Correlations of Dust Particles With Plasma Parameters in DIII–D

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Dust Measurements With The DIII-D Thomson system

Abstract. The first quantitative measurements of dust size and spatially localized number density during plasma discharges have been made in DIII-D. The particles are observed by Rayleigh/Mie scattering of ND:YAG lasers during plasma operations. The particles observed during discharges are significantly smaller (80 nm mean radius) than those injected for trajectory studies, observed by cameras and collected with wipes of the tiles after run campaigns. The small volume (0.2 cm^3) of each observation location and short laser pulse length provide a good localization of the dust in the tokamak. The observed dust particles do not penetrate into the plasma core and event rates inside the plasma edge are consistent with the neutron background rate. Studies of these particles show significant asymmetries in the dust densities for different plasma configurations. There is a significant increase in dust density with H-mode discharges relative to L-mode discharges. The dust density in H-mode discharges is sensitive to many parameters including the pedestal temperature and inner wall gap.

Overview

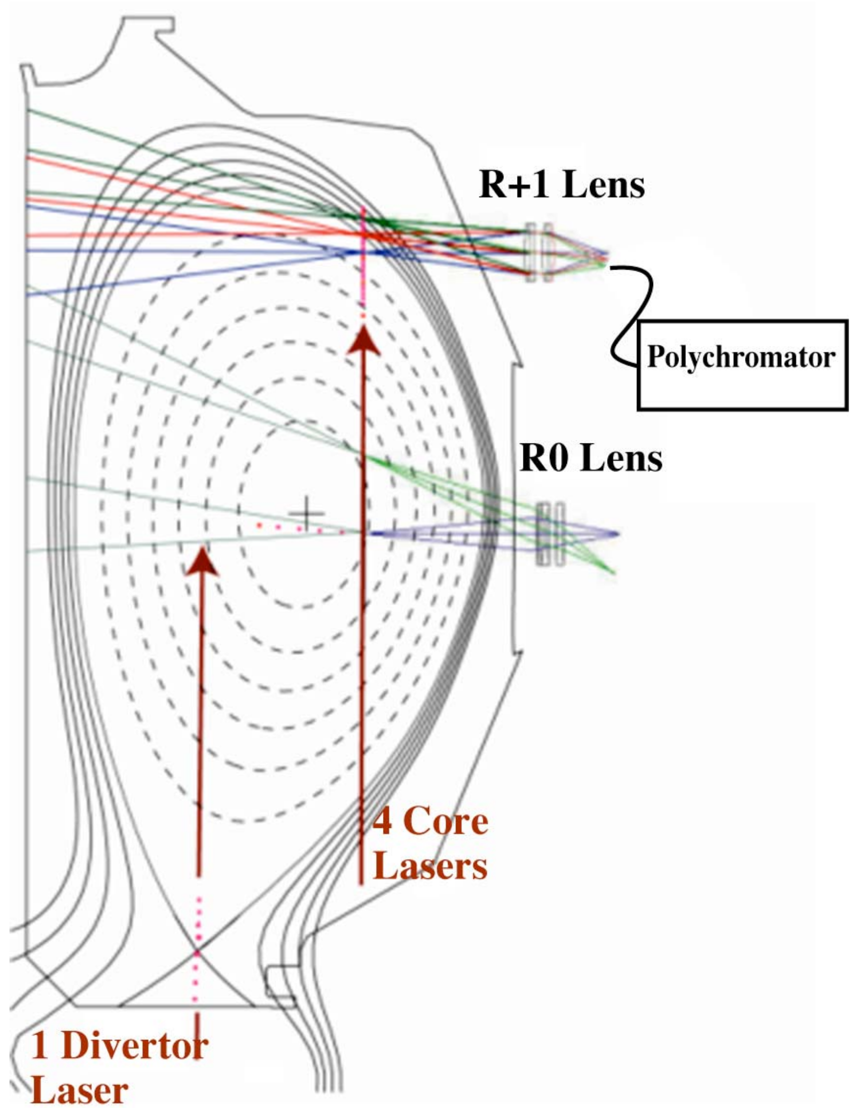
- Dust particles can be observed by Rayleigh/Mie scattering from the Thomson system lasers
- Average dust density of 4000 m^{-3} in the SOL
- Dust density is 3x as large in ELMy H-mode shots as in L-mode or QH-mode shots
- ELMy H-mode shots with high pedestal temperatures have large dust levels
- ELMy H-mode shots with small inner gaps have large dust levels while the dust level is not sensitive to the outer gap
- Likely removing codeposited layers from the vessel walls or divertor

DIII-D Provides Data On Dust Levels During Plasma Discharges

- **Dust observed in many magnetic fusion experiments**
- **Dust production and retention an important issue for ITER. Higher heat fluxes and longer discharges will produce large plasma wall interations**
- **DIII-D can measure dust densities in the plasma SOL**
- **Graphitic PFCs for study of dust production on important first wall material**
- **Observations during laser pulses allow the correlation of dust levels with plasma conditions**

