[CP1.63] Interpretation of Fast ECE and Soft X-ray Measurements During High Field Launch Pellet Fueling on DIII-D

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Similar to observations on ASDEX-Upgrade,(P.T. Lang et al.), [Phys. Rev. Lett. (1997) 1487-1490.] high field launch pellet fuelling experiments on DIII--D have produced a particle source function shifted inward in minor radius toward the plasma core when compared to the local pellet ablation source. High time resolution measurements of electron cyclotron emission (ECE) and soft X-ray emission have been obtained during the initial phase of the ablation process. These measurements reflect changes in the flux surface averaged electron temperature during pellet ablation and provide insight into details of the mass redistribution. Measurements are evaluated using the PPPL Tokamak Simulation Code (TSC). The ECE and soft X-ray measurements are also compared with measurements of ablation light and density for beam heated DIII--D plasmas with weak shear and high edge q.

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Mass Redistribution Observed During Pellet Ablation in High Temperature Plasmas

Measurements of the Electron Density Source Function made by comparing electron density profiles before and immediately following pellet injection in high temperature plasmas have shown that the radial distribution of the final source function does not correspond with the radial distribution of the local pellet source function predicted by pellet ablation rate calculations.

Differences are observe both when pellets are injected from the large major radius (low field) side [NF] and from the small major radius (high field) side [PRL].

L. R. Baylor, et. al. Nucl. Fusion, **32**, 2177 (1992).

P.T. Lang, et. al. Phys. Rev. Lett., 79, 1478 (1997).

Mass Redistribution Appears to Occur During the Period of Pellet Ablation

Issue: How Study Details During Ablation

Requirements for Study of Effective Pellet Source:

High time resolution (pellet event times 100 - 1000 seconds)

Seek to Study and Evaluate an Event which is Nominally a Localized Phenomena

Either - Make use of the difference in time scales for Temperature and Density Equilibration

Or - Make ues of a direct view of ablation process and establish a mechanism to infer the pellet source from this direct view

J de Kloe, et. al., Phys. Rev Lett, **82**, 2685 (1999).

H.W. Muller, et. al., Phys. Rev Lett, **83**, 2199 (1999).

Approach: High Time Resolution Electron Cyclotron Emission (ECE) and Soft X-ray Measurements Can Probe Redistribution

ECE has potential to satisfy requirements -- Soft X-ray can Supplement ECE

Time Response - high

Te symmetrizes more rapidly than density
- Adiabatic character of pellet perturbation allows measurement of Te to probe ne source while ne perturbation is still essentially local

Draw Backs:

ECE signals are affected by high plasma density - Cutoff can limit measurements

Soft X-ray Signal may be Difficult to Interpret in Detail

TFTR Results from OUTSIDE LAUNCH Suggest Fast ECE as Suitable Diagnostic for Study of Pellet Mass Redistribution

Pellet enters plasma along mid-plane radial line from low field side

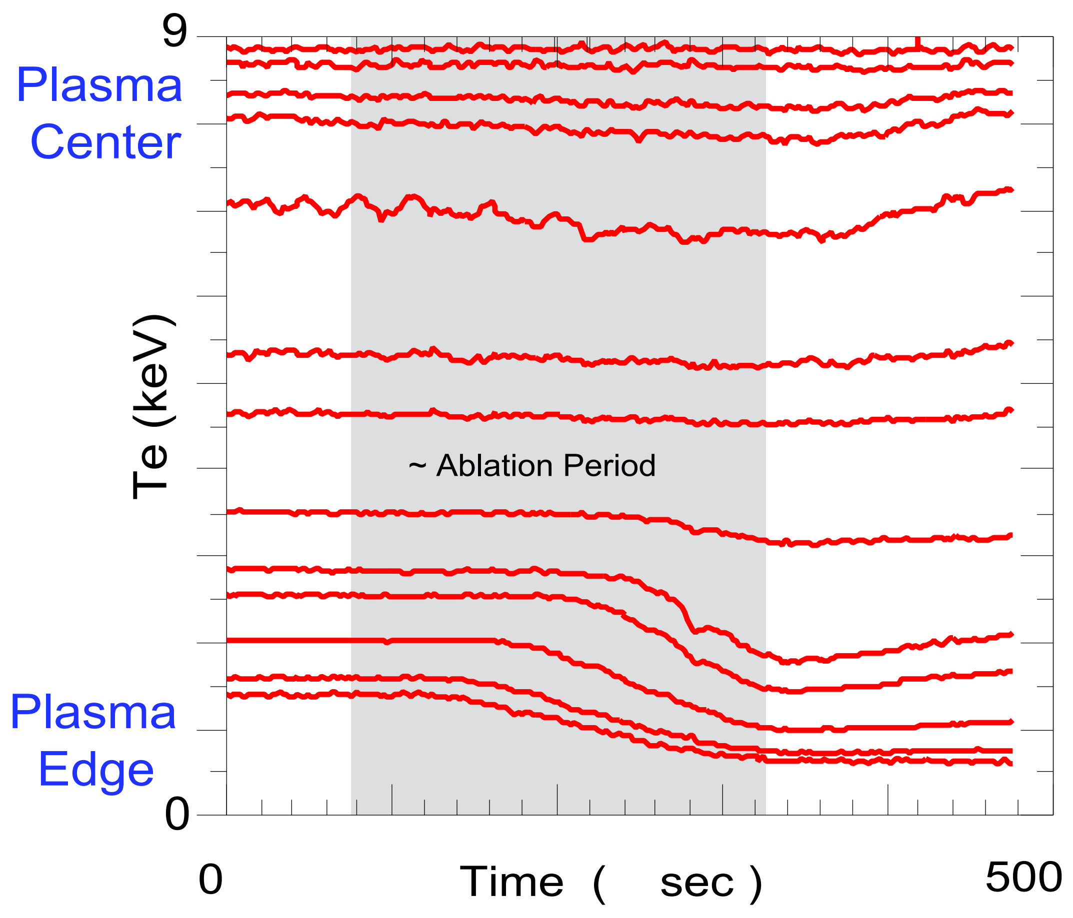
Each value of electron temperature in figure represents a flux surface radial position

