Disruption and Runaway Electron Mitigation with MGI in DIII-D

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presented by
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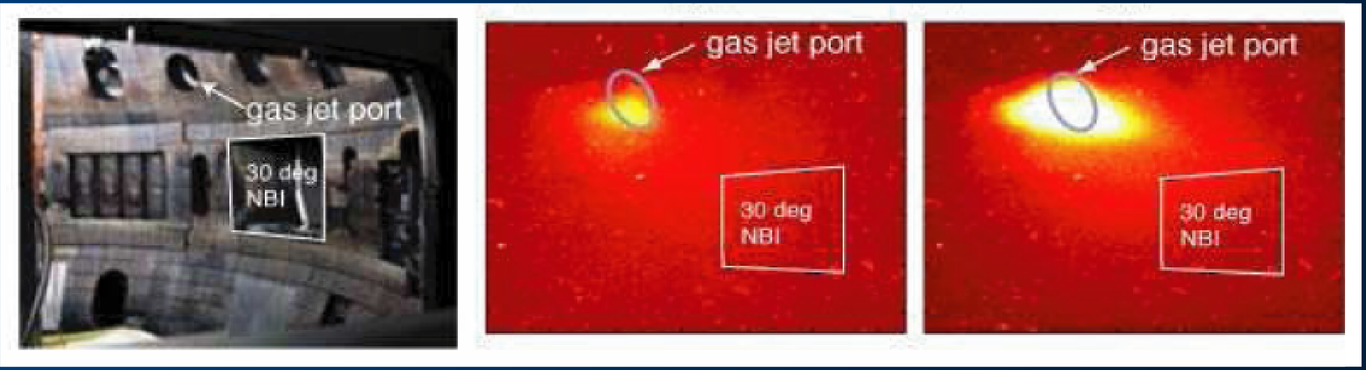
at the



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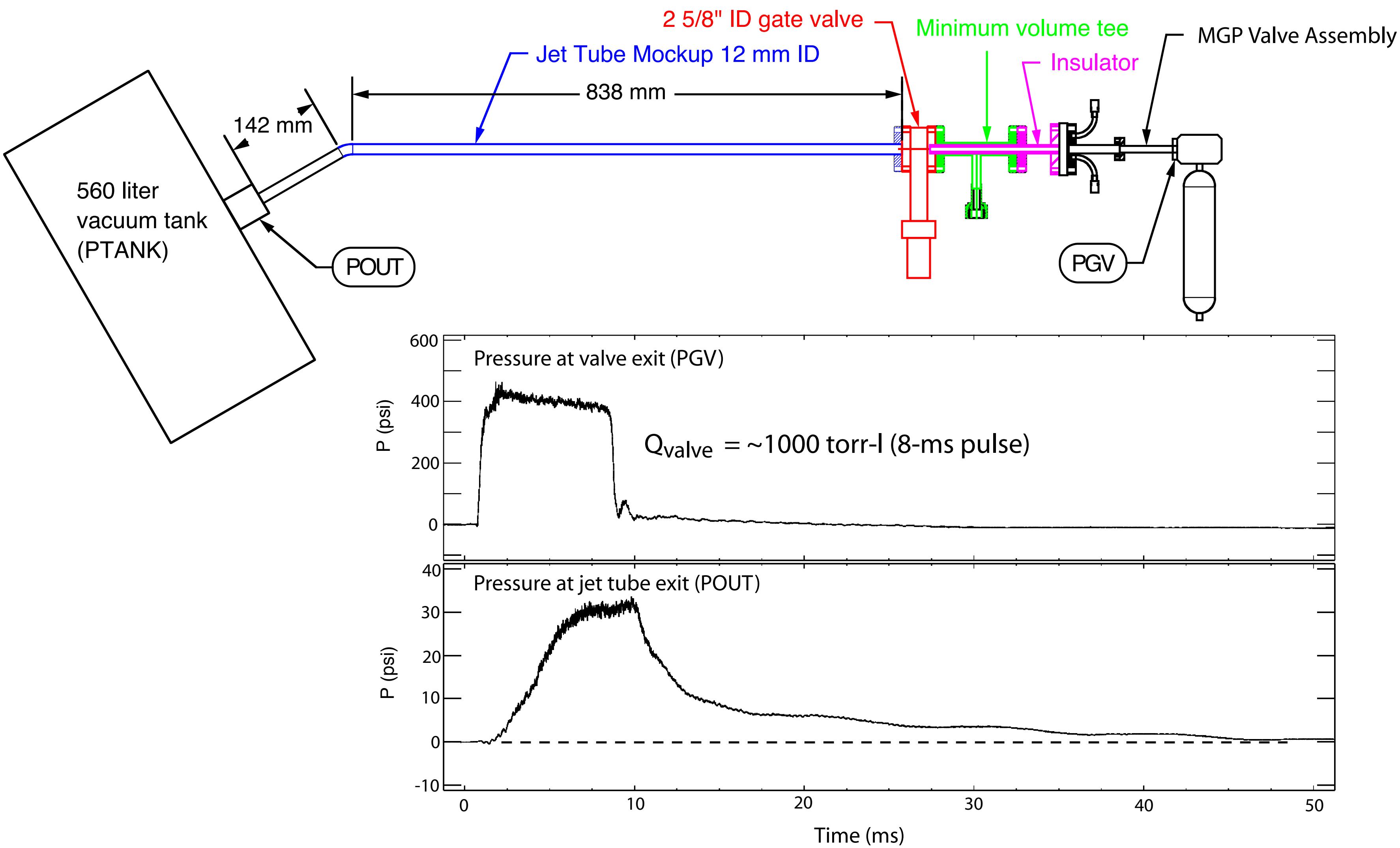
GENERAL ATOMICS

