Electron cyclotron heating assisted start-up experiments in J-TEXT

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I. Research background

Start-up is the first stage of tokamak operation.
For ITER,

- Low toroidal electric field of 0.3V/m to support breakdown in 2025
- The required ECH power to ensure an effective breakdown assist at ITER is not yet clear.

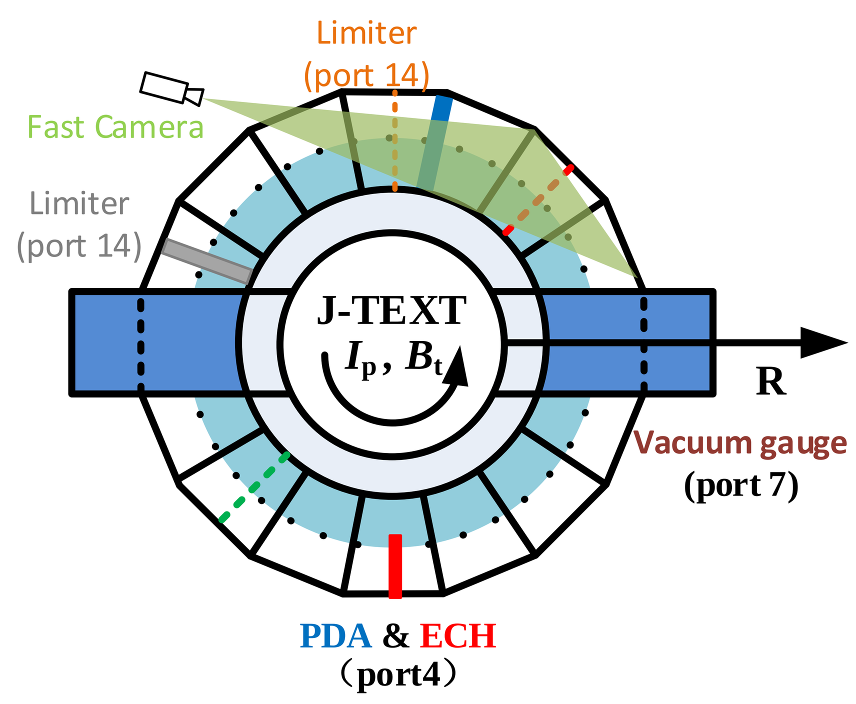
J-TEXT has conducted the Electron cyclotron heating (ECH) assist start-up experiments since 2019. These experiments aimed to

- Determine the minimum ECH requirements to assist in the breakdown
- Develop a better physics description of the process.

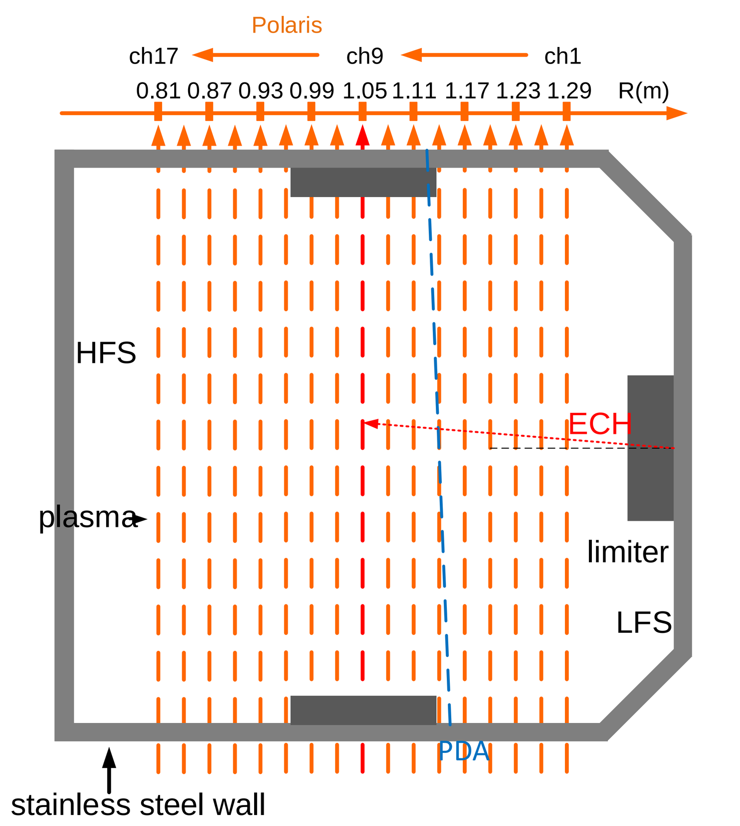
II. Experimental setup

Resources

- ECH system (105GHz/500kW/1s)
- Polaris
- PDA
- Vacuum gauge
- Fast camera
- Gas puffing (applied before ECH applied)