Drop in given flux surface temperature begins when pellet crosses that flux surface

Temperature drops occur first at plasma edge and move inward with pellet

Temperature drop continues on a surface after pellet has passed

Temperature drops cease on all surfaces simultaneously at end of pellet ablation



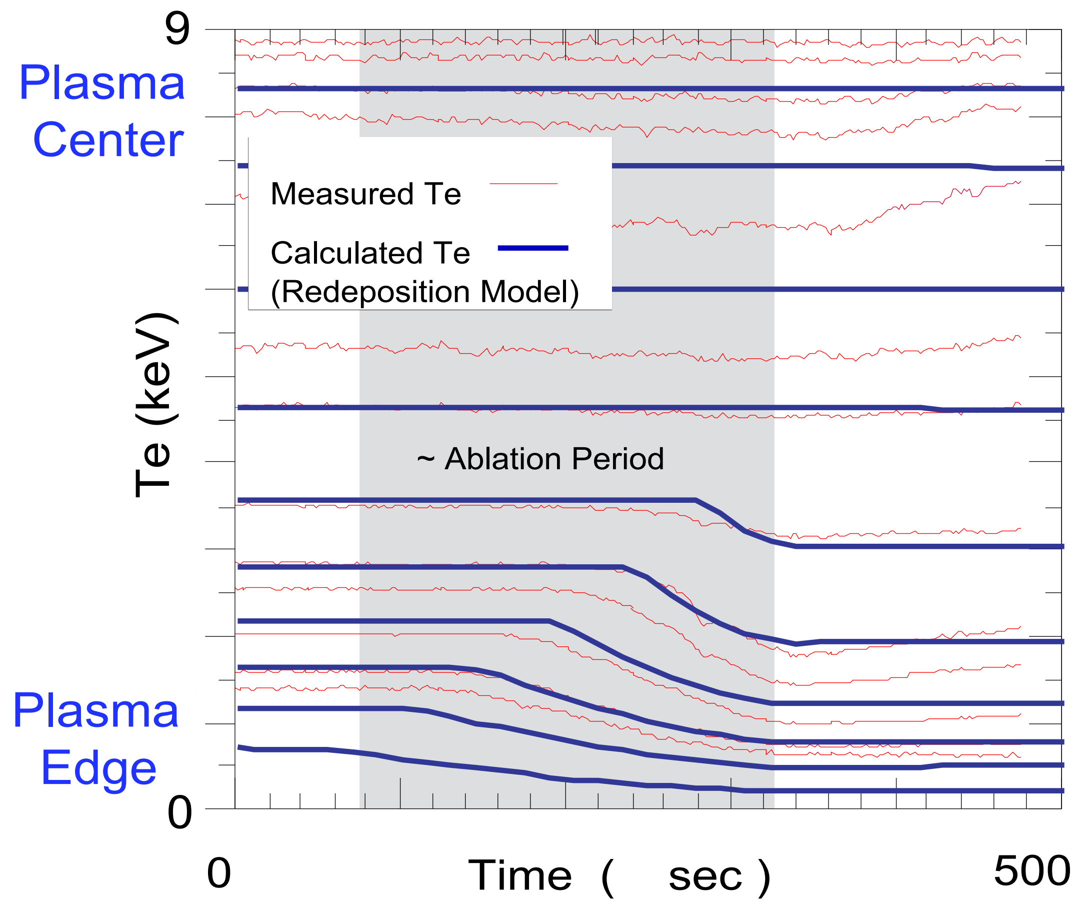
Simple Empirical Model for Mass Redistribution Reproduces ECE Measurements in TFTR [APS 1997]

