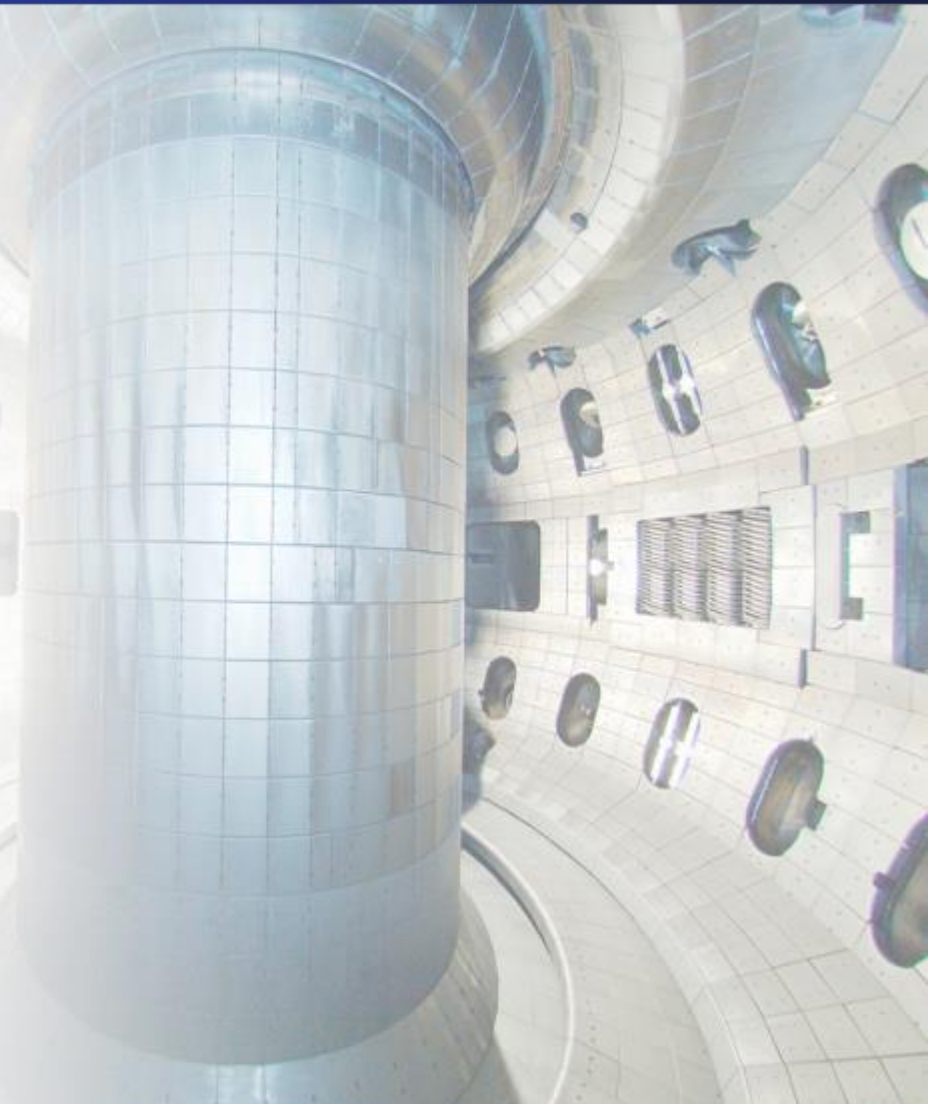
Study of the halo current region resistivity on the DIII-D tokamak



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3rd IAEA Technical Meeting on
Plasma Disruptions and their Mitigation
ITER Headquaters
September 3—6, 2024

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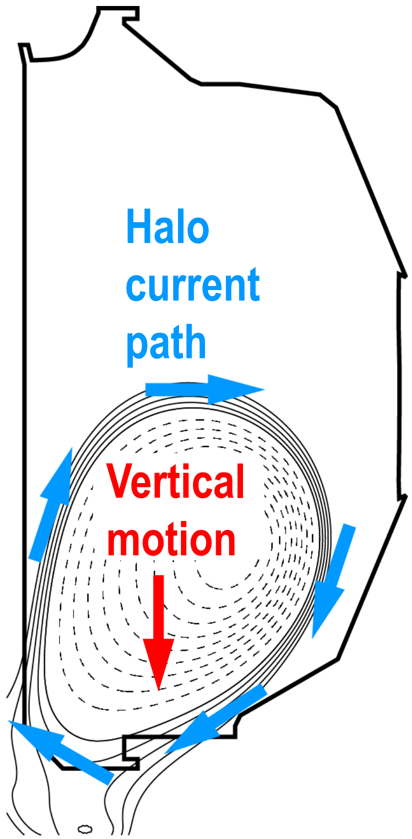
GENERAL ATOMICS

Outline

- The temperature and density of the halo current region were measured on DIII-D using the upgraded Thomson scattering diagnostic
- Deliberate downward vertical displacement events (VDEs) were employed and the halo current region upward expansion was captured by the core Thomson channels
- ‘Type I’ and ‘type II’ VDEs were studied using H-mode and ohmic target plasmas respectively
- ‘Type I’ VDE, having the current decay rate faster than the plasma vertical motion, characterizes by the electron temperature of the halo region in the range of 1−2 eV
- ‘Type II’ VDE has the opposite time scale dynamics and greater halo region electron temperature of 1−10 eV
- VDEs of both types result in the electron density of the halo region comparable with the core plasma density and quickly decreasing to the edge
- Peak halo currents exhibit values greater by about 5% in documented ‘type II’ VDEs
- Other key parameters of VDEs are also analyzed, providing a valuable input for validation of models