Top view of related diagnostics and auxiliary system

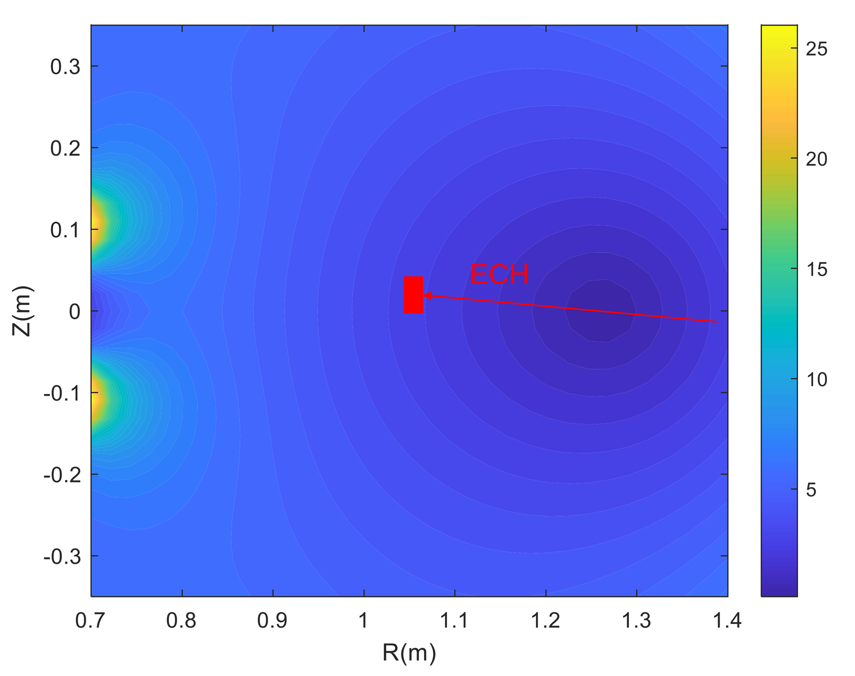


Section view of the measurement area of related system

II. Experimental results

Stray field

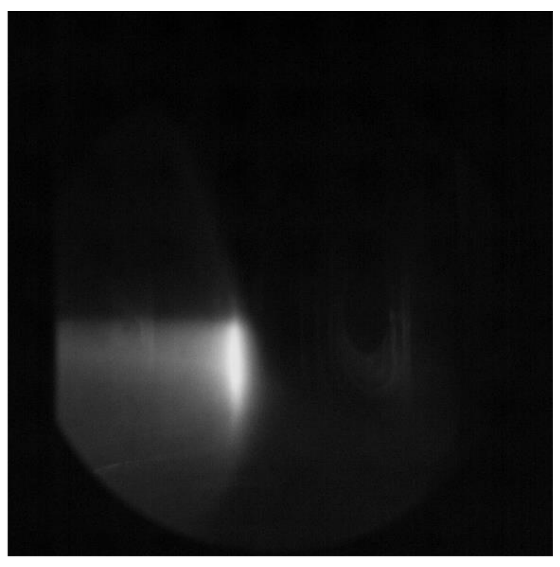
Field null structure, calculated by EFUND