Model is Active only During Pellet Ablation

Ablation Rate based on Local Parameters

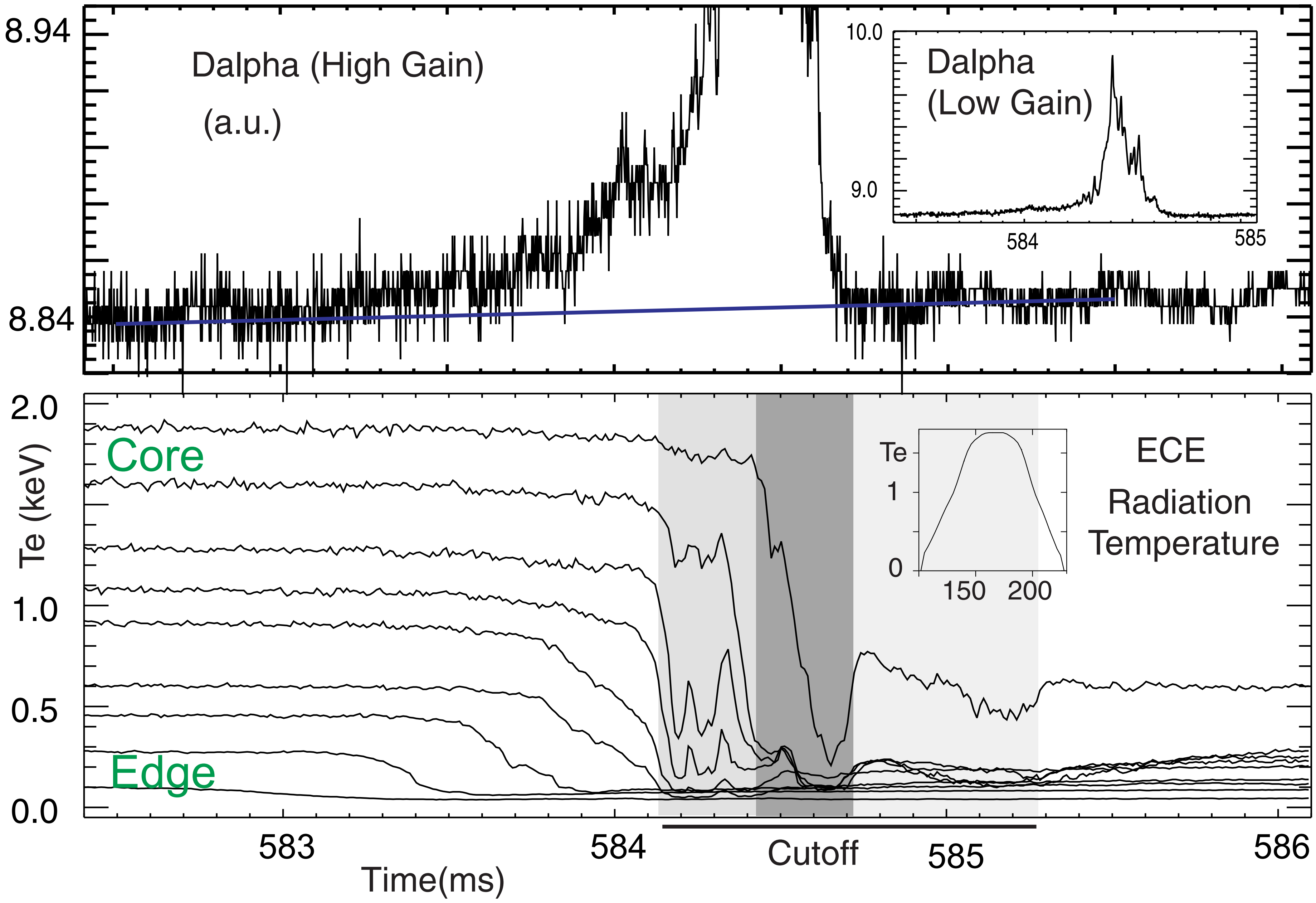
Ablated Mass Redistributed Continuously Across all Minor Radii Outside Instantaneous Pellet Location

Loss of Pellet Mass Accounted for by Redistribution of a Fraction of Ablated Mass to Surfaces Outside Confined Plasma



G.L. Schmidt, S Jardin et. al. APS 1997

High Time Resolution ECE can Follow Pellet Perturbation in certain DIII-D Plasmas with only Brief Loss of Data near Termination of Pellet Ablation



Study Evolution of ECE signals during pellet ablation for inside launch trajectory

Signals cutoff only during final period of pellet ablation phase

Use DIII-D Target Plasma with Low Density and High q(a)