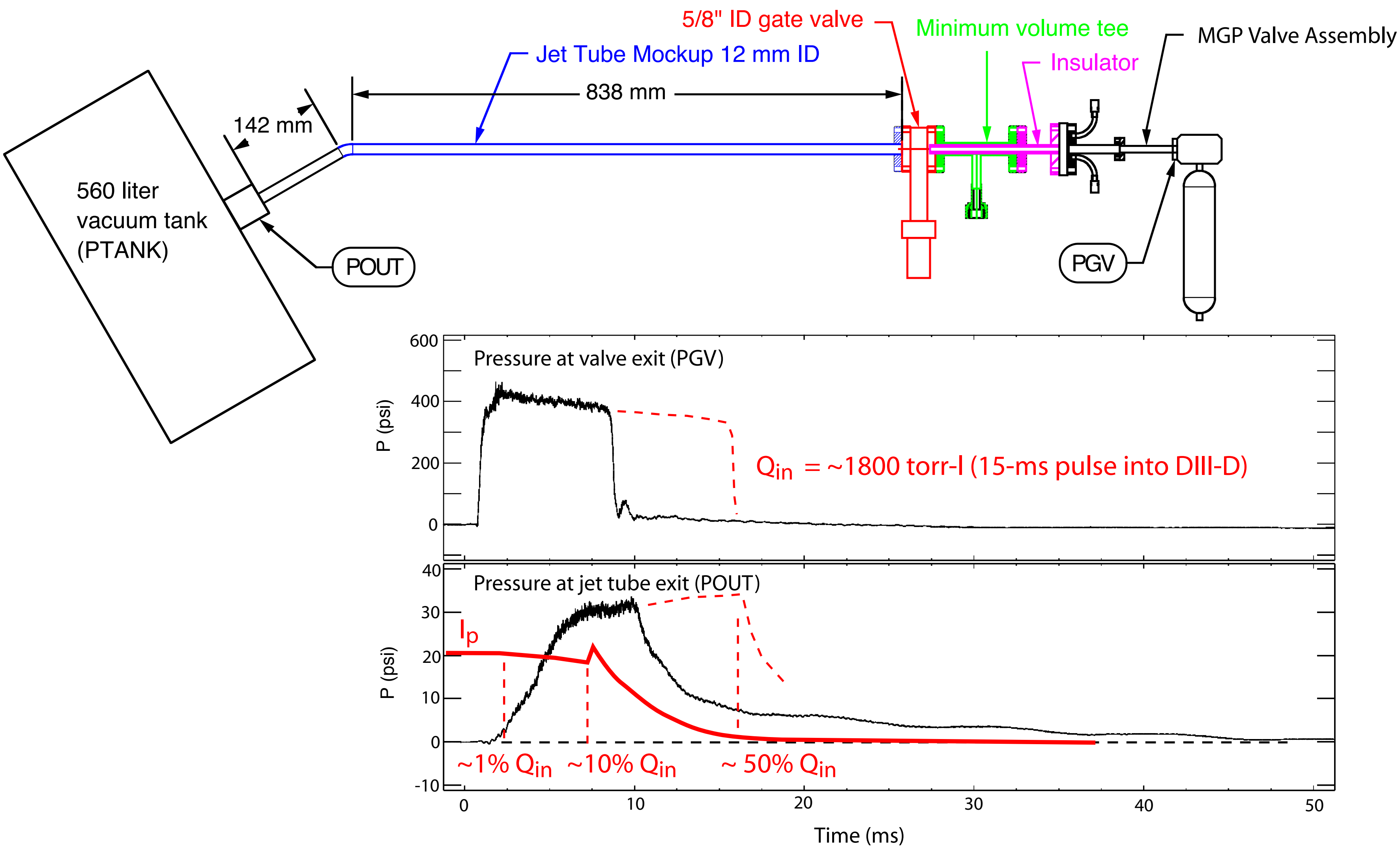
2004-2005 experiments have elucidated MGI physics basis, mechanisms and application to ITER

- Directed-jet high intensity gas injector (L = 1.3 m)
  - 10-ms exit flow rise time (argon)
  - Initial Q $\propto t^2/t_{rise}$; hence $Q_{MGI} \leq (0.01-0.5)\ Q_{total}$ (argon)
  - Mixed gas: 2% Ar is entrained in faster H_2 flow
- B_T, I_p, q and/or W_{th} target plasma variations
  - Gas does not penetrate ⇒ surface-localized fueling
  - Edge j'-driven MHD ⇒ inward ion transport + outward energy transport and a 'slow' erosive thermal collapse; ends with 'fast' internal j(r) 'reconnection'
  - Surface fueling + W_{th}-enabled MHD ⇒ ion and electron assimilation proceeds during the TC, but 'efficiency' is finite, and $n_{e,total} << n_{RB}$ at the start of CQ

ORNL tests show ~10-ms exit pressure ‘rise time’ (Ar)