Introduction and Motivation

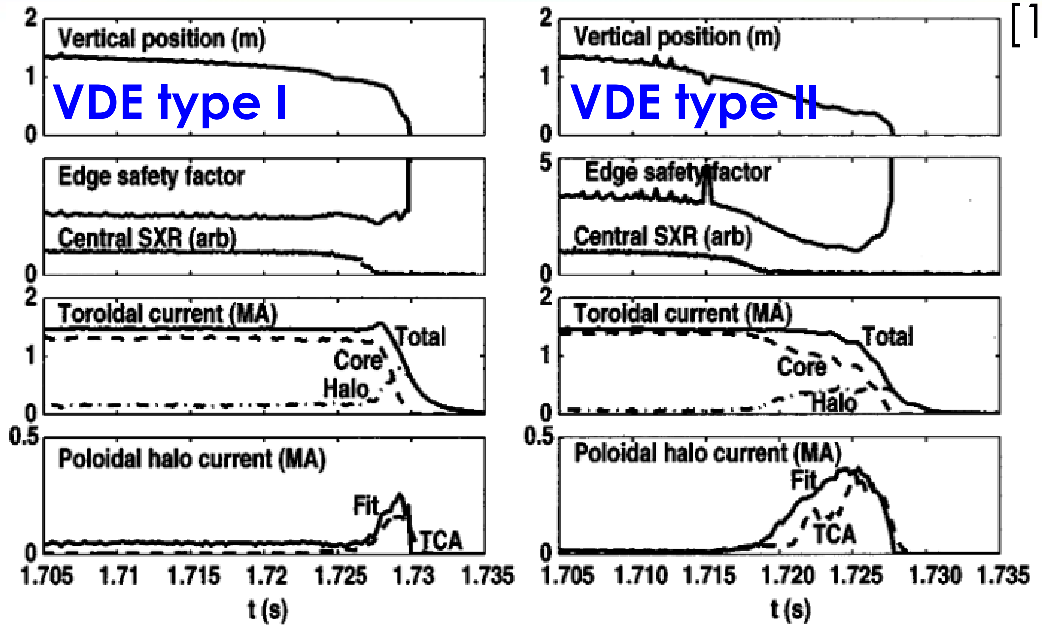
Halo currents can cause strong I_HxB forces during disruptions



Poloidal halo current flowing in the SOL and vacuum vessel

- Elongated plasma in tokamaks is naturally vertically unstable
- Sudden loss of thermal energy or position control can lead to plasma moving vertically and touching the wall
- Moving, shrinking and decaying plasma induces toroidal and poloidal halo currents
- Halo currents partially flow through the vessel wall
- Interaction of poloidal halo current and toroidal magnetic field causes strong local and net vessel stress

Halo current dynamics is set by plasma motion and current decay rates



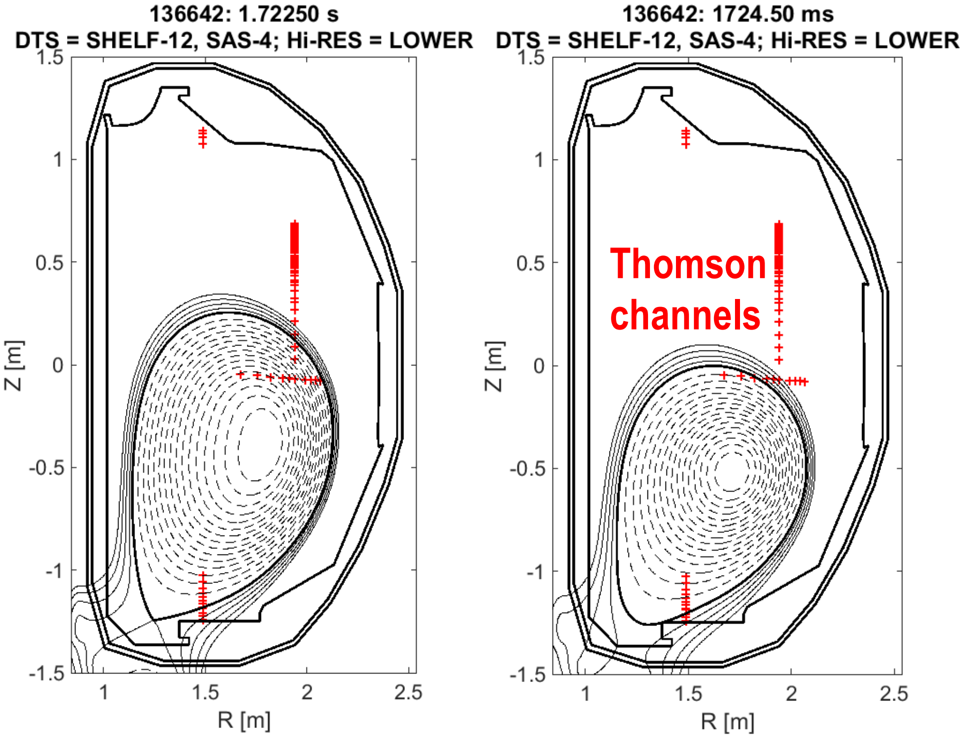
[1]

- **Type I VDE is observed when plasma vertical motion is slower than current quench rate**
  - Safety factor changes slowly and peak halo current is moderate
  - So-called "resistivity dominated" (cold) VDE
- **Type II VDE is observed when plasma vertical motion and area reduction is faster than current quench rate**
  - Safety factor quickly drops which causes greater peak halo current
  - "Motion-enhanced" (hot) VDE
- **Halo region resistivity and width are required to validate VDE/halo models**

[1] Humphreys PoP 1999

Key Tools and Scenario

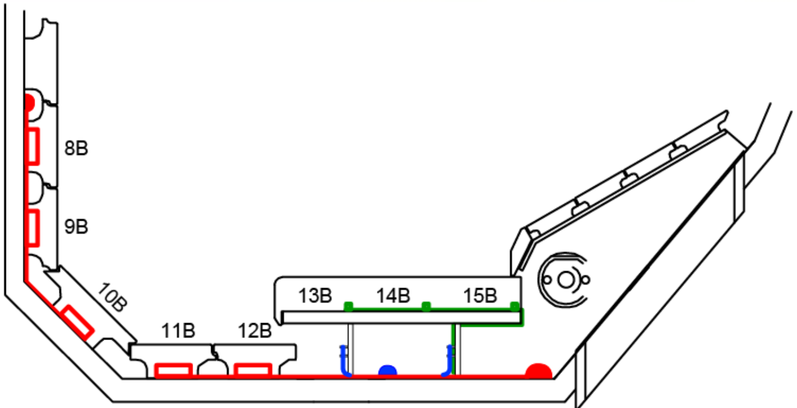
Upgraded Thomson scattering is used to measure halo region's temperature and density



Configuration of Thomson scattering channels and VDEing plasma

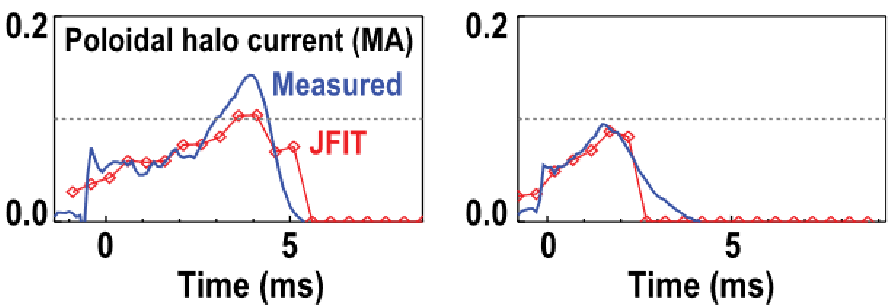
- Thomson scattering provides absolute measurements of T_e, n_e along vertical, core, and divertor channels
- Recent upgrade with narrow-bandwith polychromators enabled low T_e access (~1 eV)
- The bunch of Thomson's lasers can be triggered with a small time step (~0.1 ms) to cover a narrow time window