Distribution of poloidal stray field before toroidal electric field applied

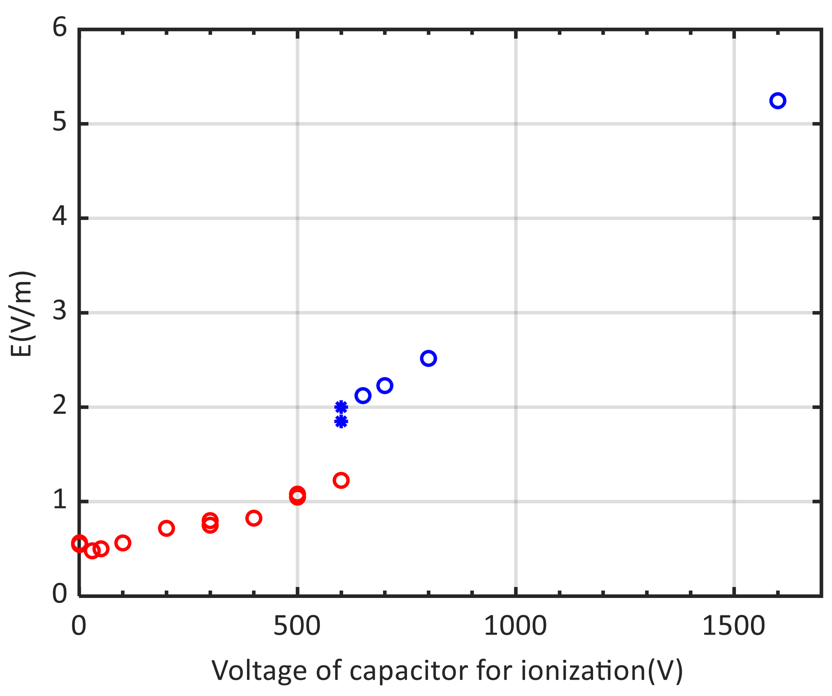
$L_{eff} = 0.25 \times a_{eff}\ B_T / B_\perp \approx 500m$

Apparent ECH pre-ionization phenomenon



Photos of ECH pre-ionization by fast camera

Electric field studies



Relationship between toroidal field and voltage of ionized capacitor.
Blue: pure Ohmic start-up Red: EC assist start-up.
Circle: successful discharges Asterisk: failed shot

Critical toroidal field: E~2V/m
Minium toroidal field: E~0.56V/m
(300kW, X2, θ=3°)

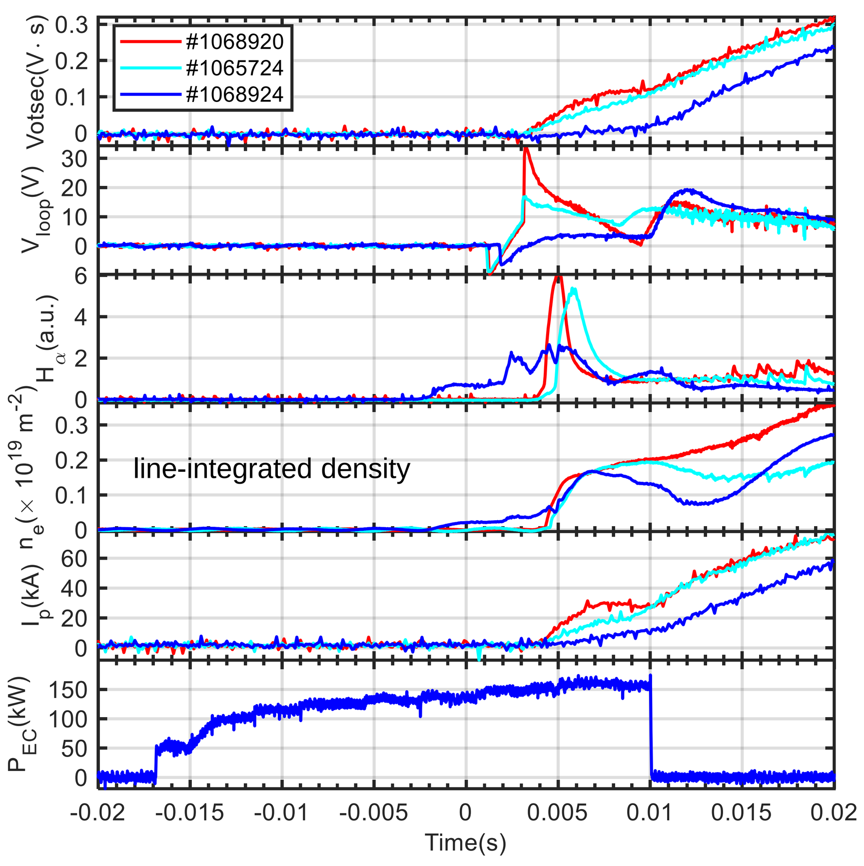
Toroidal electric field limitation

- Wall conditioning
- Hysteresis effect

Hypothesis

Relationship between initial density, toroidal electric field and breakdown delay