Test data indicates DIII-D MGI gas quantities ≤ 50% Q_{in}



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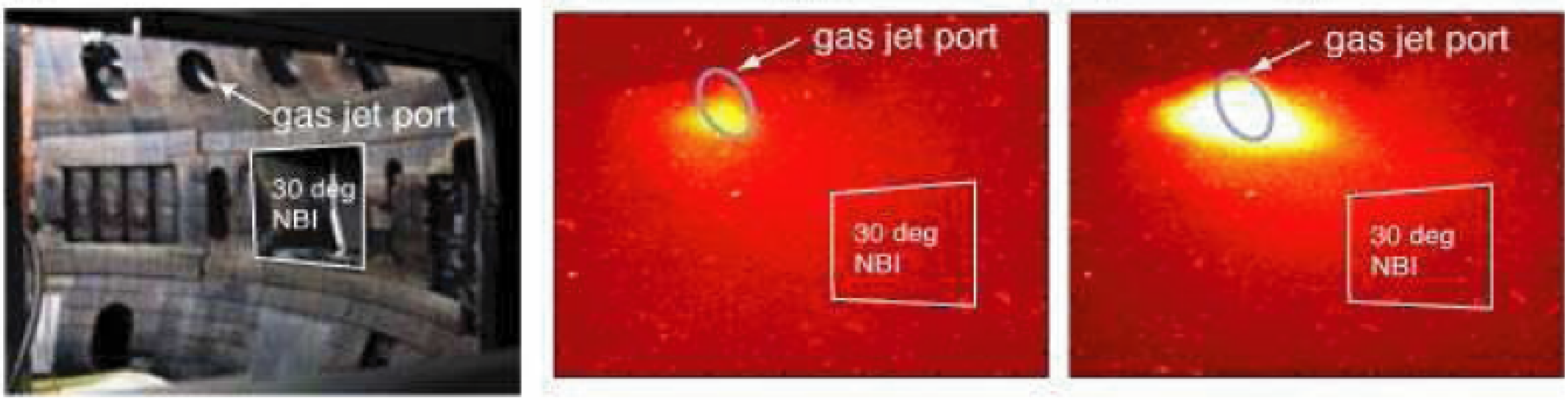
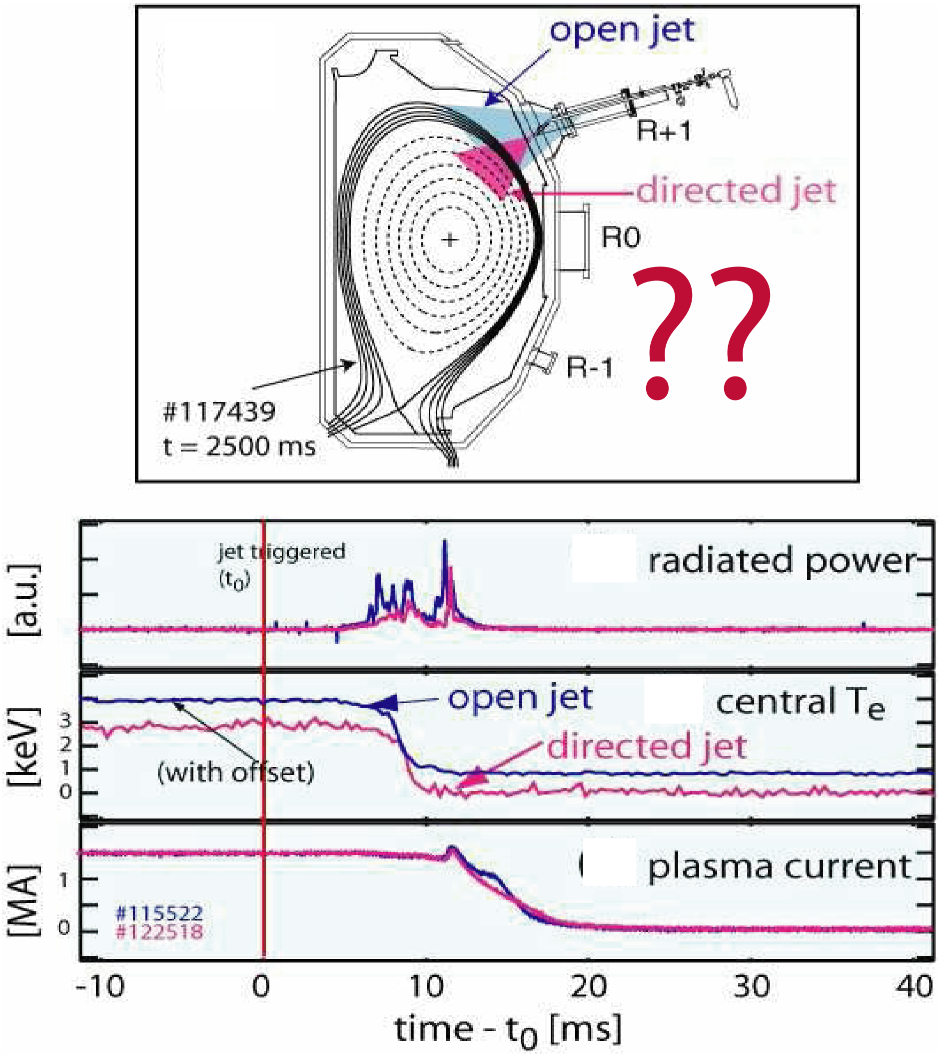
Fast camera imaging: jet does not penetrate ≥ few cm

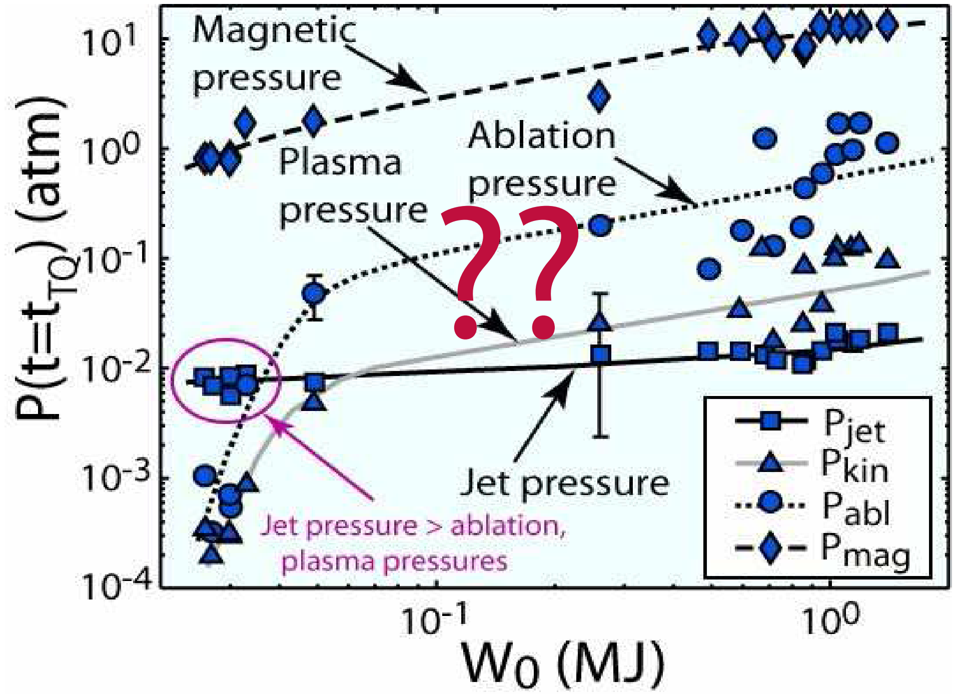
- Ar I images show surface-localized ionization + along-B streaming



- Ar ion and radiation profiles (from SXR) and plasma l_i data all support optical observations of only minimal neutral penetration
- No increase in penetration for B_T = 0.5 T, W_{th} ≈ 0 or CQ plasma
- No difference in penetration with high-intensity vs. open-valve jet