JFIT distributed current fitting code reconstructs halo current



Only currents flowing through shelf can now be measured (in blue)

[2]

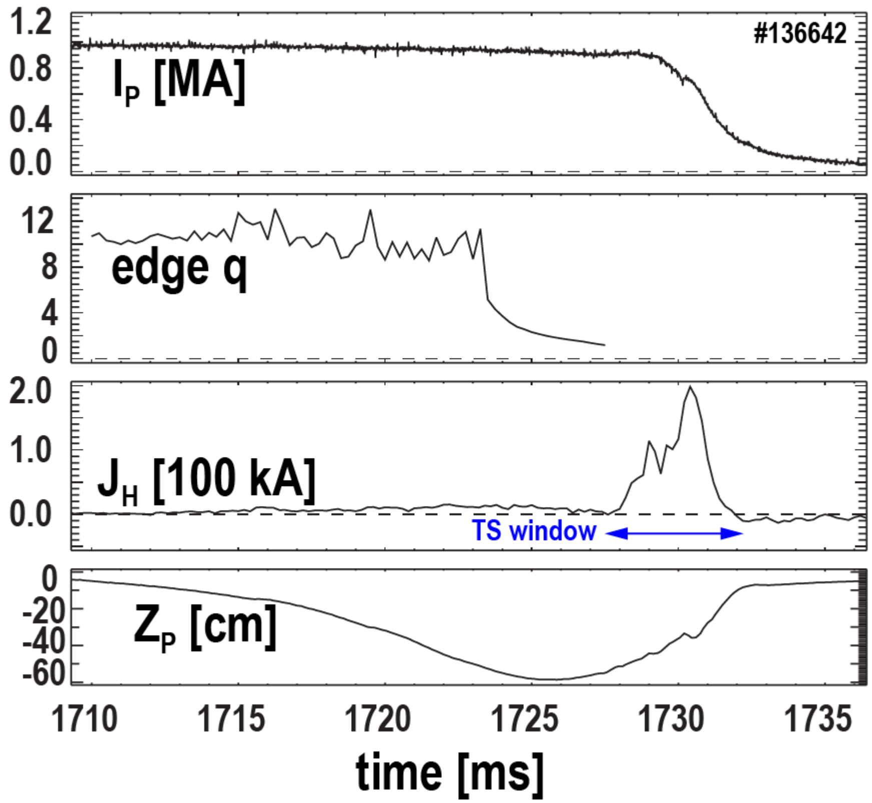


Measured and JFIT-reconstructed halo currents

- **Instrumentation of DIII-D with halo sensors decreased over time to very limited coverage**
- **Halo currents can be reconstructed by fitting magnetic measurements using distributed current elements with JFIT code** [1]
- **Past experiments with wide halo sensor coverage exhibited good agreement between measured and reconstructed halo currents** [2]
- **Presently JFIT is the main tool to study halo currents**

[1] Humphreys PoP 1999
[2] Shiraki PoP 2016

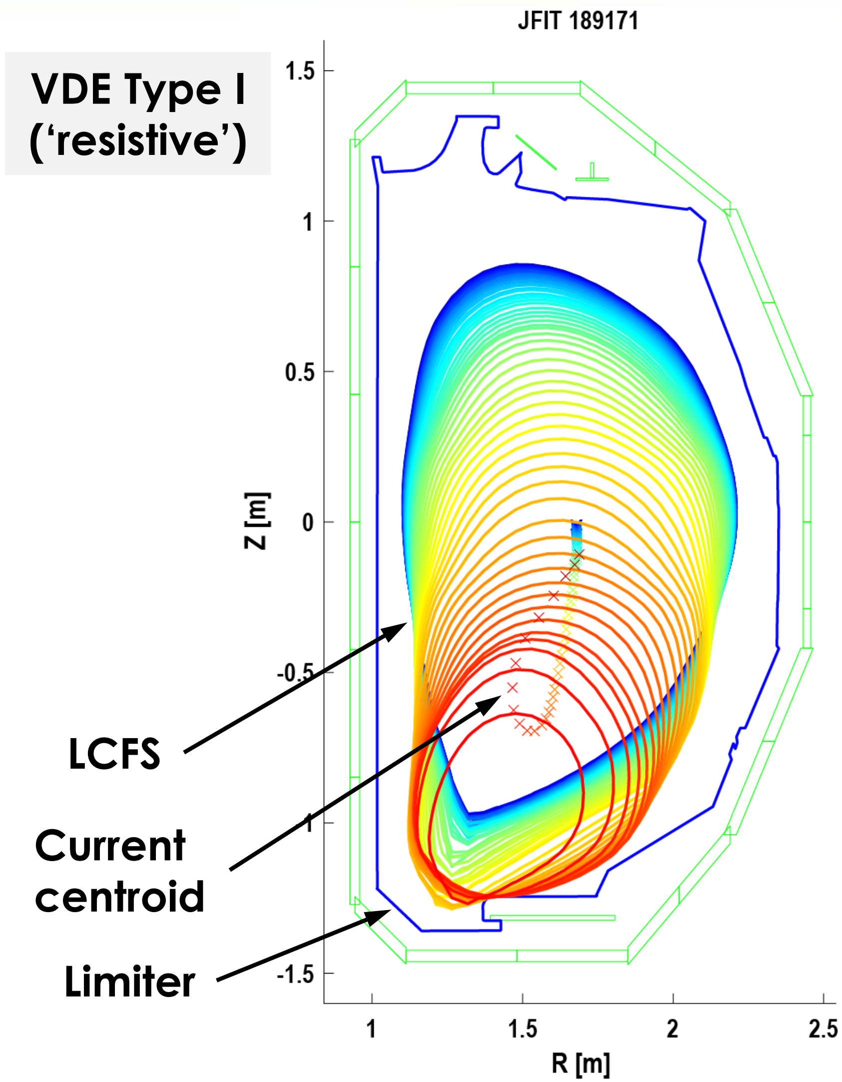
Experimental approach: Deliberate VDE of H-mode and ohmic plasmas to study ‘type I’ and ‘type II’ halo cases