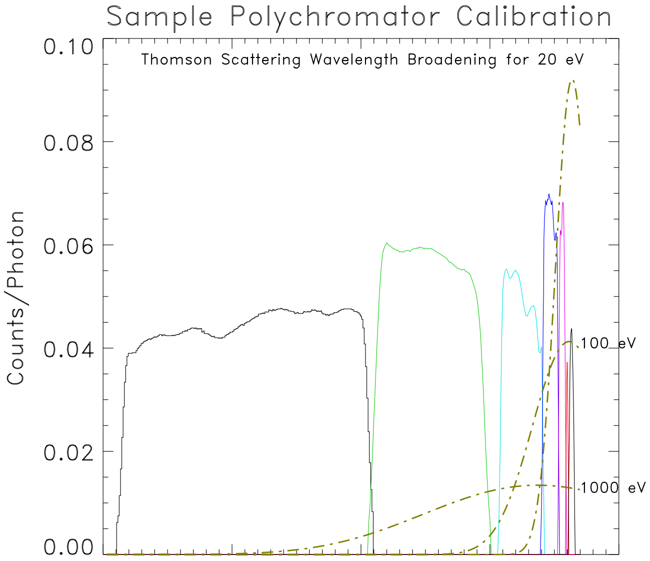
Thomson System Measures Electron Temperature and Density Throughout DIII-D

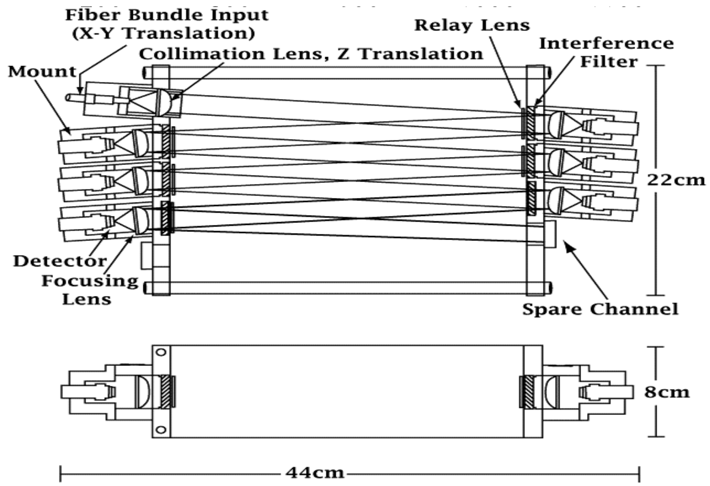
- Three paths through the vessel to cover from the center to the edge and the divertor
- Scattered light from the laser beams is imaged on arrays of fiber optics and transported to 44 polychromators which measure the temperature and density
- Core channels have overlapping viewing areas on the back wall which is used for rejection of background events from the wall



Thomson System Polychromators Contain a Channel Sensitive to the Laser Wavelength

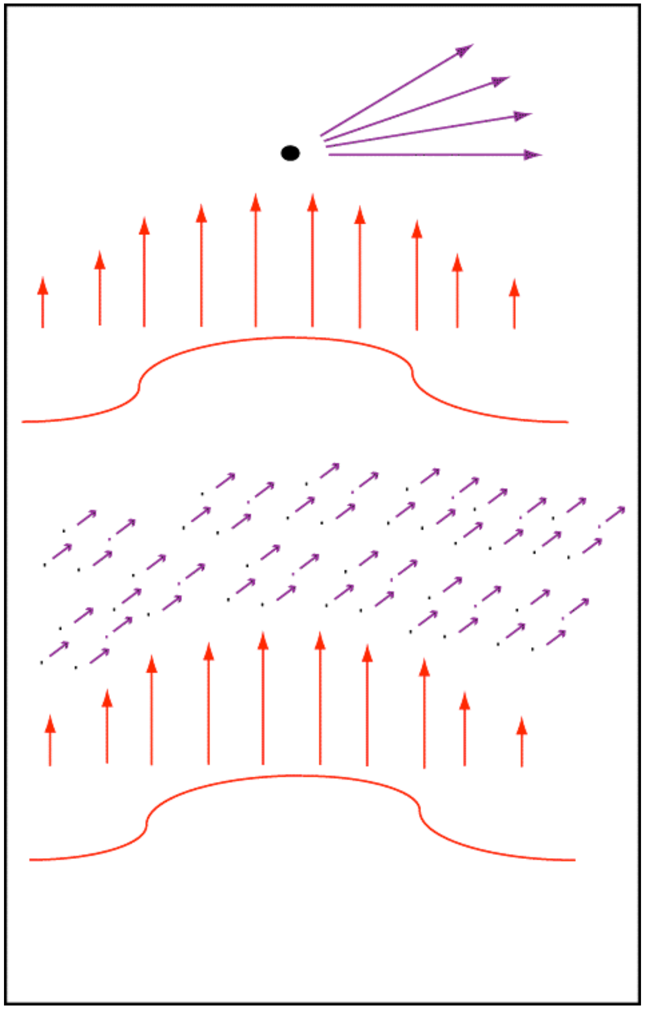
- **Polychromators contain 5 to 7 filters**
- **One bandpass filter at the laser wavelength (1064.3 nm) is used for dust detection**
- **Narrow 1062 nm channel used for low temperature plasmas in the divertor and edge of the core has a 10^2 to 10^4 rejection factor for YAG light**