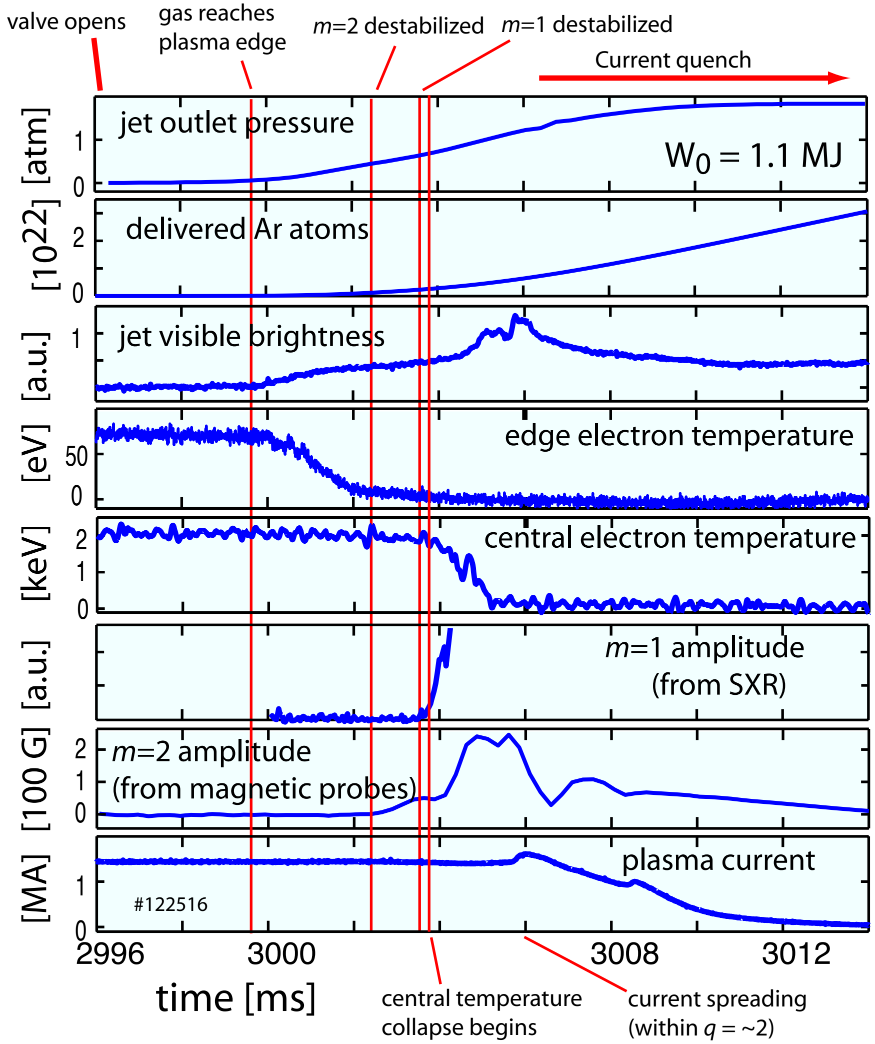
Jet and target plasma variations have little effect





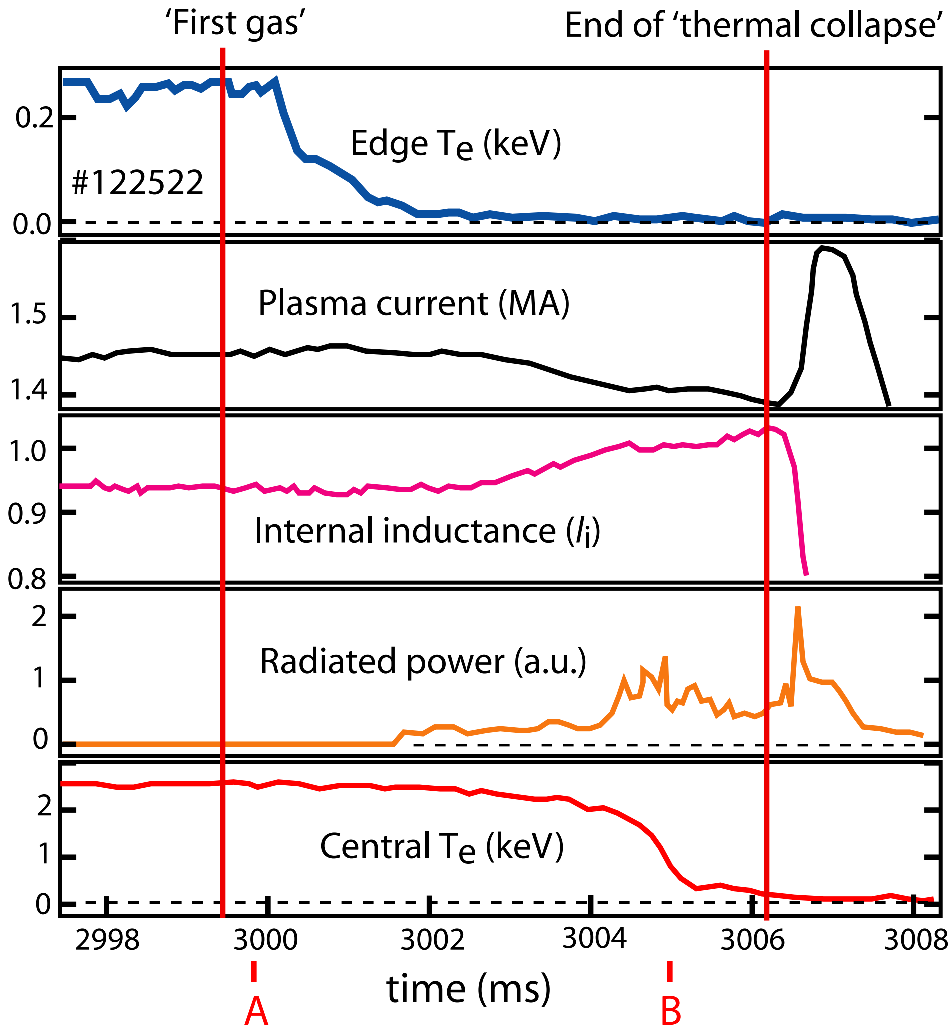
B_T and W_{th} variations do not affect penetration

Gas surface fueling + MHD 'mixing' effect a 'slow' progressive radiative dissipation of W_{th} that is followed by a 'fast' CQ



- **Gas reaches plasma edge**
- **Ar ionization, dilution, and Ar+ radiation cooling produce edge *j*(r) 'scrape-off' and high edge d*j*/dr**
- ***m* = 2 destabilized; Ar+ and *j*' fronts propagate inward; *m* = 2 grows**
- ***m* = 1 destabilized; Ar+ and *j*' fronts continue to propagate inward; central W_{th} starts to be transported outward to radiating Ar+ region**
- **Core W_{th} radiation complete ~5 ms after 'first gas'; fast internal ($q \lesssim 2$) current spreading follows**
- **Fast (5-ms) current quench consistent with cold ($\lesssim$ 5 eV), impurity-radiation dominated plasma, hence low I_{halo}, TPF**

Magnetic, profile and MHD data elucidate the progressive nature and mechanisms of MGI 'thermal collapse'