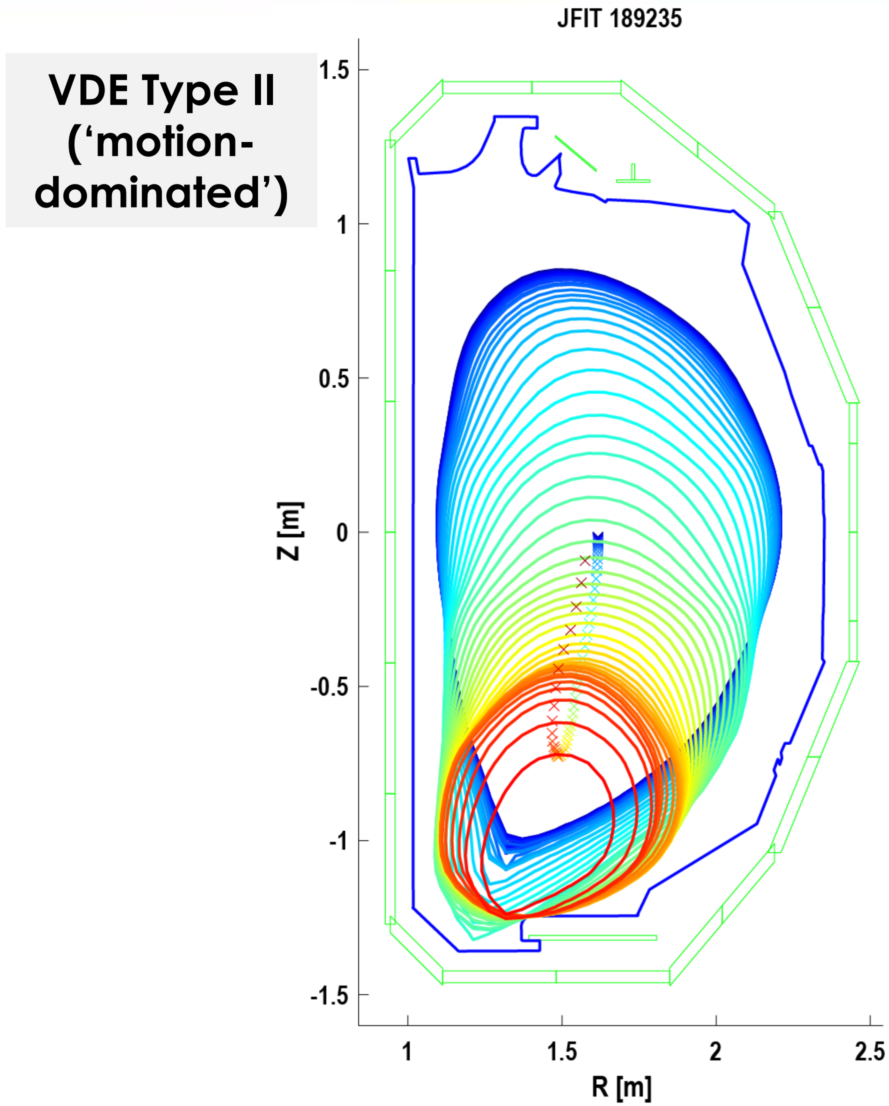


- **Deliberate repeatable VDE can be reliably studied on DIII-D**
- **Downward VDE of H-mode plasma realizes ‘type I’ (‘resistive’) halo cases**
- **Ohmic plasma is used to study ‘type II’ (‘motion-dominated’) halo cases**
- **Thomson bunch is set to capture the expected time of the halo formation**
- **JFIT reconstructs halo current evolution**