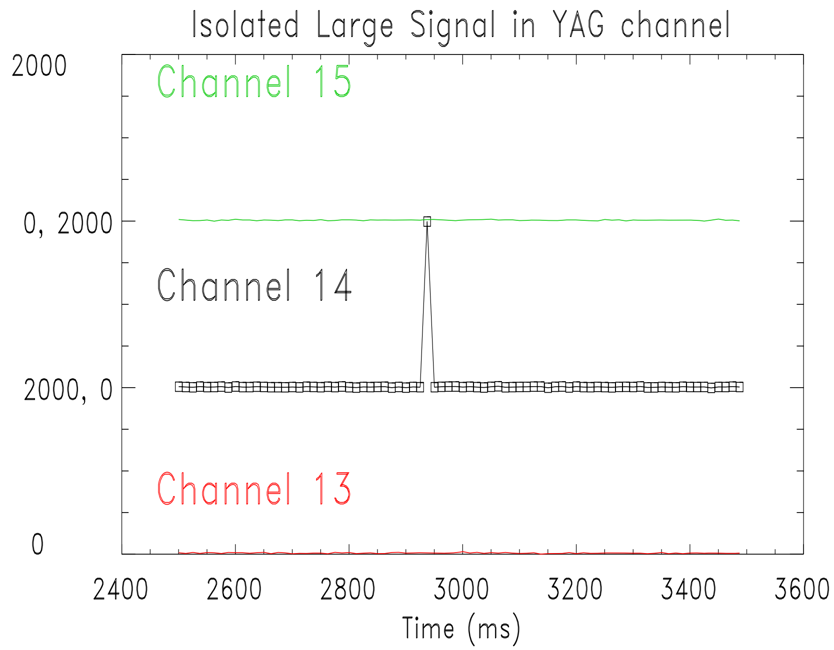
Dust Particles Produce Large Signals at the Laser Wavelength

- Consider a single large particle producing a signal equivalent to the Rayleigh scattering from 1 Torr of argon ($3.3\ 10^{16}\ cm^{-3}$ at 22°C)
- $\sigma_{Dust} = 10\pi/3 * k^4 a^6$
- Laser – Flat power profile Radius 0.15cm
- Scattering region 1 cm long
- 200cnts/Torr = 8.66×10^{-14}/ Ar atom
- σ_{Ar} -> a = 1.1A radius
- Size = $1.1\ (200/8.66\ 10^{-14})^{1/6}$
- Particle = 400 A = 40 nm radius



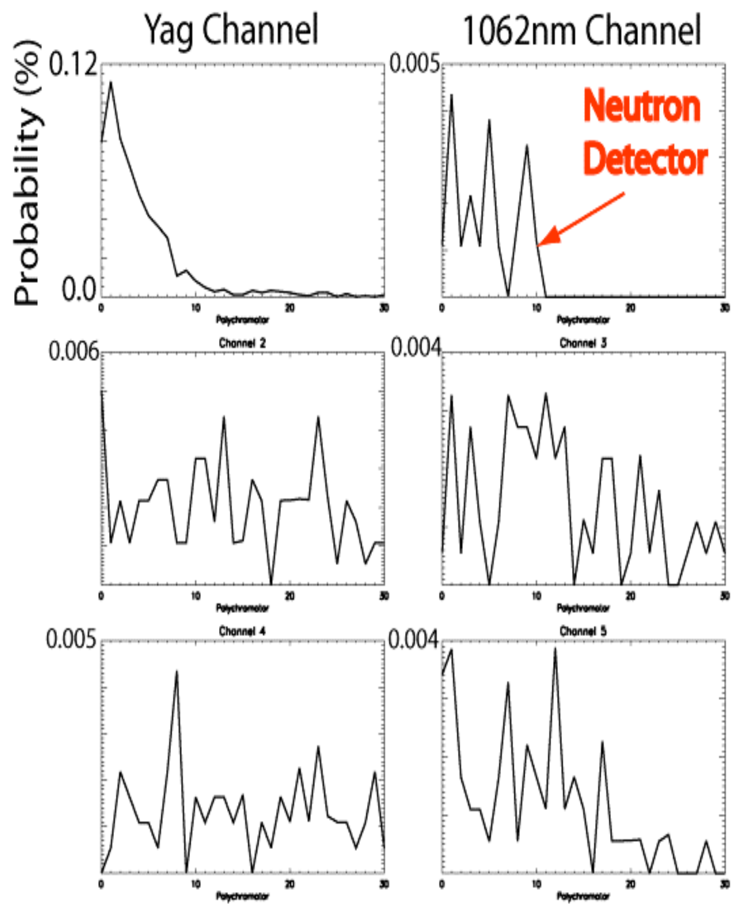
Selection Criteria For Scattering From Dust

- Look for large changes in signal compared to events before and after the candidate event
- Require large changes in signal with the same laser (stray light can vary significantly with laser parameters)
- Ignore events which show simultaneously in multiple channels
- Require low background light levels to eliminate saturation and high noise levels



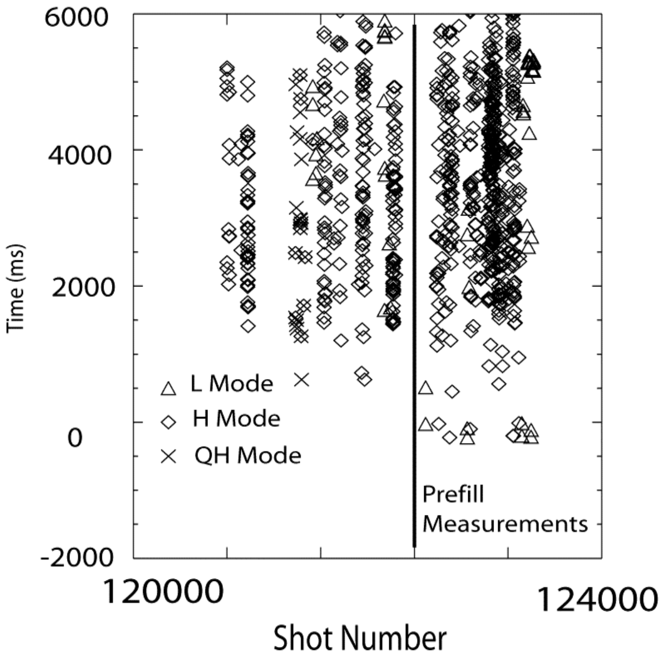
Neutron Induced Events Provide The Largest Background In The Dust Events