Target:
$ne(0) = 1.8 \times 10^{19}\ m^{-3}$
$q(a) \sim 8$

CP1.63 - Pg 8 CP1.63 - Pg 7 CP1.63 - Pg 9

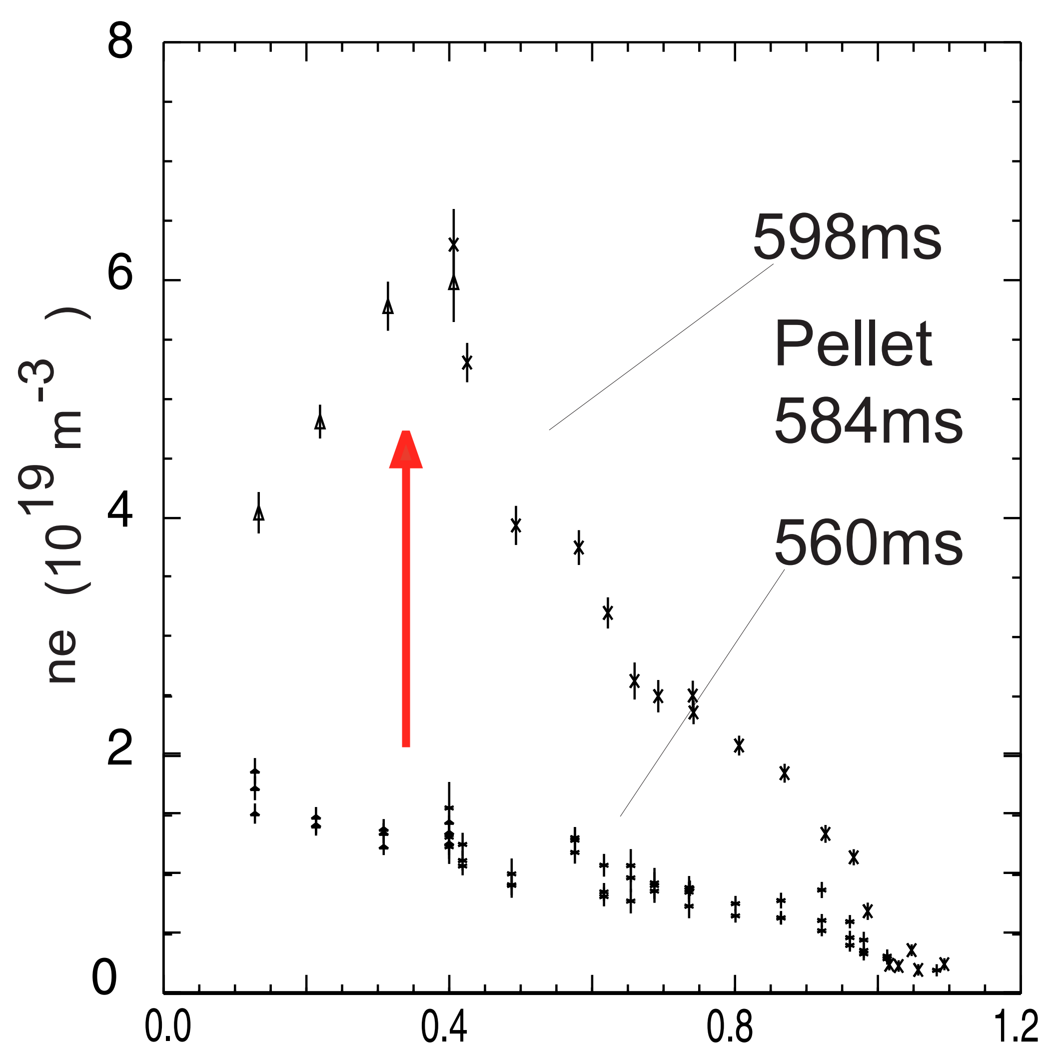
Deep Pellet Source Observed

Prolonged ECE Cutoff Avoided

Changes in Density Following Pellet Injection Indicate a Pellet Source is Present Deep in Plasma Core During Pellet Ablation

= Core Thomson

= Tang Thomson

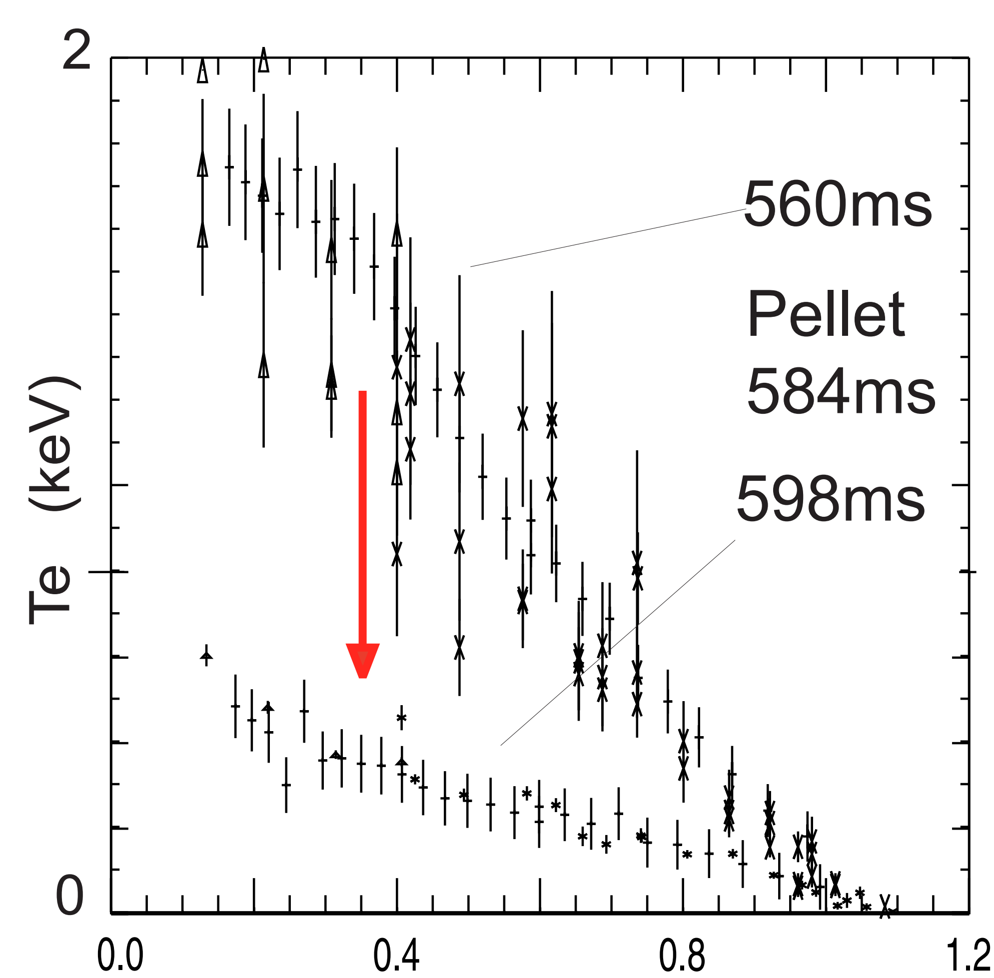


Agreement between ECE Measurements of Te and Thomson Scattering Te both Before and After Pellet Injection Confirm that Loss of ECE Signal is of Limited Duration