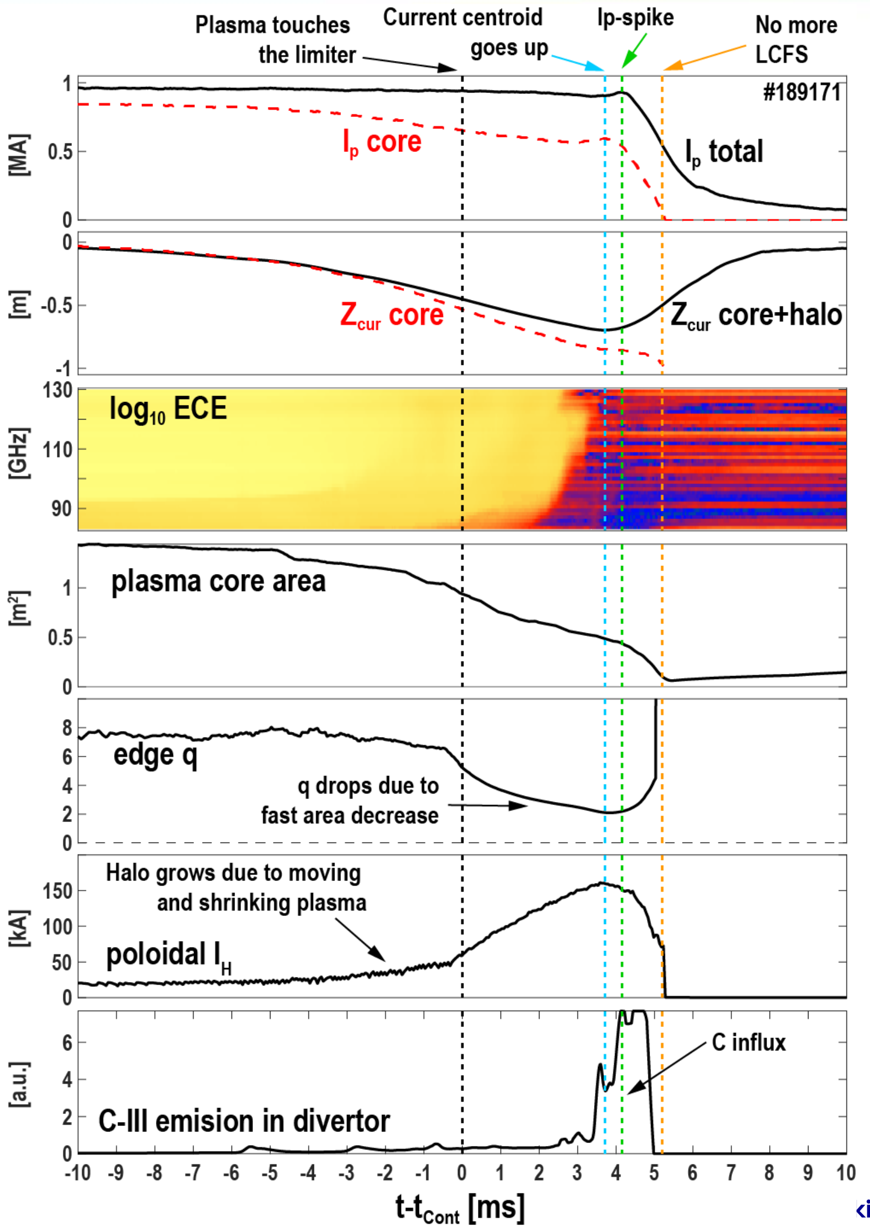
Experiment

Plasma motion and shape evolution are well reconstructed by JFIT during VDE





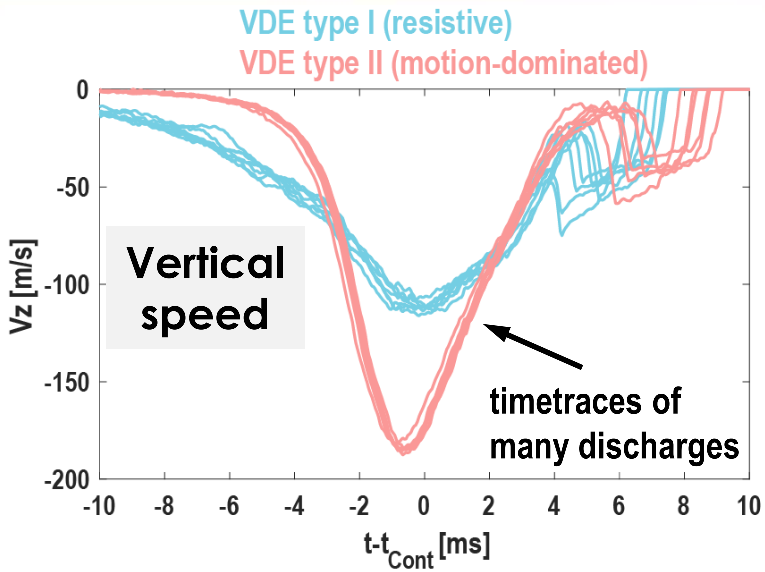
Phenomenology of VDE and halo current

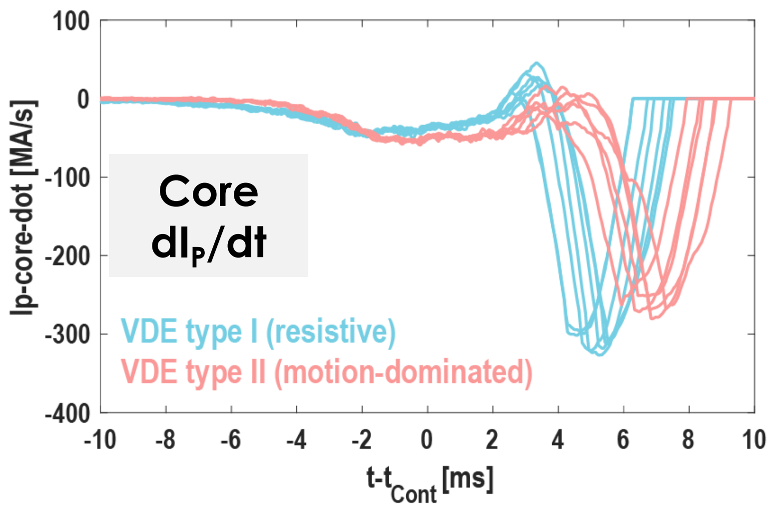


- **Plasma is pushed downward via PF-coils' programming**
- **Poloidal I_H start growing before plasma touches the wall due to change in enclosed toroidal flux**
- **When plasma touches the wall and starts to shrink (at nearly constant I_P), edge q drops and poloidal I_H peaks**
- **I_P quickly decays after thermal quench due to highly resistive plasma**
  - Current quench becomes the main driver of I_H as q increases
  - Strong carbon influx is observed
- **Peak I_H=150 kA, stress = 28 kN/m²**

Comparison of type I and II VDEs

VDE of H-mode plasma indeed shows type II (motion-dominated) dynamics: greater V_Z and slower current quench





- **Vertical speed of VDE type II reaches twice greater peak value compared to type I:**
  v_Z = 200 m/s vs 100 m/s,
  (γ_Z = 400 rad/s vs 150 rad/s)

- **Decay of core plasma current is slower for VDE type II compared to type I:**
  dI_P/dt = −250 MA/s vs −300 MA/s
  (γ_{Ip} = 120 rad/s vs 270 rad/s)
  - Core current decay of VDE type II starts later after the vessel contact

- **Both observations support more resistive nature of VDE type I**

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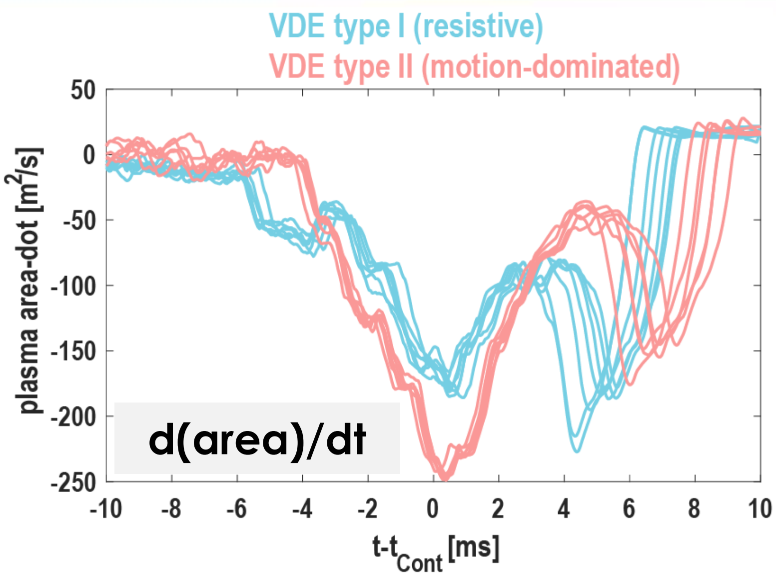
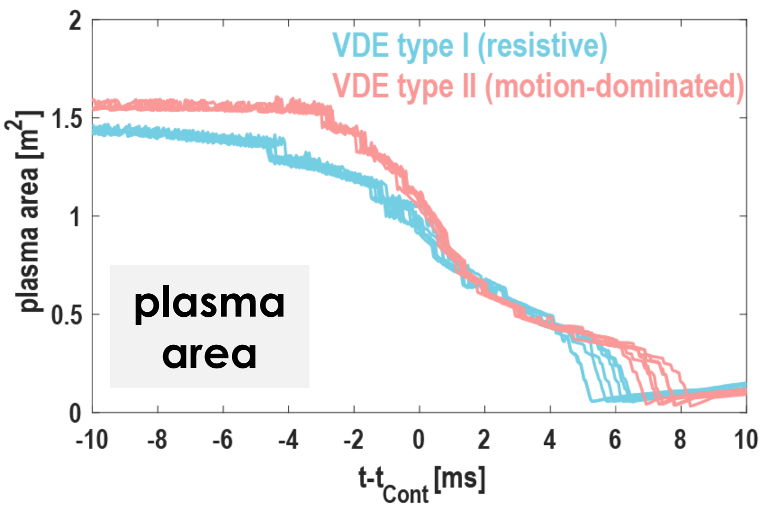
Shrinking rate of the core plasma area is also increased for VDE type II