- Similar detector and electronics are mounted behind an opaque plate to monitor background
- Events are believed to be due to γ and n fluxes in the Thomson room
- Event rate on the “neutron” detector is similar to event rates in the center of plasma and on shifted wavelength channels
- Contributes a density of 10 m^{-3} on all detectors



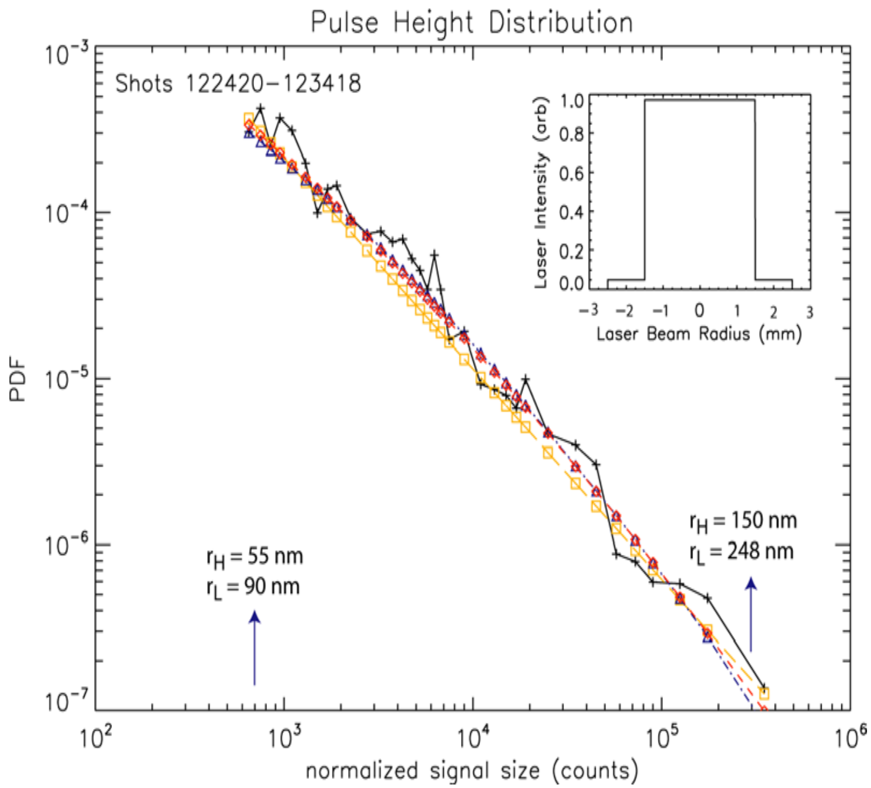
Dust Is Observed During Plasma Discharges

- **2500 events in 3630 discharges**
- **2005 campaign contains primarily USN H-mode with LSN L-mode and QH discharges**
- **Search for dust observed during breakdown at end of 2005 campaign**



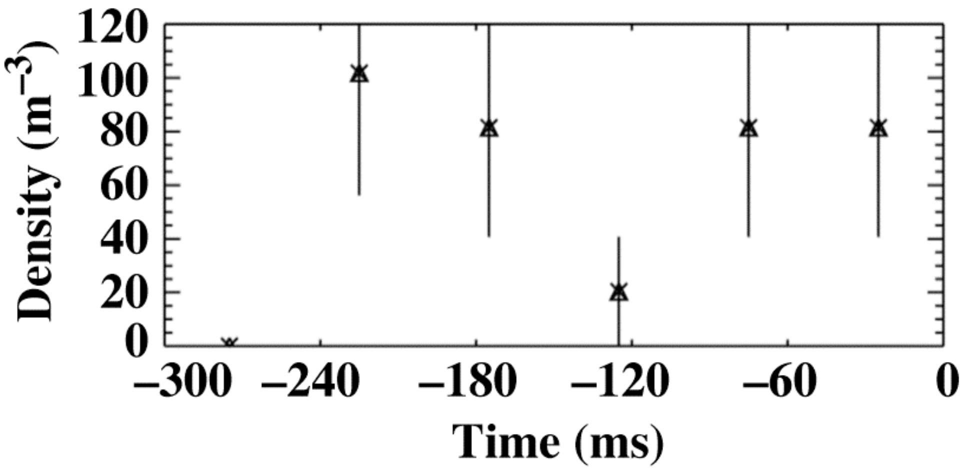
Estimates of the Particle Size Can Be Made From The Pulse Height

- **Measurements of the dust particle size have previously been reported (West PPCF 2006)**
- **Gaussian size distribution is convoluted with a top hat laser power profile to fit the observed spectra**
- **1062 nm filter is used to increase the dynamic range of the pulse height distribution**
- **Average dust particle radius of 80 nm is observed**



Little Dust Is Observed During Prefill and Breakdown

- Small gas injection (<1 mTorr) at -300 ms
- Little dust is disturbed by the injection and carbon has no effect on the breakdown phase
- Consistent with observations during argon calibrations
- Dust can be seen with argon (0.5 Torr) after vents and vessel entries
- No dust is seen with 3-5 Torr of argon during calibrations after operations but no vents