= ECE R>R0

= Core Thomson

= Tang Thomson



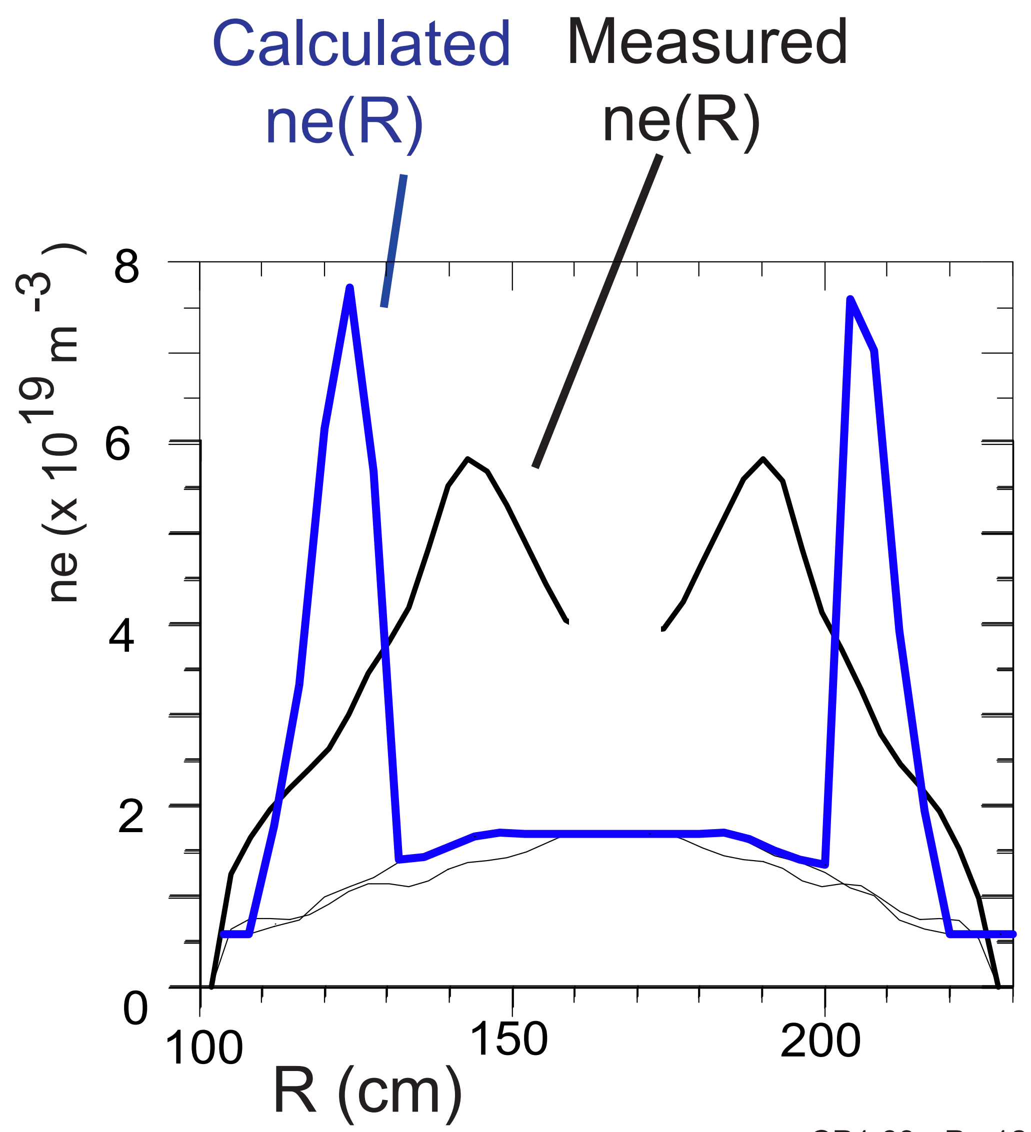
For This DIII-D Case:
Calculated Ablation Occurs in Outer Plasma
No Core Deposition Predicted

Differences between Calculated and Measured Density Profiles before and after Pellet Suggest:

Either Mass Redistribution
or Deeper Penetration
or Both are Required to
Account for Final Density Profile

Pellet Speed = 270m/s
Radial Pellet Speed = 170m/s
Pellet Particles = 3.9 x 10^{20}

Tokamak Simulation Code (TSC) Ablation Calculation based on Kuteev ablation rate [Kuteev, Nucl Fusion 1167 (1995)]