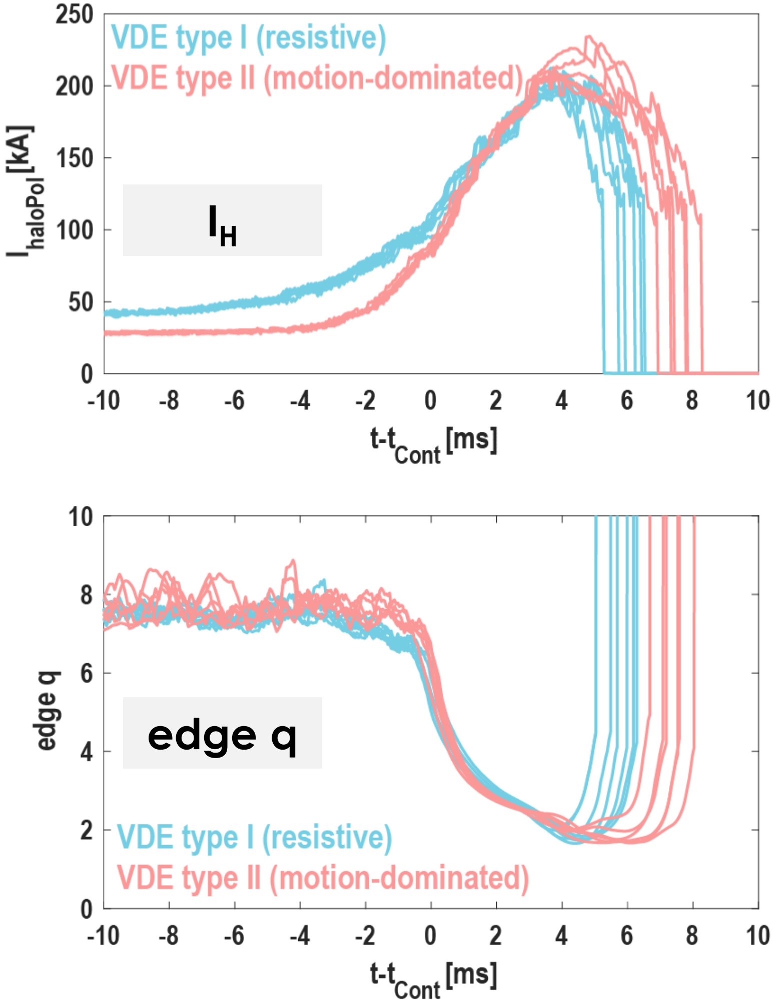




- **Core plasma area shrinks by almost 70% faster for VDE type II (motion-dominated): −250 m^2/s vs −150 m^2/s**
  - VDE type I shrinks slower but exhibits two peaks of about the same magnitude
  - 1st peak is when plasma touches the wall
  - 2nd peak is during the CQ

- **Both VDE type I and II have about the same core plasma area of 1 m^2 when they contact the vessel**

VDEs of ohmic and H-mode plasma exhibit close halo current dynamics



- **Both VDE type I and II show about the same peak poloidal halo current**
  - Halo type II is greater by 5%
  - However, halo type II is observed for 30% longer
- **VDE type I has all typical signatures: slower V_Z, slower area shrinking, faster CQ rate, but lacks expected nearly constant edge q and much greater halo current**
  - Edge q similarly decreasing both for VDE type I and II explains why VDE type I has about the same peak halo current ($I_{Hpol} = I_{Htor}/q$)
  - Target plasma experiencing TQ before it moves vertically may be required to enhance VDE I

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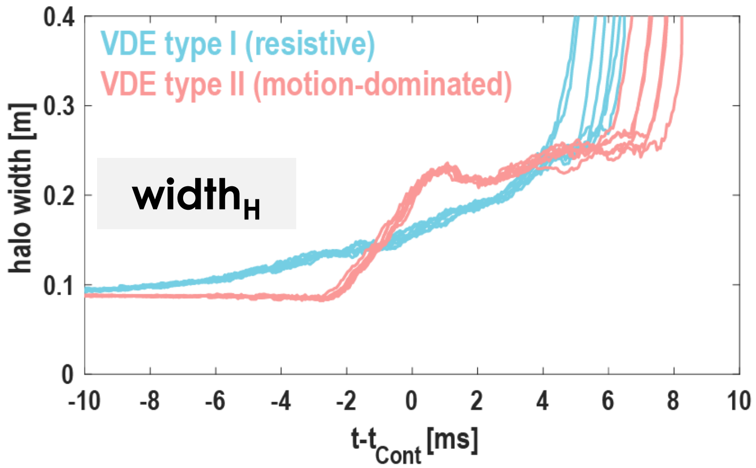
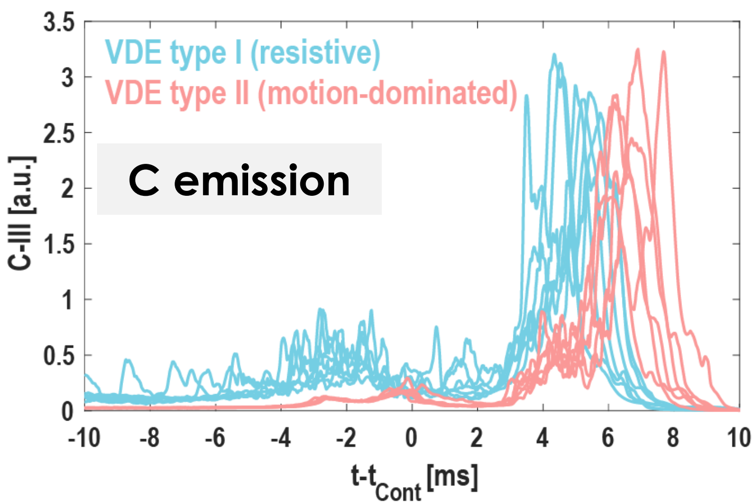
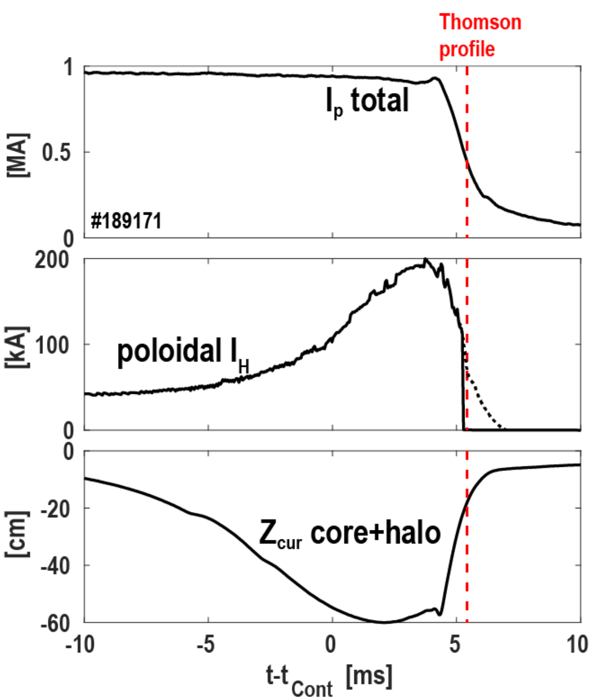
VDE type II has different dynamics of halo width