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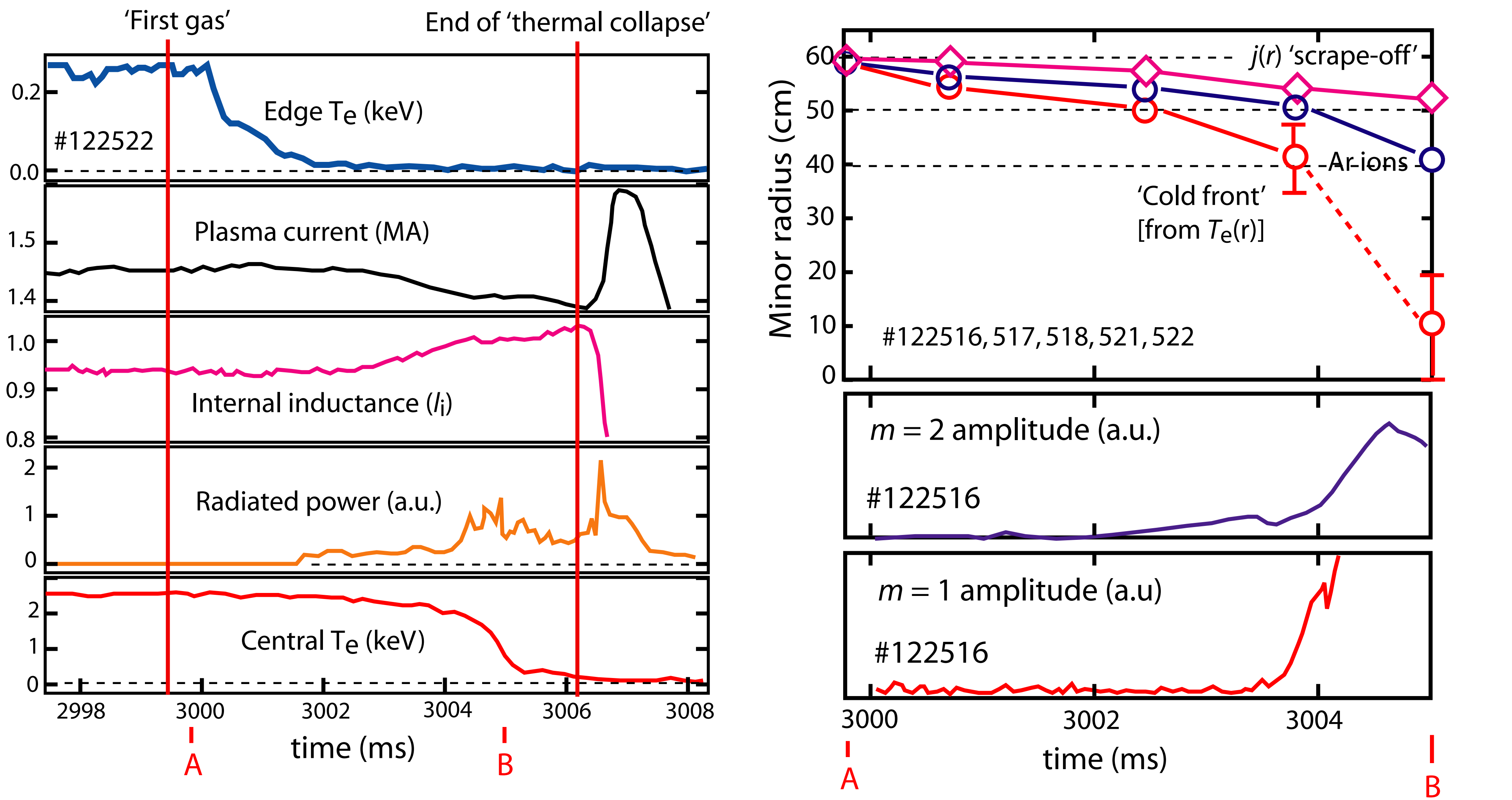

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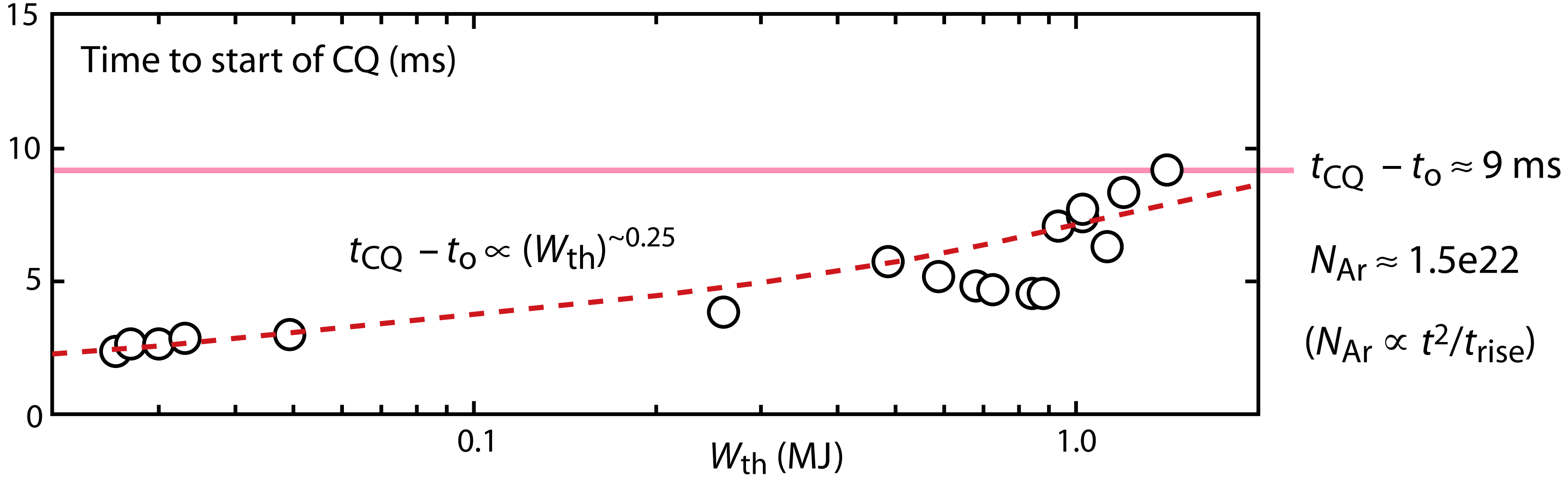
Thermal collapse duration and CQ-start gas and electron assimilation increase with initial plasma thermal energy