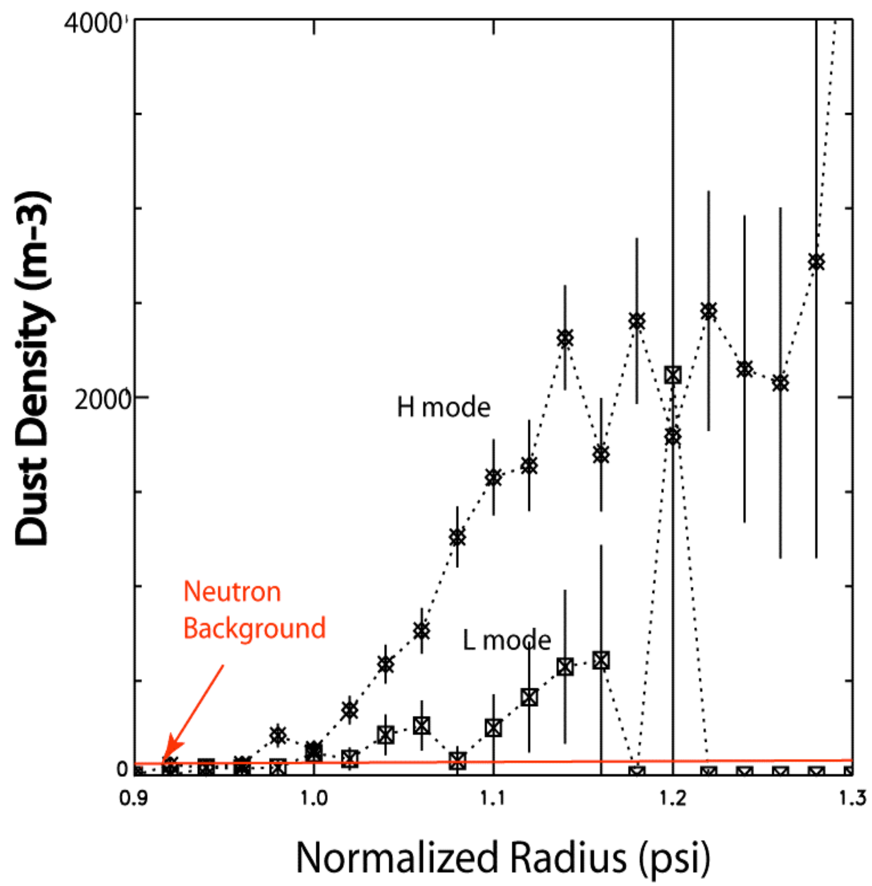


Searches For Dust After Disruptions Are Hampered By Systematic Problems

- **Vibrations of the machine after disruptions shake the baffle tubes designed to reduce stray YAG light in the machine**
- **Reflections from the tubes produce huge YAG light pulses in all polychromators**

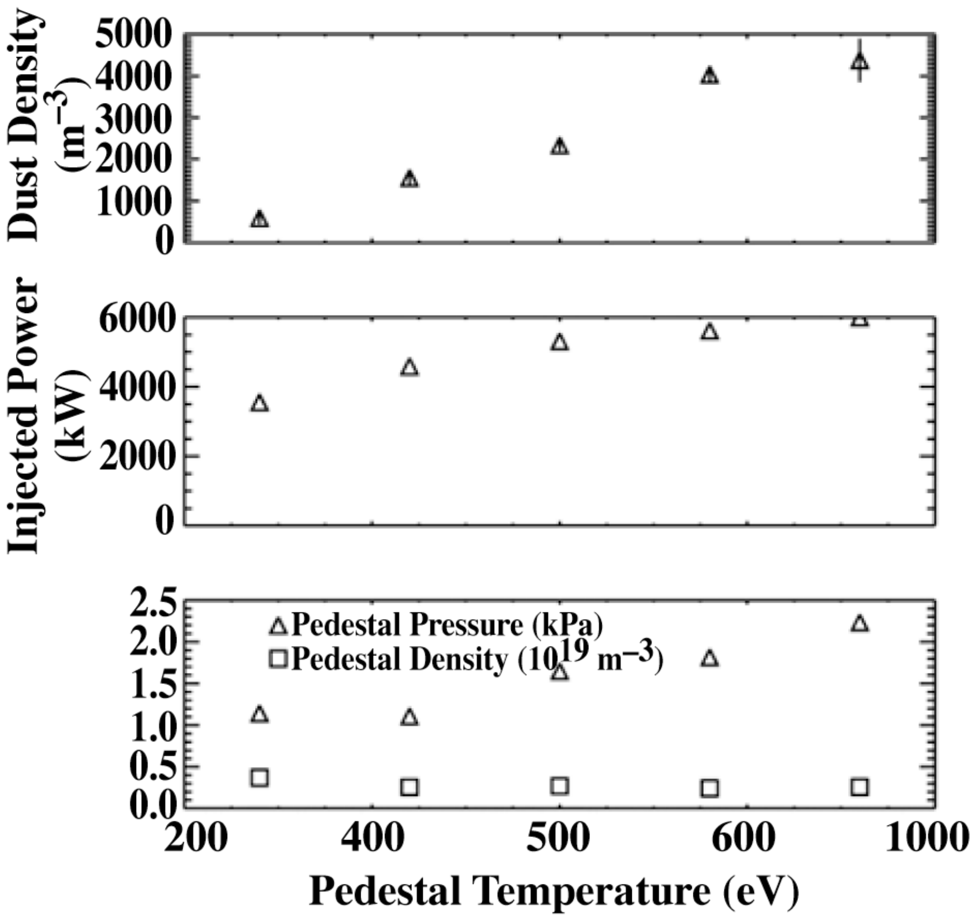
Dust Density Rises From the LCFS into the SOL