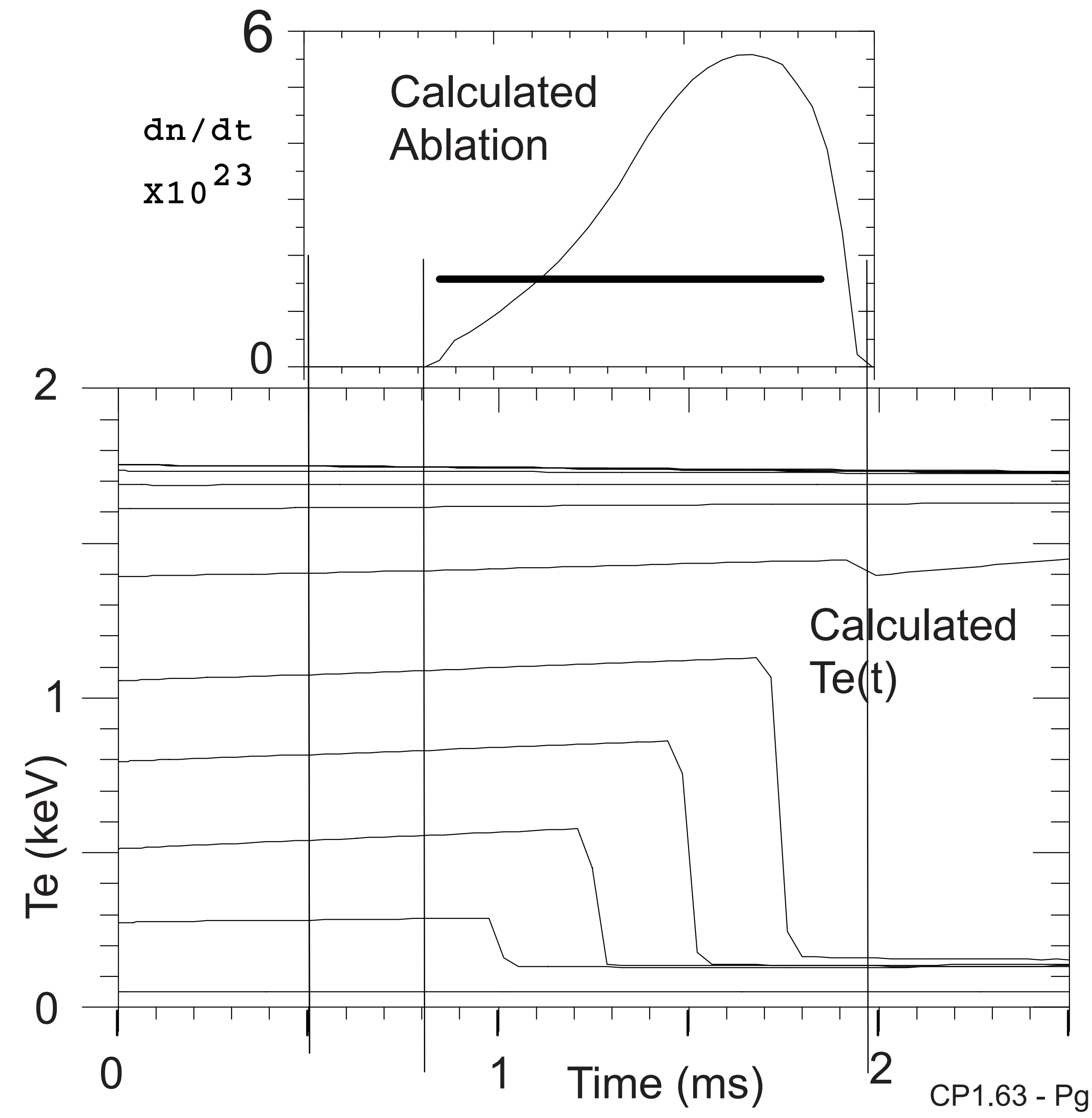
For This Case:
Duration of Calculated Ablation Less than Observed.
Depth of Calculated Penetration Less than Observed.