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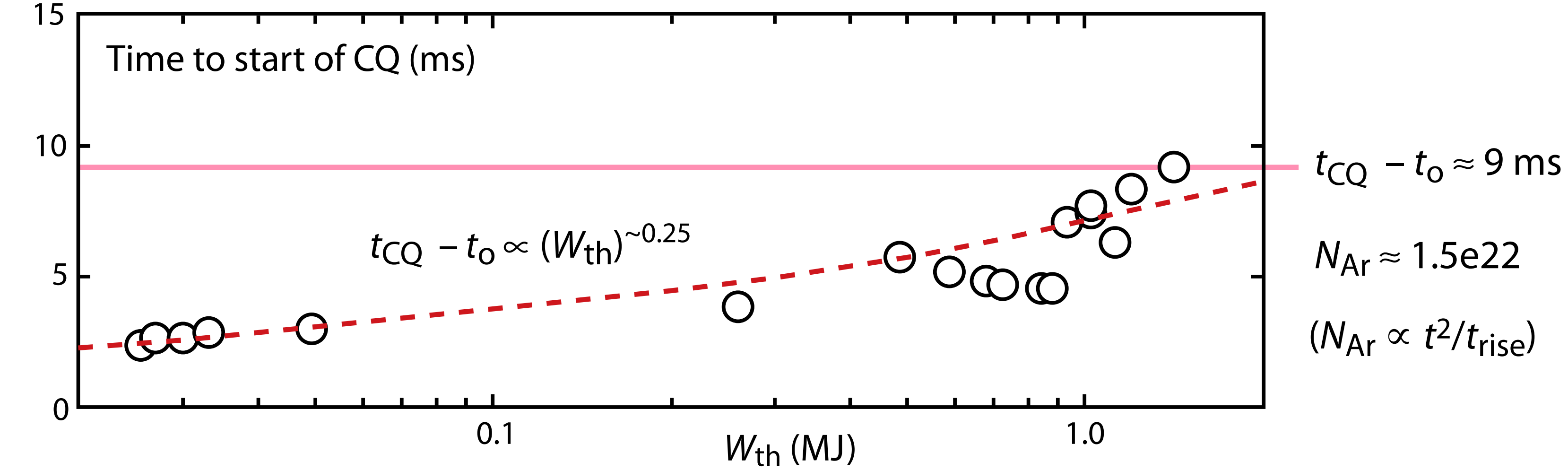

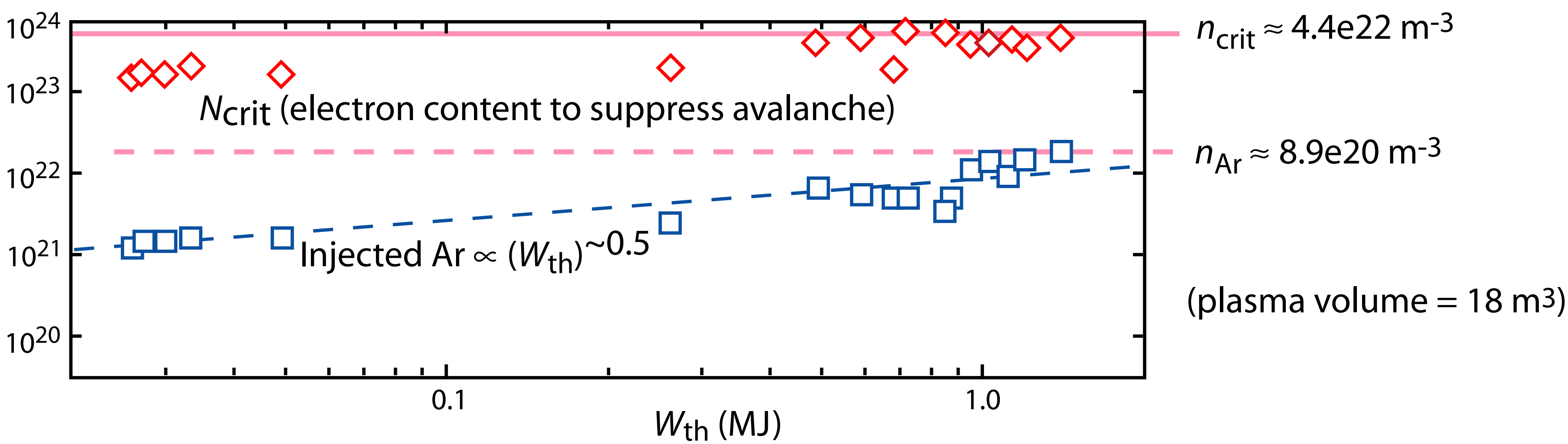

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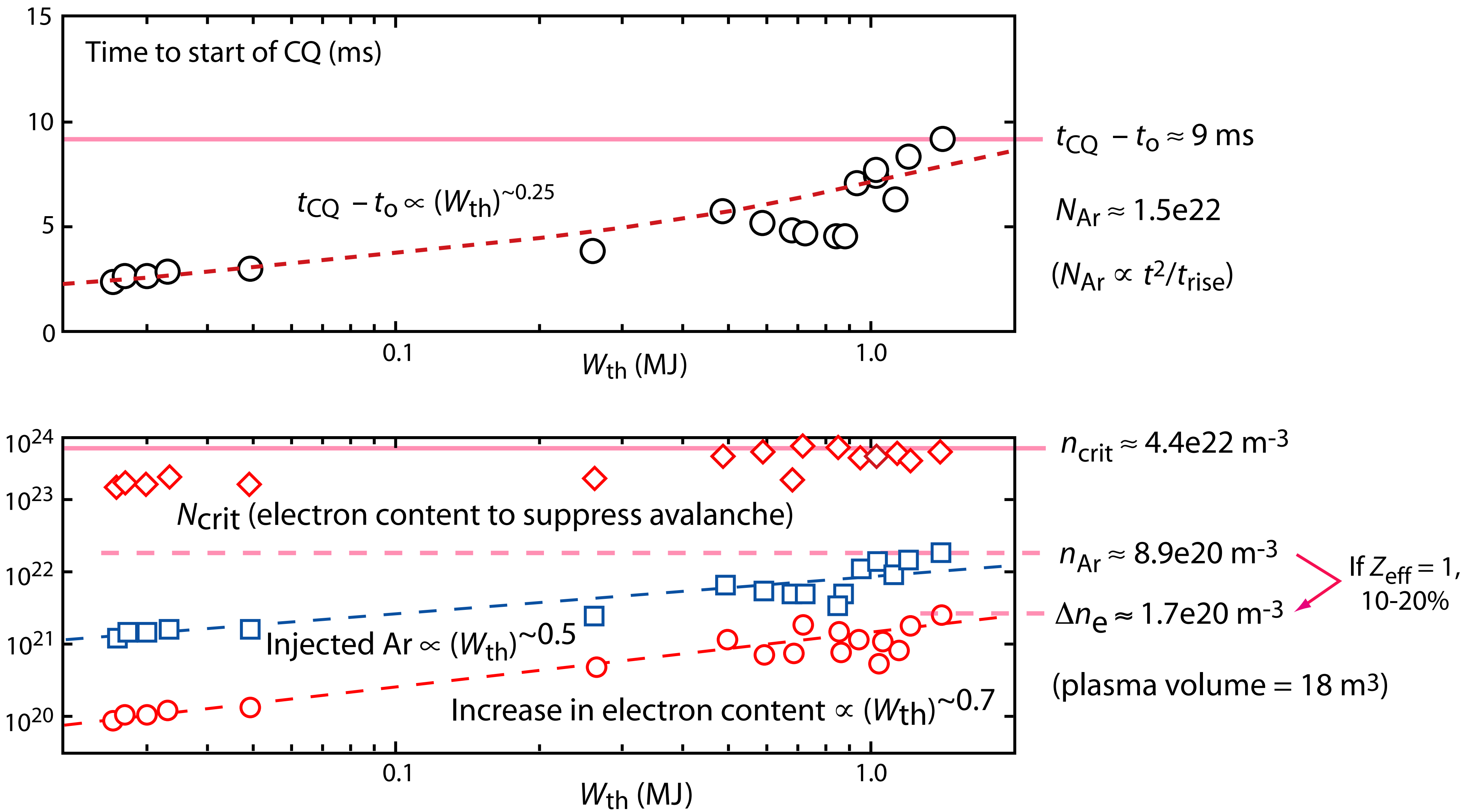