- Small residual rate inside the LCFS is equal to the observed neutron background rate
- Dust density is significantly larger during H-mode discharges than L-mode discharges
- ELM energy deposition is significantly below the carbon ablation threshold



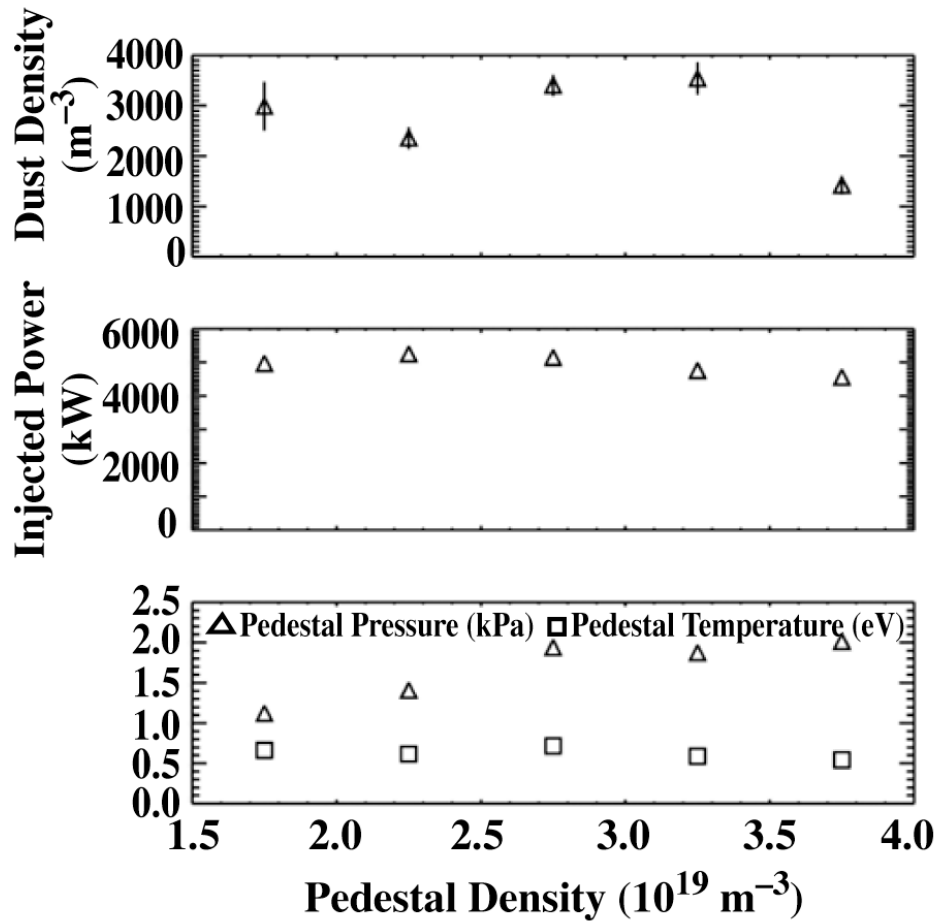
Dust Density Is Correlated With Pedestal Temperature In H-Mode Discharges

- **Pedestal temperature is correlated with collisionality and injected power**
- **Pedestal pressure and ELM energy fraction also increases with temperature**



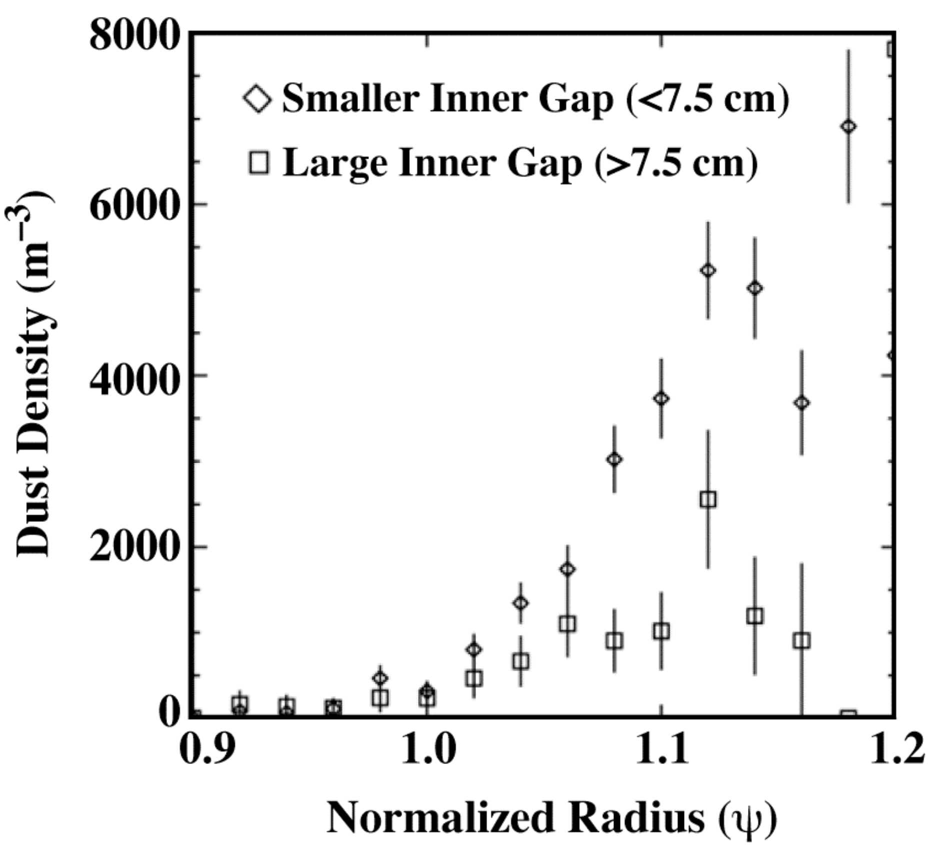
Dust Density Decreases For Very High Pedestal Densities