Calculated Ablation Duration
1.2 ms

Observed
1.4 - 1.7 ms

In Calculation Pellet Reaches
Te = 1.1 keV
R = 130cm

Deposition Observed to Reach Core:
Te = 1.8keV, R=165cm



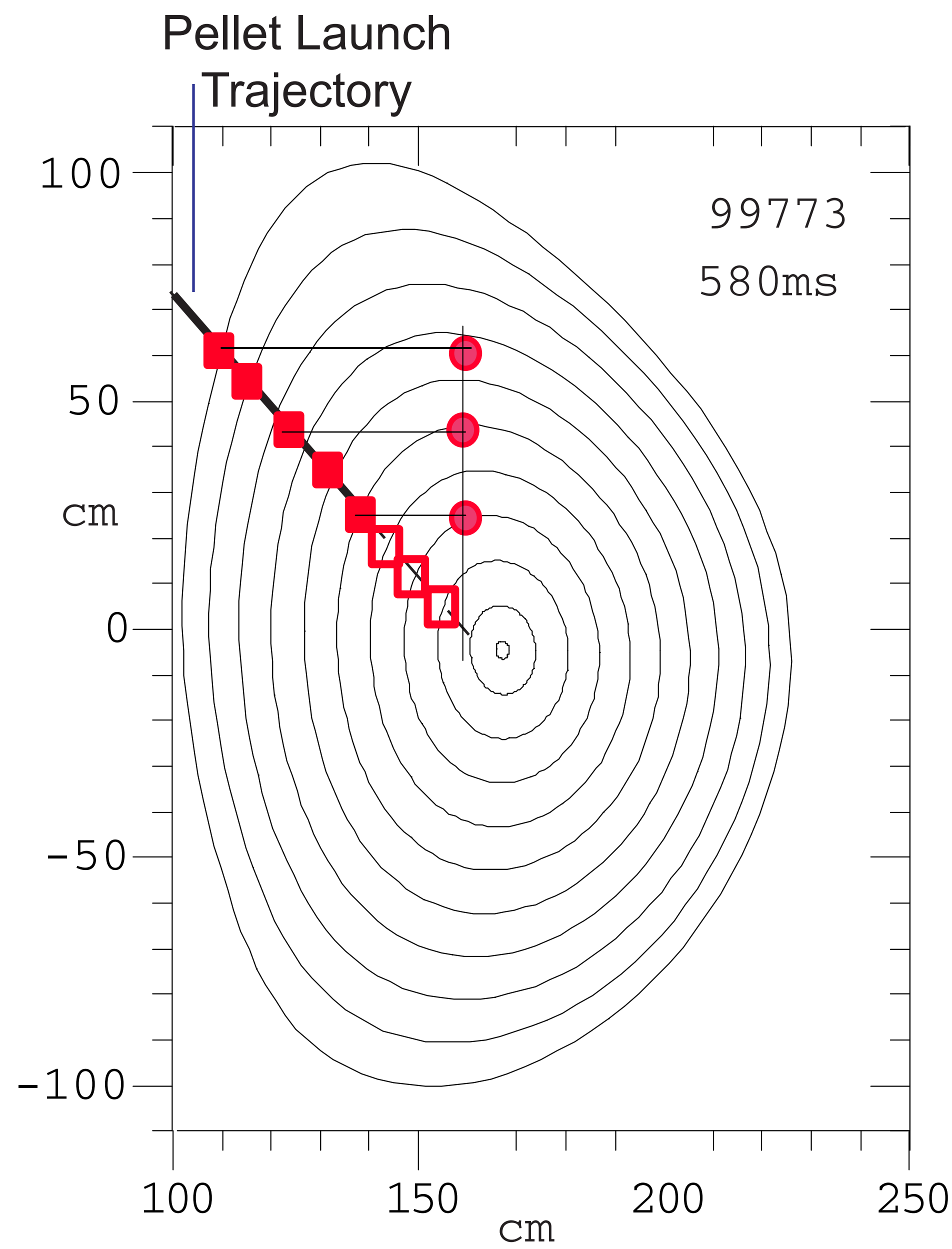
Injection Geometry

Pellet Launch Trajectory is From Inside Above Mid-Plane Downward toward Magnetic Axis

Squares (■, □) Indicate Timing Marks along Trajectory. Similar Timing Marks in Next Figure indicate Temperature and Time Corresponding to Marks in This Figure

Solid Marks Represent Points Reached by Pellet During Both Calculated and Measured Ablation. Open Marks represent Additional Points Reached During Observed Ablation Beyond Calculated Ablation

Circles Represent the Mapping of a Pellet Position Timing Mark to a Deeper Flux Surface. The Mapping Identifies a Region Between the Squares and Circles in which Mass Redistribution would occur assuming Redistribution takes place in a Horizontal Plane

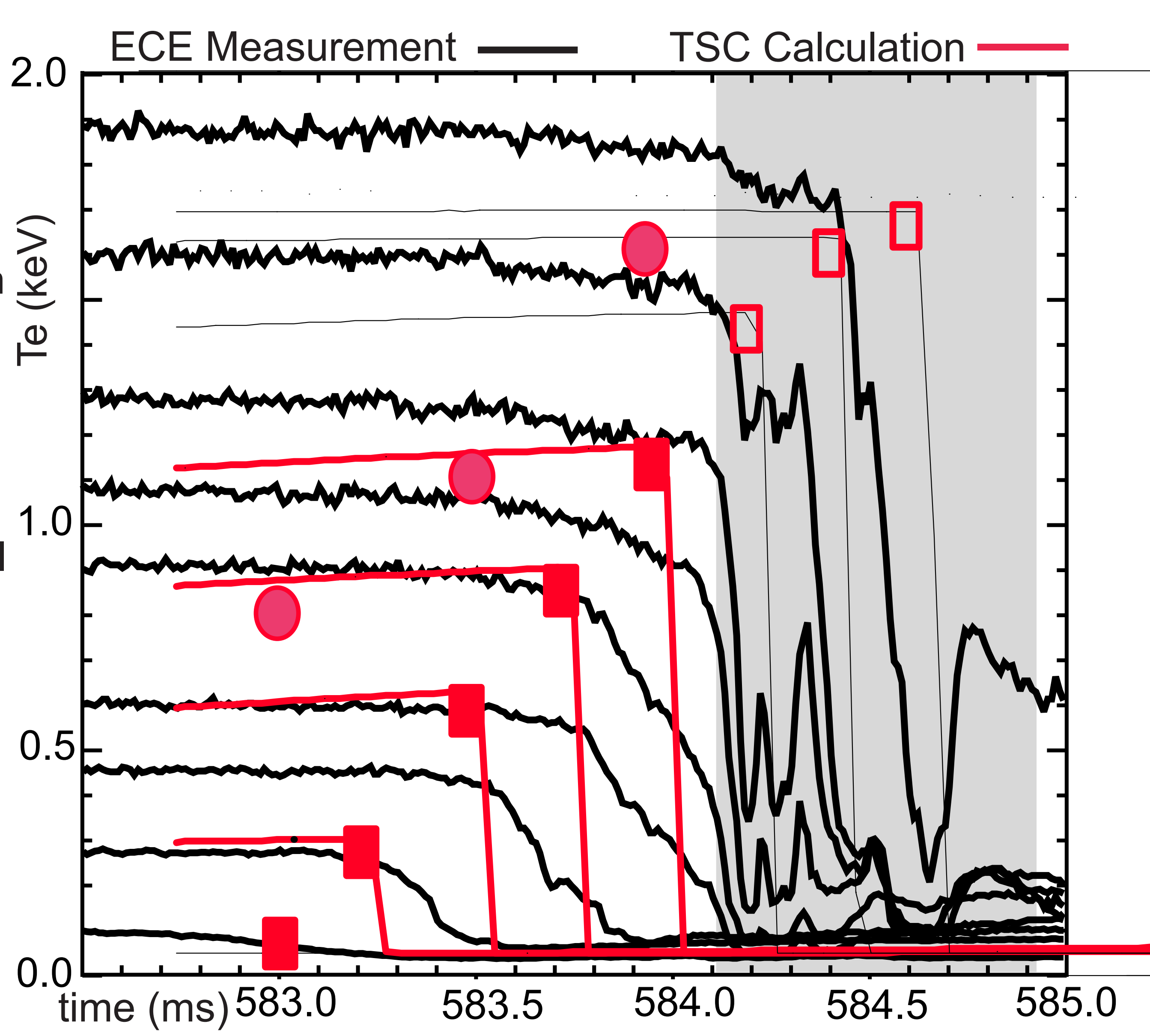


Timing of Pellet Entry Critical to Interpretation. Extensive Inward Mass Redistribution Not Seen at Low Te if Calculated Pellet Entry Coincides with Drop in Edge Te