Typical discharges



Evolution of different signals when discharging with ionization capacitor of 1600 V (red), 800 V (cyan) and 1V (blue). The last one is assisted with 300 kW ECH power while two others are pure Ohmic heating

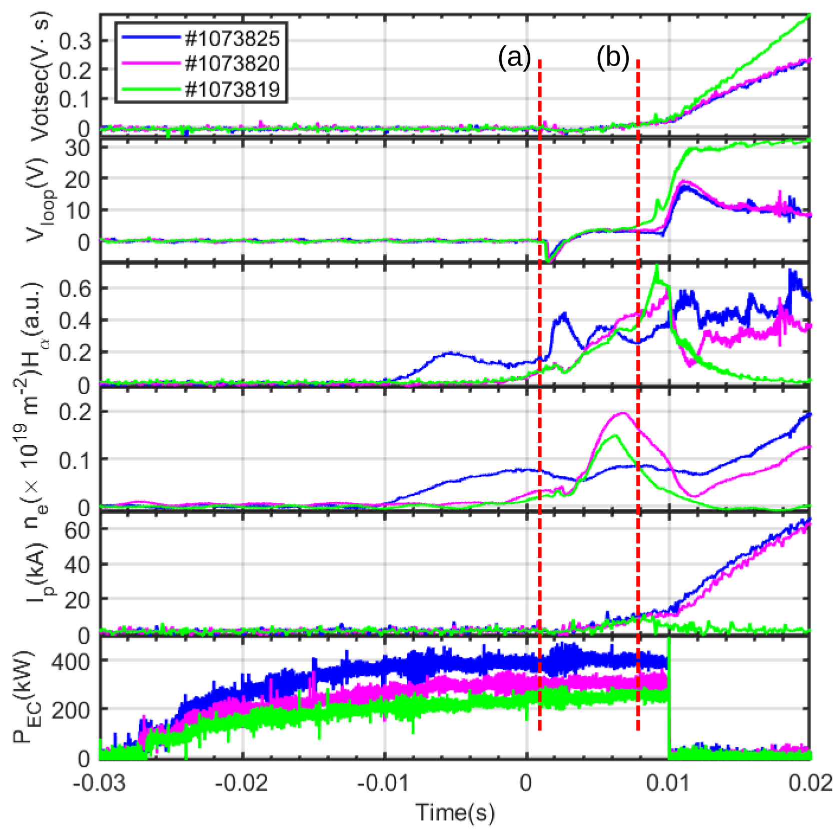
Conventional pure Ohmic heating start-up: #1068920
Critical pure Ohmic heating start-up: #1065724
Typical EC assist start-up: #1068924

Phenomenon:

- Apparent differences in breakdown voltage
  Loop voltage: 34→3.7V (0.56V/m)
  125 kW X2-mode ECH
- Ha and ne appears earlier (~15ms delay)
- Vot-seconds consumed, but also low plasma current

Explanation:
ECH pre-ionization → seed electrons →easy breakdown

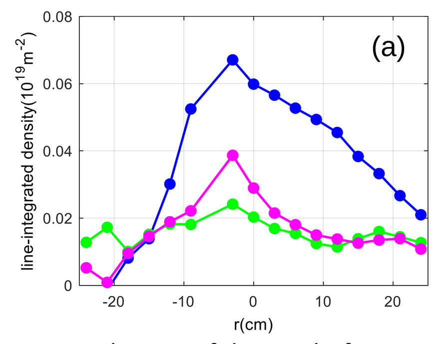
ECH power studies



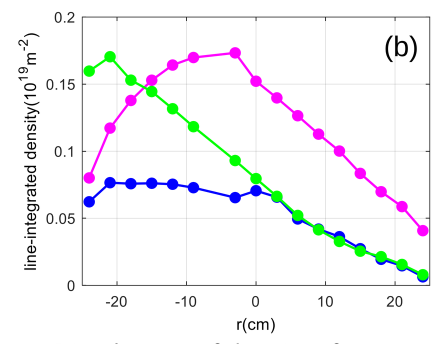
Evolution of key signals with different ECH power for assist start-up.

