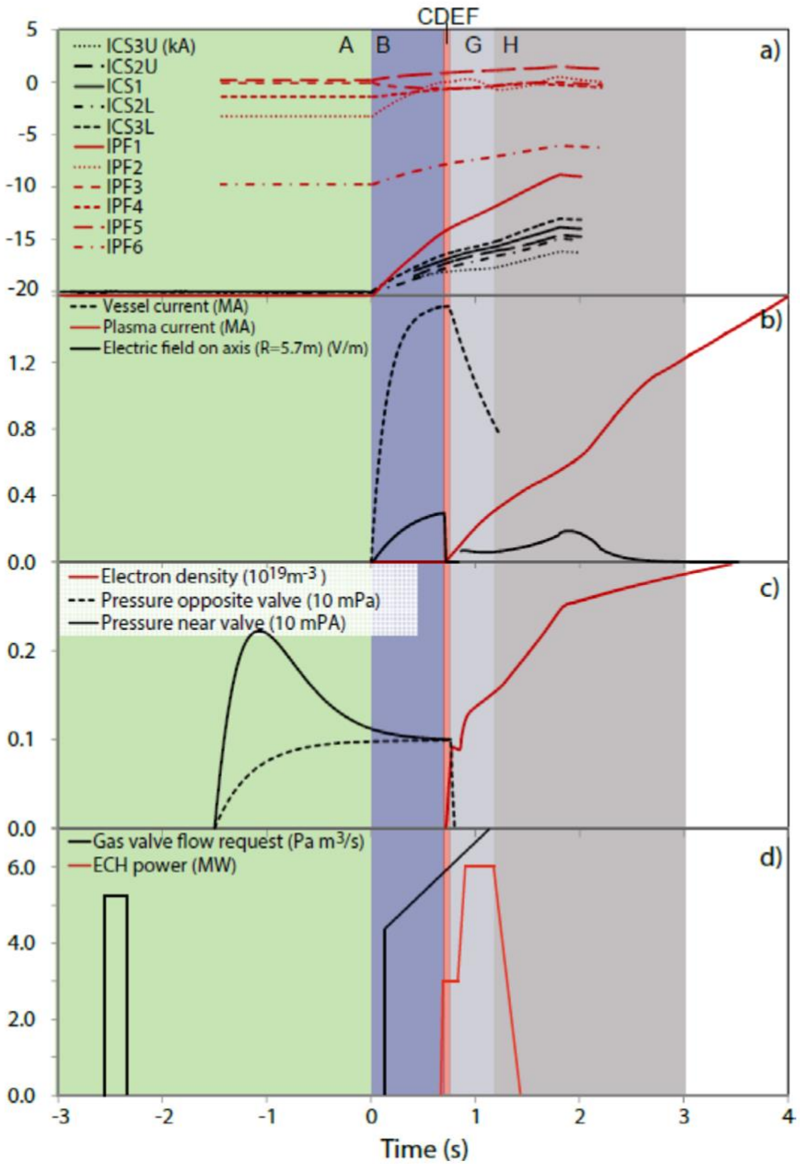
- RT03 WEST → 2022
  - Low loop voltage achieved by operation “sans valve”, nonstandard
  - Explore IC assisted breakdown scenario → 15 pulses
  - Two preparation session proposed to develop scenario “sans valve”: One with IC

- Plans remainder 2021
  - Preparation WEST IC breakdown experiment
  - Analysis AUG results: BT, PD, X3, IC
  - Preparation contingency proposals
  - Activate D2 proposals

- RT03 SCs
  - Daria Ricci
  - Tom Wauters until Sept 2021 (joined ITER IO)
  - Ernesto Lerche starting Sept 2021

Back-up slides

Breakdown and current ramp up



A: preparation : pressure and poloidal field

B: development of the electric field by discharging the CS, PF1 and PF6

C: pre-ionisation

D: breakdown or avalanche phase

E: closed flux-surface formation

F: plasma formation (CC)

G: burn-through

H: controlled current ramp-up