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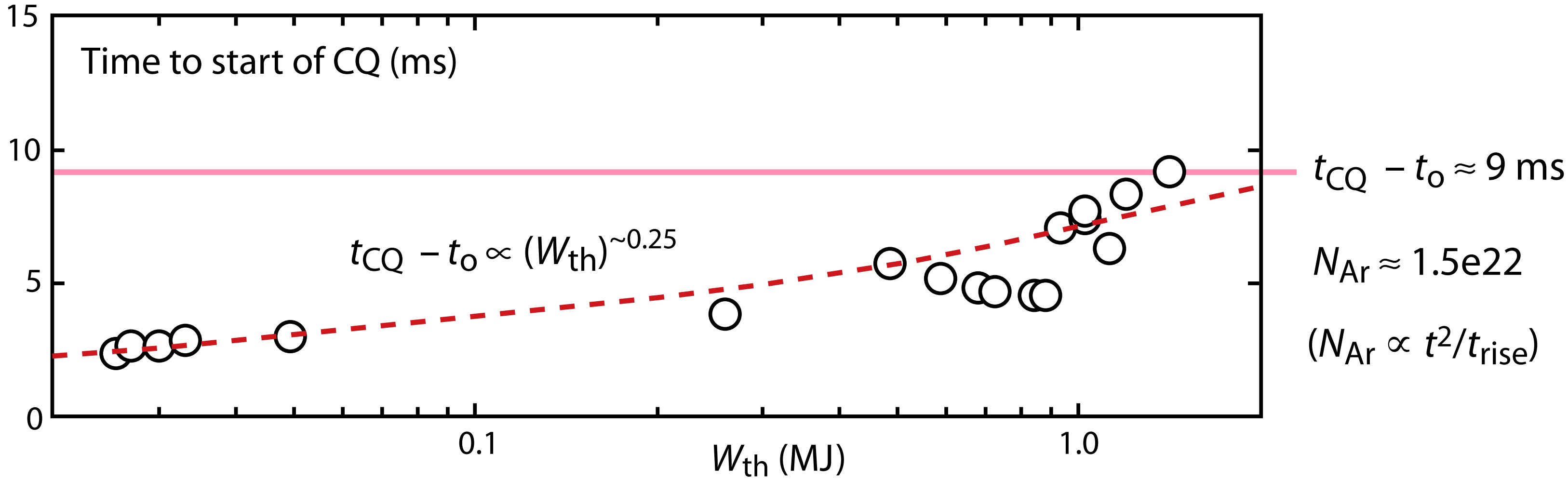