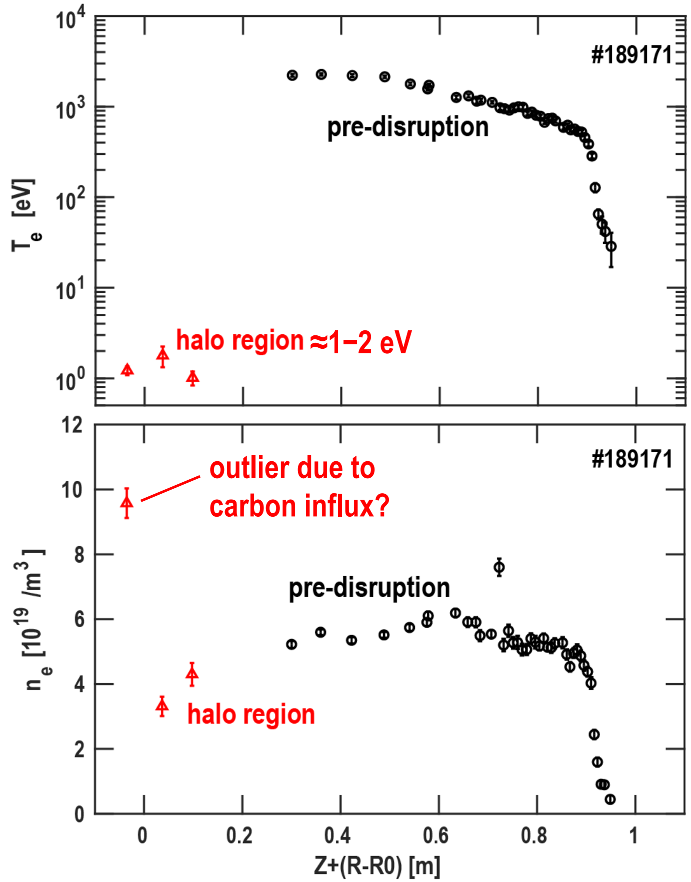


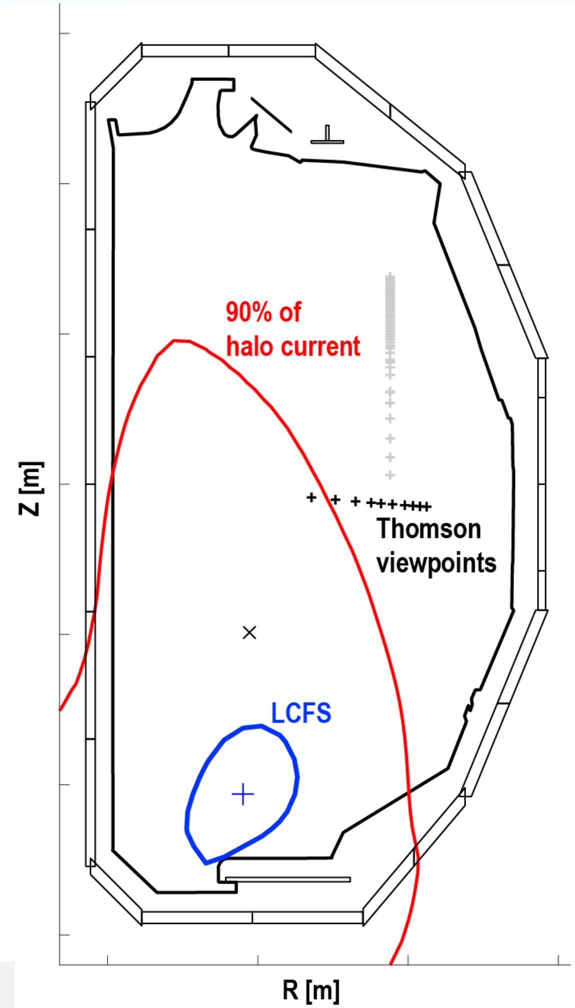


- **Width of the halo current decreases gradually for VDE I, while VDE II has clear phases with a plateau once plasma touches the vessel**
    - Halo width here is the average distance from LCFS weighted with the halo current
- **Both type I and type II VDE show about the same carbon influx as evidenced by filterscopes**
    - Though unsaturated signals are available only for the floor region