- **Dust density insensitive to pedestal density for moderate densities**
- **Very high pedestal densities produce smaller ELMs and have lower dust density**
- **Weak injected power dependence suggests injected power is not responsible for the increase in dust density with temperature**



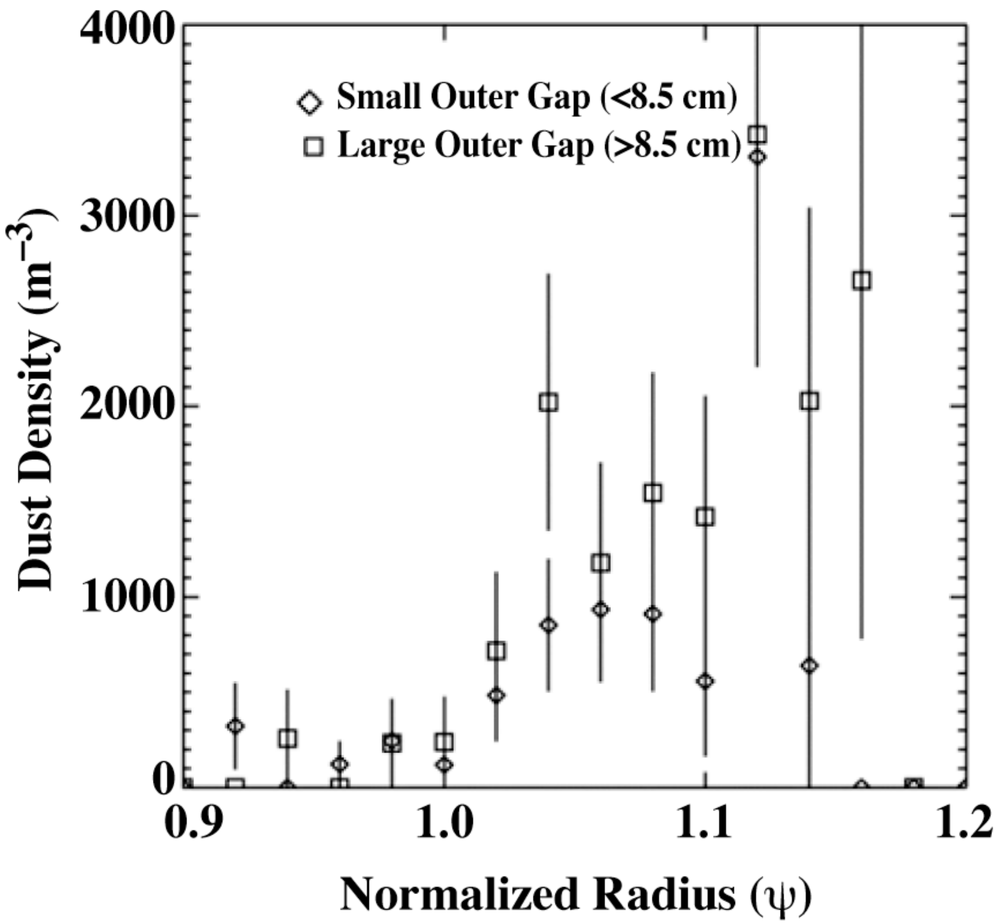
Small Inner Wall Gaps Correlated With Large Dust Densities

- H mode shots with small inner gaps have much higher dust densities than large inner gaps
- Small inner gap discharges also have much higher background light from inner wall suggesting interactions heating the tiles
- Small and large inner gap discharges have similar kappa distributions