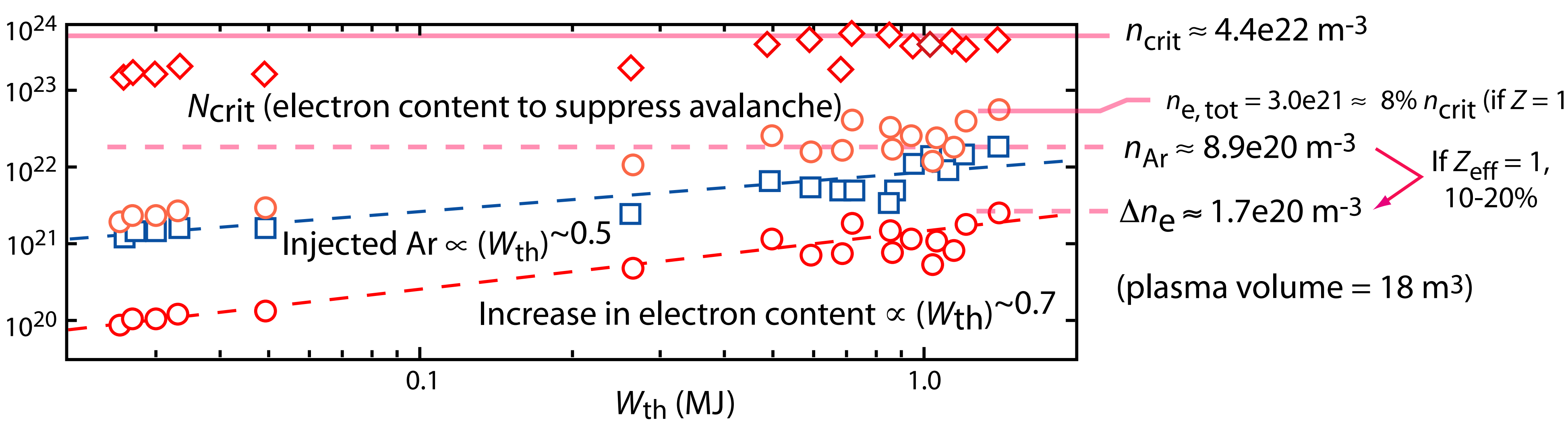

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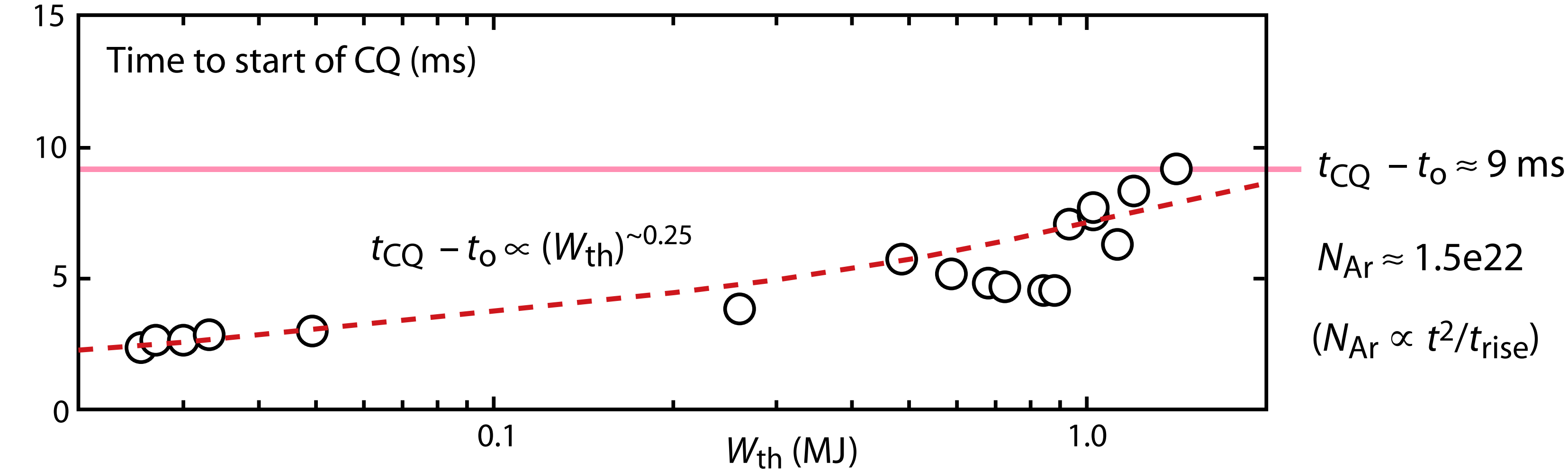

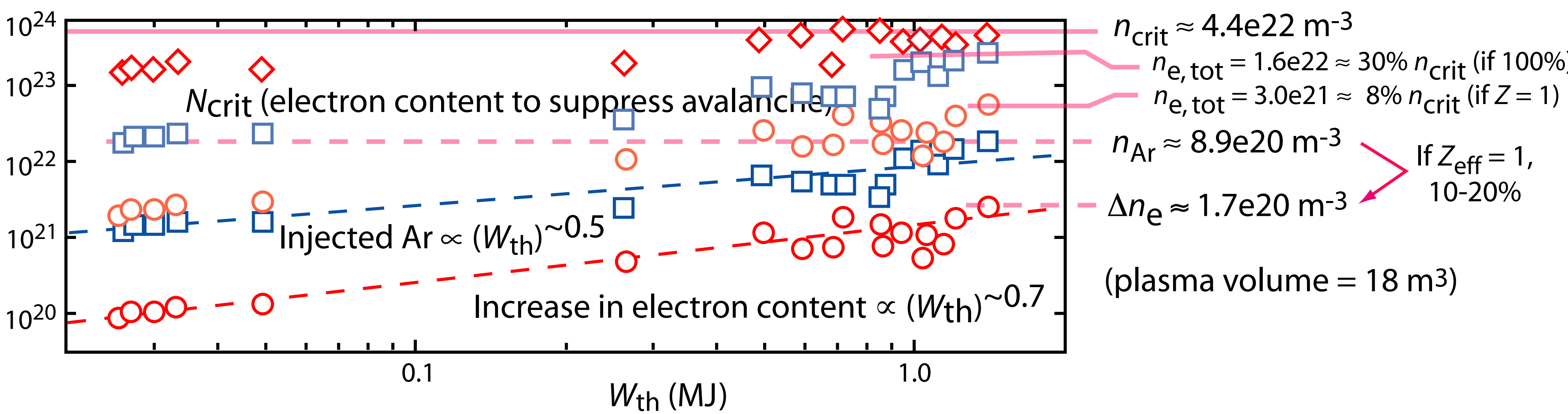

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Directed-Jet "W_{th}-variation" experiments have elucidated gas assimilation and runaway avalanche suppression

- Duration of the thermal collapse phase and the total quantity of neutral Ar delivered to the plasma surface up to onset of the CQ both increase with increasing W_{th}. The observed ΔN_e (increase in plasma electron content) also increases with increasing W_{th}
- The observed ΔN_e, interpreted as being due to singly-ionized Ar, corresponds to a gas assimilation fraction of 10-20%. The observed 'as-Ar+' assimilation fraction increases only weakly with increasing W_{th}
- The 'measured' added electron content, $\Delta N_{e,tot}$(as Ar+), corresponds, on a 0-D basis, to total (free + bound) electron densities that are about 1-10% of the corresponding Rosenbluth no-avalanche densities
- The estimated added electron content, $\Delta N_{e,tot}$(as Ar), assuming 100% assimilation of injected Ar, corresponds, on a 0-D basis, to total electron densities that are about 10-30% of the Rosenbluth density
- The lack of major RE generation in the Ar D-J experiments cannot be attributed to collisional suppression of Coulomb avalanche gain

Summary and Implications for ITER

- **Jet tubes and exit flow rise time limit the initial rate of gas delivery. For the D-J system, Ar quantity at CQ onset is ~10% of nominal**
- **There is no indication of direct neutral penetration. This observation is consistent with jet stopping by displacement of the $B^2/2\mu_o$ magnetic pressure**
- **Magnetic, ion and T_e profile and MHD fluctuation data show edge cooling and edge-*j*'-driven MHD effect an inward transport of ionized impurities and outward transport of core thermal energy. The resulting 'erosive' radiative collapse proceeds on a ~5-ms time scale**
- **MHD instability and gas assimilation as ionized impurities proceeds for as long as the plasma thermal energy source, W_{th}, remains. Higher W_{th} promotes increased assimilation. But the observed at-CQ assimilations are well below unity**
- **Lack of major RE generation in the Ar D-J experiments cannot be attributed to collisional suppression of avalanche gain. Low levels of well-confined runaways are frequently observed, and would likely avalanche in a high-gain plasma**