During the Initial Phase of Pellet Ablation at Low Te Overlay of ECE Inferred Temperature and Calculated Pellet Arrival Times Show Little Evidence for Mass Redistribution Toward Larger Major Radius **If Entry Coincides with Drop in Edge Te**

Details of Core Deposition Obscured by Loss of ECE Signal

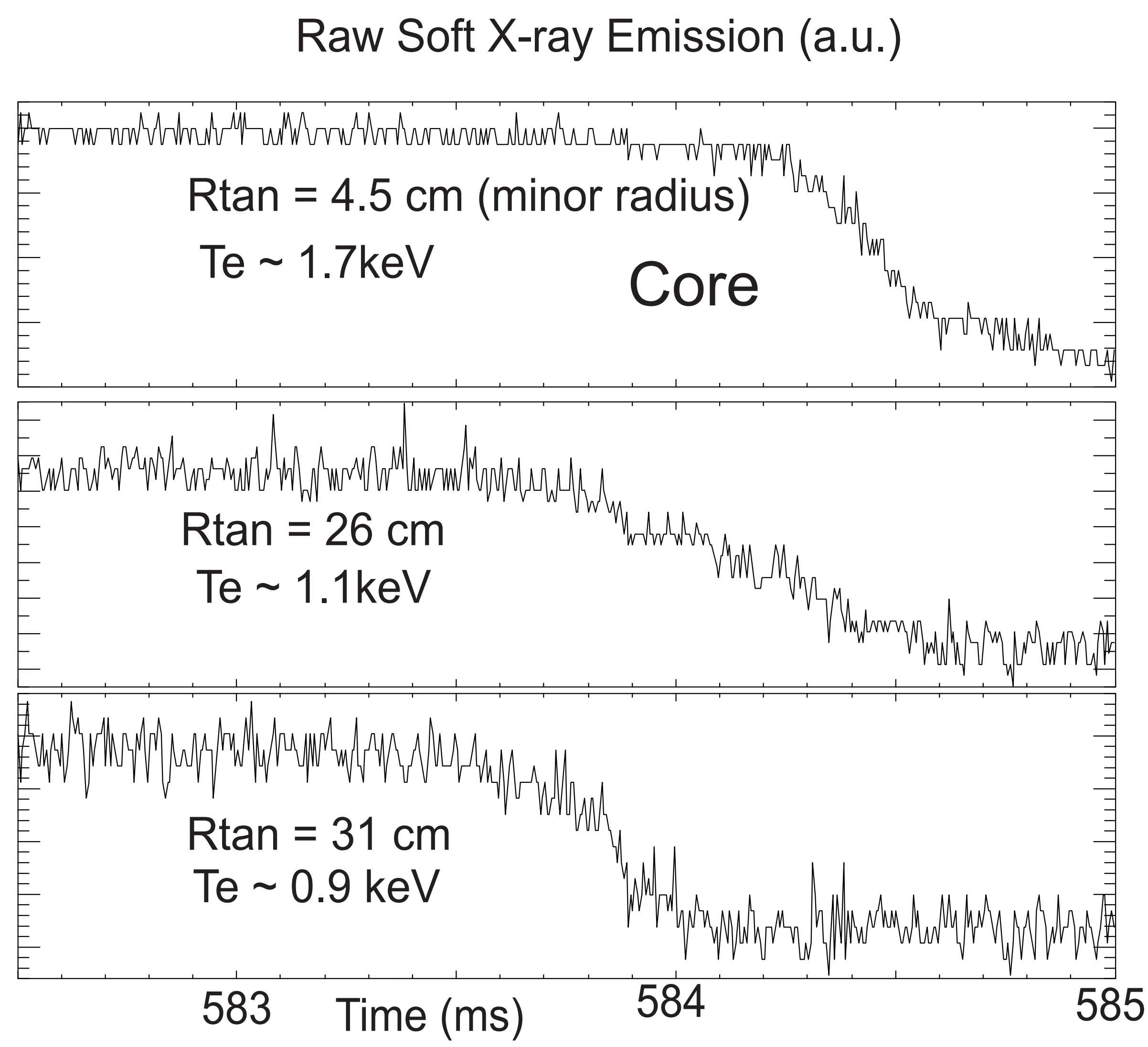
Extended Response of Te after Pellet (~300 s) Could Result from Finite Te Response Time and Finite Local Pellet Deposition Region



Core Pellet Perturbation can also be Studied With Soft X-Ray

Signals Indicate little loss of Core Te Until Late in Pellet Event - Similar to ECE Measurements

Drop in Core Signal Occurs Largely over 300   s Period at end of Pellet Ablation



CONCLUSIONS

ECE and Soft X-ray Systems Can be Used During Inside Launch Pellet Experiments to Infer Features of Pellet Mass Deposition from Changes in Electron Temperature

Timing of Pellet Entry Critical to Interpretation

For Single Case Studied Here (Low ne, Moderate Te Target Plasma)

Except Possibly at End of Ablation, Extensive Inward Mass Redistribution Not Seen During the Ablation Process IF Pellet Entry Taken to Coincide with Drop in Edge Te

Increased Pellet Shielding beyond that predicted by our ablation model should be considered to help explain apparent penetration depth greater than that calculated

Need for Study of Penetration and Redistribution for Inside Launch as a Function of Ablation Rate (Target Te and Ablatant   ) to Evaluate Onset Conditions for Mass Redistribution

Improved Ablation Light Monitor Near Plasma Edge Important to Confirm Pellet Entry Timing