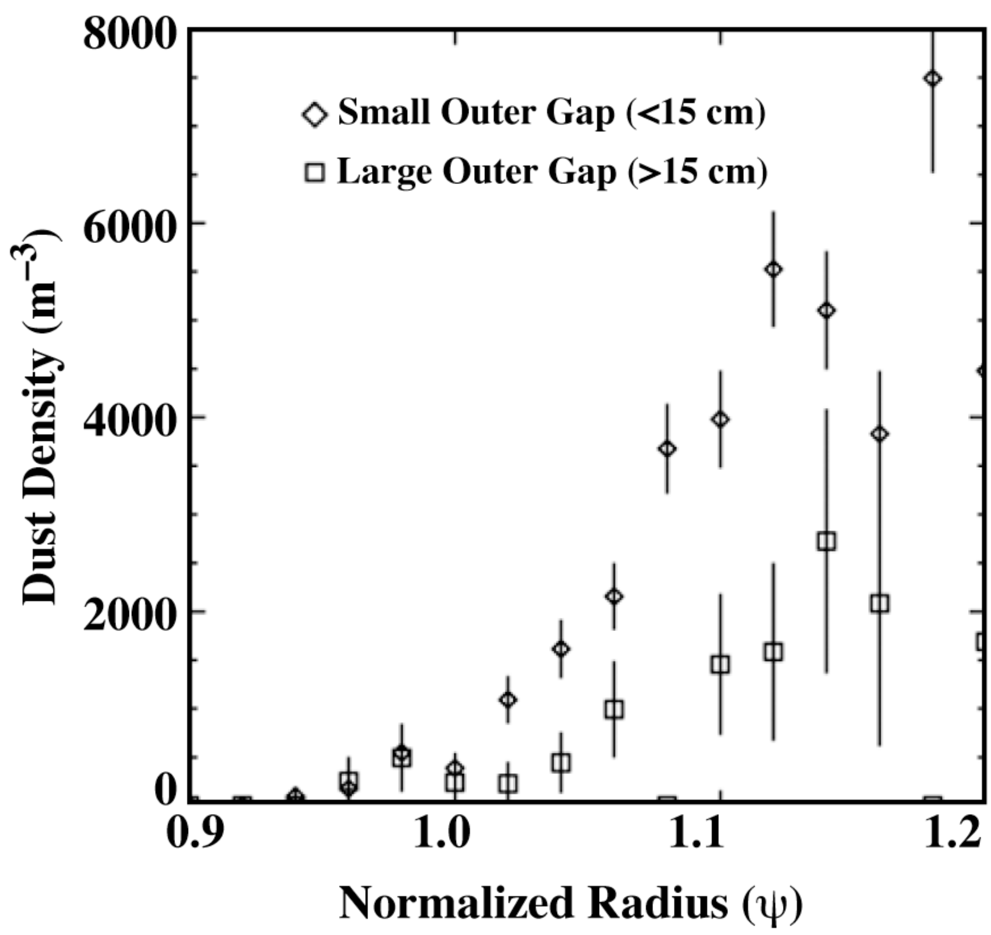
The Outer Wall Gap is Not As Significant

- **Power from ELM mostly travels to outer wall but dust density does not seem dependent on spacing between wall and plasma**



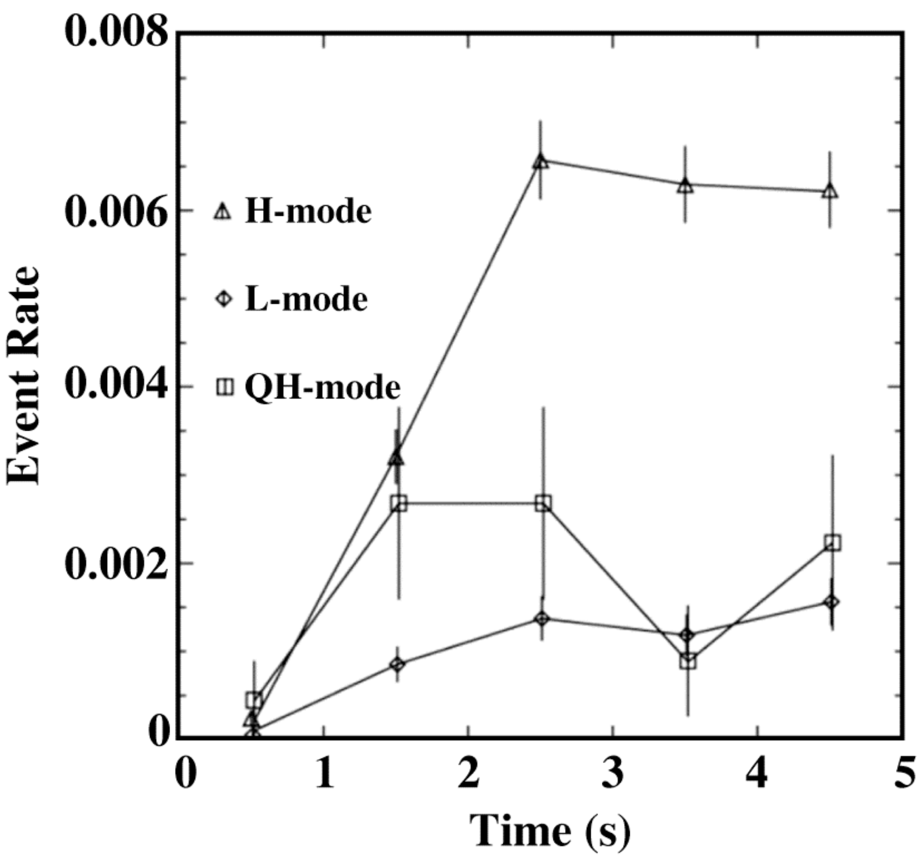
Upper Gap Sensitivity

- Small upper gaps give higher dust levels
- Observation position near the upper plenum
- May be local increase in dust levels
- Dust levels expected to be higher near production location



H-mode Plasmas Have Larger Event Rate Than L or QH Mode

- **Dust rate rises during the first two seconds of shot**
- **Dust levels are low at the start of the discharge and do not suddenly increase when the plasma is diverted**
- **Dust levels are low during L and QH-mode shots**
- **QH shots have high temperature pedestals and large injected power but dust rate is 5X higher in ELMy phases than ELM-free phases**



Summary

- Dust is observed during plasma discharges in the SOL at DIII-D
- Dust is not observed inside the LCFS but dust densities rise in the SOL
- Dust much more prevalent during H-mode discharges than QH or L modes
- Little carbon is present during breakdown or disturbed by injecting gas into the vessel
- Dust levels rise during first few seconds of discharges
- Dust levels of 4000 m^{-3} contain too little carbon to fuel the carbon contamination in the plasma
- Higher edge pedestal temperatures correlated with larger dust levels
- Dust densities increase for shots with smaller inner gaps
- ELMs likely producing increased dust from codeposited layers
- Graphite ablation threshold poor energy limit for dust production