Temperature of the halo region during type I VDE ('resistive') is about 1–2 eV

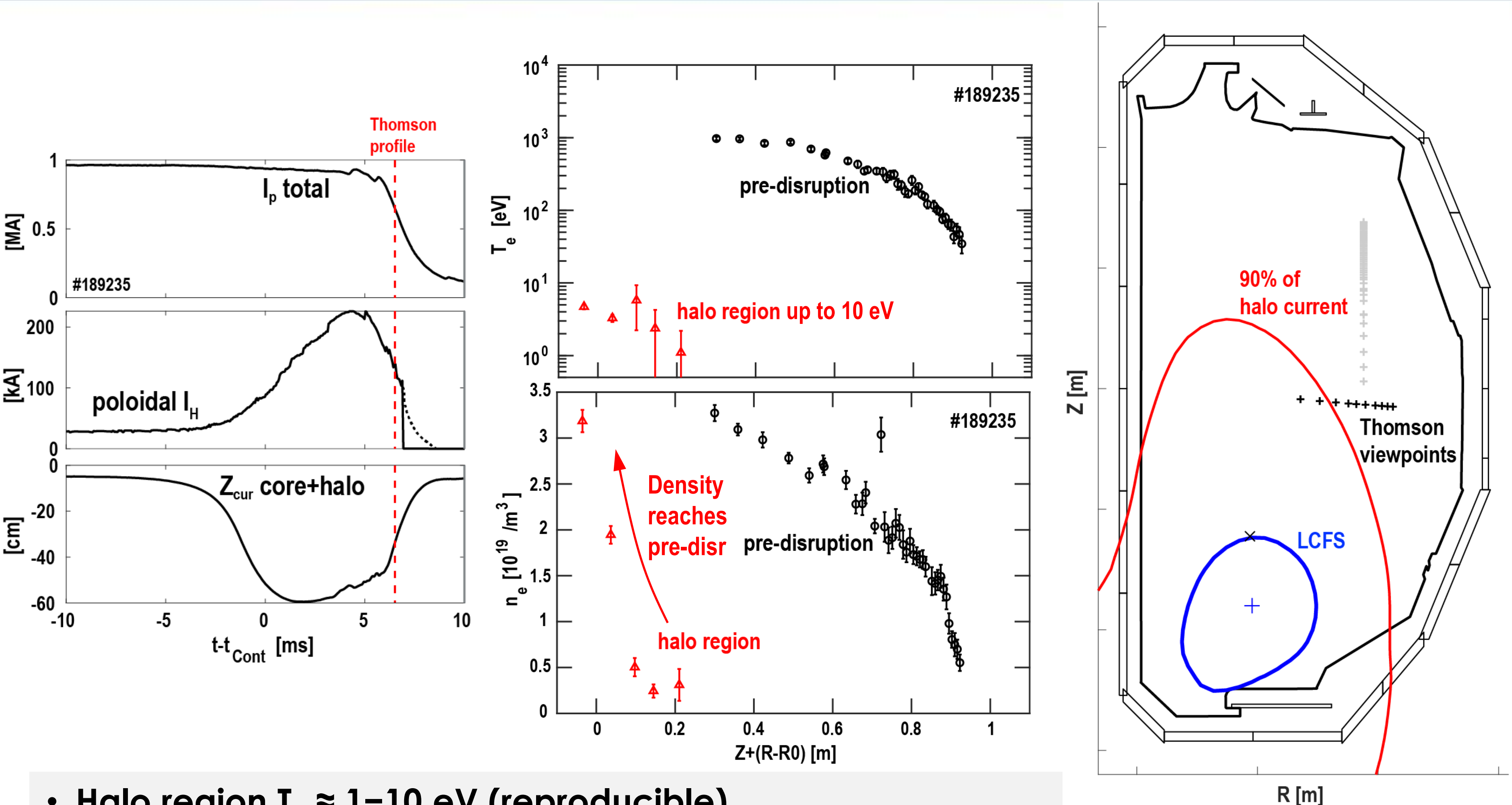






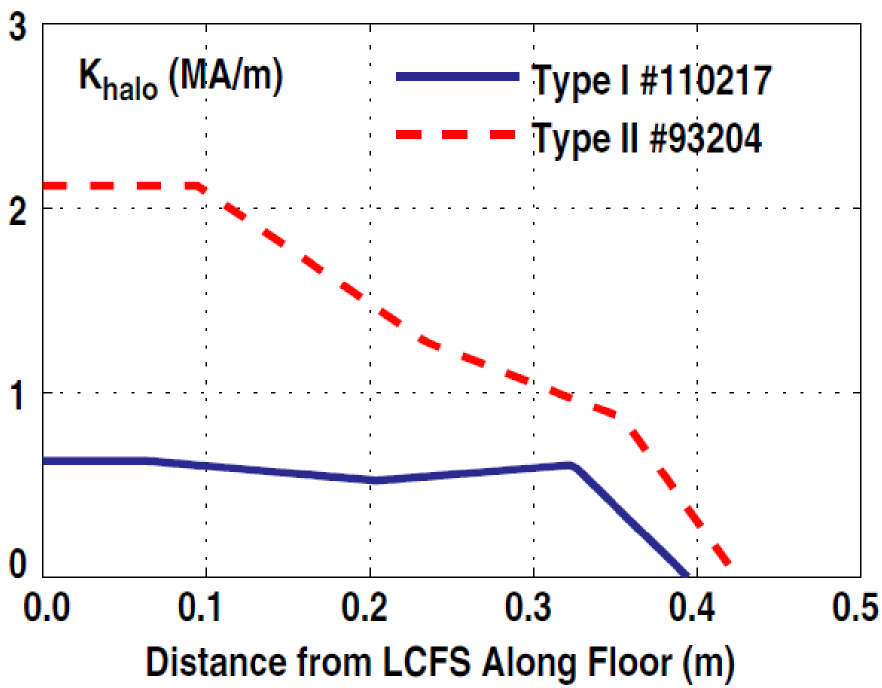
- Halo region $T_e \approx 1–2$ eV (reproducible)
- Halo region n_e is comparable with the pre-disruption value
- Spitzer resistivity 6e-4 ($Z=1.5$, $T_e=1.5$ eV, $\ln\Lambda=15$)

Temperature of the halo region during type II VDE ('motion-dominated') is up to 10 eV



- Halo region $T_e \approx 1\text{–}10$ eV (reproducible)
- Halo region n_e is comparable with the pre-disruption value
- Spitzer resistivity 6e-5 ($Z=1.5$, $T_e=7$ eV, $\ln\Lambda=15$)

Temperature and halo current density profiles during VDE I and VDE II are in good agreement



Measured poloidal current distribution along the floor of the vessel at the time of peak halo current [1]

- Almost flat and low halo current density profile was measured during VDE I in contrast to peaked and elevated profile during VDE II [1]
- This is in good agreement with measured temperature profiles: flat and low during VDE I and peaked and elevated during VDE II
- These observations indicate that to correctly account I_HxB vessel forces both halo current amplitude and profile have to be considered
- Presented detailed experimental data will be valuable to improve and validate halo current models

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[1] Eidietis NF 2011