Phenomenon:
High power leads to low breakdown delay, high initial plasma density
Simple conclusion
Critical power of ECH assist start-up is ~200kW

Phenomenon:
Low ECH power leads to failed discharge
Explanation:
Low ECH power→high toroidal field(Power compensation)→"abnormal" density distribution

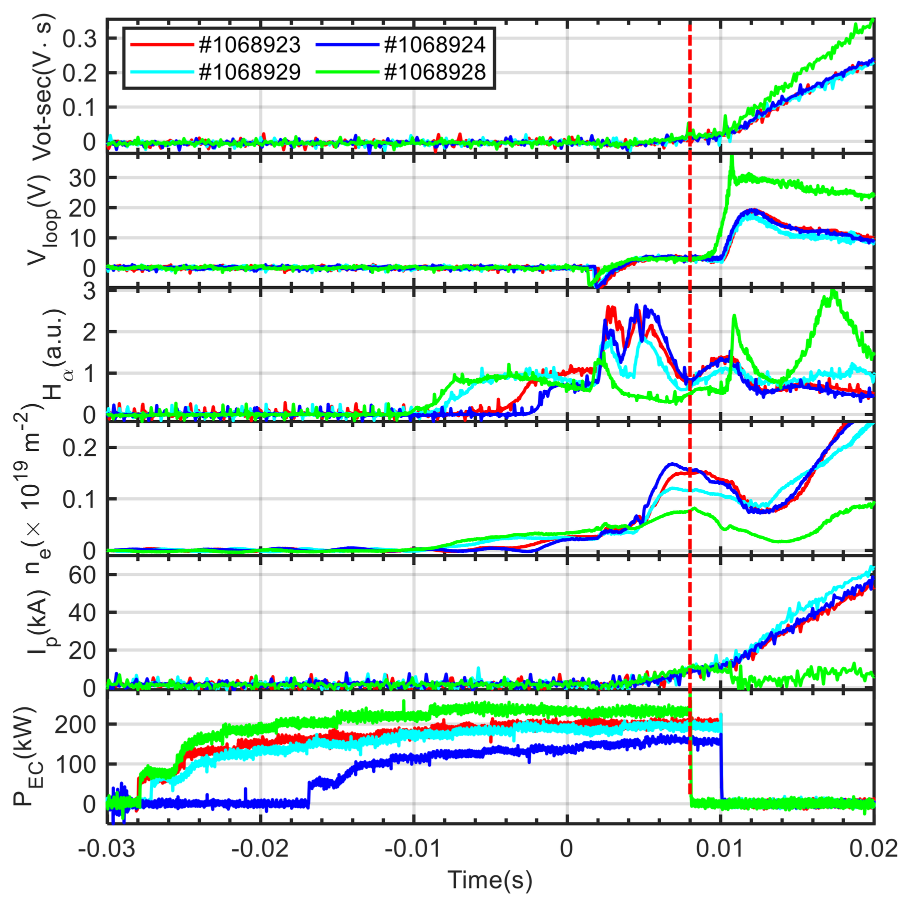


Distribution of density before toroidal field applied (t=1 ms)



Distribution of density after toroidal field applied (t=8 ms)

ECH pulse width studies



Evolution of key signals for different ECH pulse width.

Phenomenon:

- ECH power is off, density decreases while plasma loop voltage increases
- Low power and short pulse shot (blue) works well

Explanations:

- Enough power is needed for burn-through. (same to the former)
- Lower power and less time to generates enough electrons, forming better plasma distribution(Semi conjecture)

Some discharge results with different ECH pulse width

T_{on}(ms)	t_{off}(ms)	result
-25	10	success
-15	10	success
-5	10	failure
-25	5	failure
-35	8	failure

IV. Summary

- Breakdown voltage reduced from 34 V to 3.7V (0.56V/m) by 125 kW X2-mode ECH
- Critical power of ECH assist start-up is ~200kW if ECH is injected for a long time.
- High power leads to faster and stronger breakdown. Low ECH power will fail during burn-through because of lack of input power.
- A short pulse width and low ECH power can achieve a similar effect as long pulse width and high ECH power if it injects at a proper time.

Reference

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[6] J. Sinha, P. de Vries, M. Walker, et al., Nuclear Fusion 62, 066013 (2022)

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