Mobile dust particle trajectories in NSTX

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Abstract

The transport of dust in plasmas may play a significant role in the performance of next-step fusion devices. [1]. Highly mobile incandescent dust particles are routinely observed on NSTX using fast visible cameras. The dynamics of the dust trajectories can be quite complex exhibiting a large variation in both speed (10-200m/s) and direction. Particles may have constant velocities or exhibit various degrees of acceleration or deceleration. Abrupt reversals in direction are sometimes observed while some of the larger particles are seen to break apart during mid-flight. Measurements of dust trajectories taken simultaneously from two observations points with two different fast cameras are being used to derive 3D trajectories of the dust particles. Experimental results will be presented along with preliminary comparisons of the motion of the dust with DUSTT[2] calculations.

[1] S.I. Krasheninnikov, Y. Tomita, R.D. Smirnov, R. K. Janev, Phys. Plasmas 11 (2004) 3141
[2] A. Yu. Pigarov et al., to be published in Physics of Plasmas (December 2005)

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Main dust-related issues in fusion

Safety:

DIIID port (see the word “DUST” written by dust)

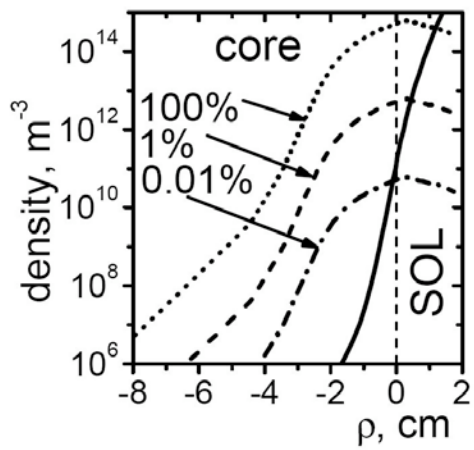
- tritium inventory
- explosion risk in the case of LOVA or LOCA
- chemical/radioactive hazards

- Dust is very mobile
- Dust spreads all over the tokamak and accumulates.
-For a year of ITER operation, dust inventory in pumping duct can be kilograms.
-1kg C dust=2.6 kg TNT

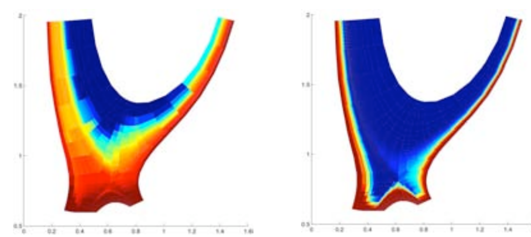
Tokamak Operation:

- transport and ablation of dust is a source of impurities advanced toward core plasma
- material migration
- surface modification
- tools to control dust inventory

Even small amounts of dust can substantially advance impurity ion source toward the core plasma



DUSTT/UEDGE modelling for NSTX.



With dust   Without dust

Density profiles of impurity atoms in outer midplane region originated from wall sputtering (solid) and from dust (broken) for different impurity-to-dust conversion efficiency.

Plasma Diagnostics:

- plasma flows, turbulence (blobs), ELM dynamics

Modelling capabilities:

V&V, DUSTT+UEDGE+safety codes

Why Study Dust?

- Dust migrates to diagnostic mirrors and view ports, and can "blind" sensitive diagnostics.
- Mobile dust will enter the main chamber as an impurity.
- Plasma profiles can be affected by large quantities of charged dust particles.
- Need to develop operating scenarios that mitigate erosion by controlling events that create dust such as large ELMS and disruptions.
- 'Loss of Vacuum' accident could contaminate surrounding area with tritiated dust. Dust may also be explosive under certain conditions.
- Modeling of the dust dynamics will allow greater predictability of the above effects for next-step devices.

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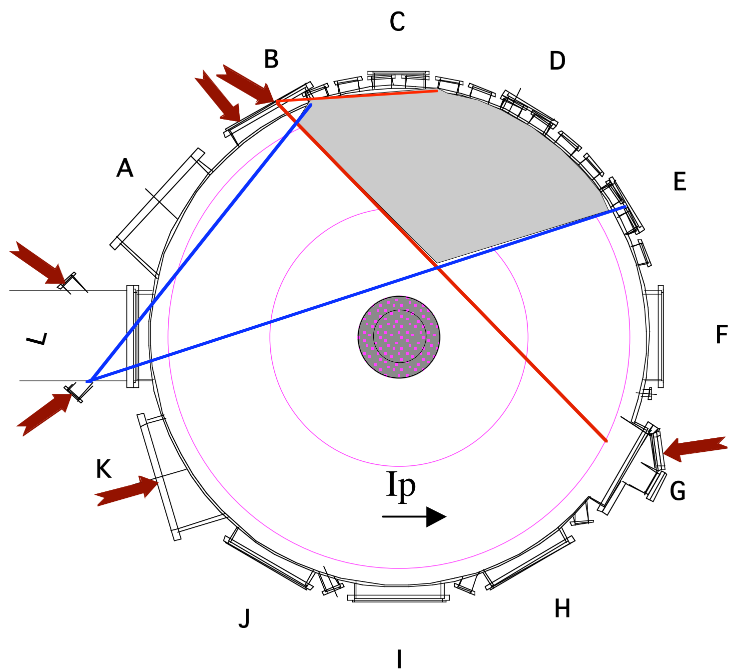
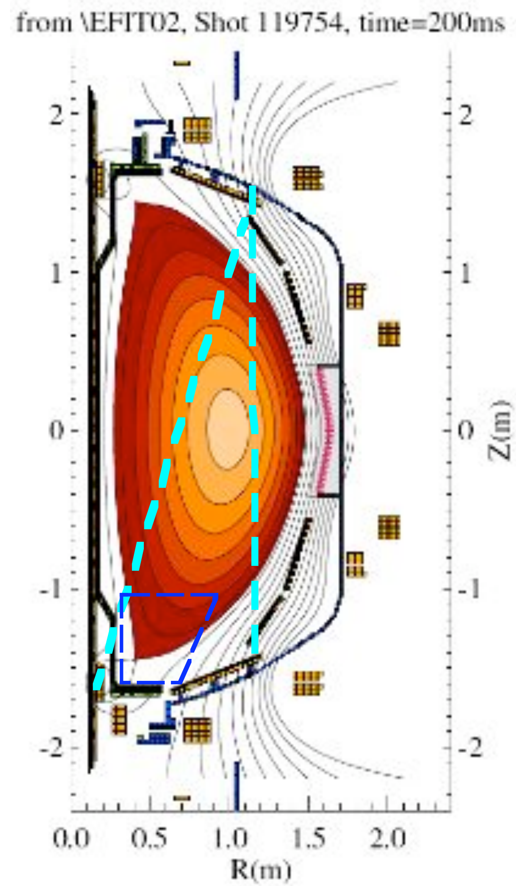
Fig 1a.

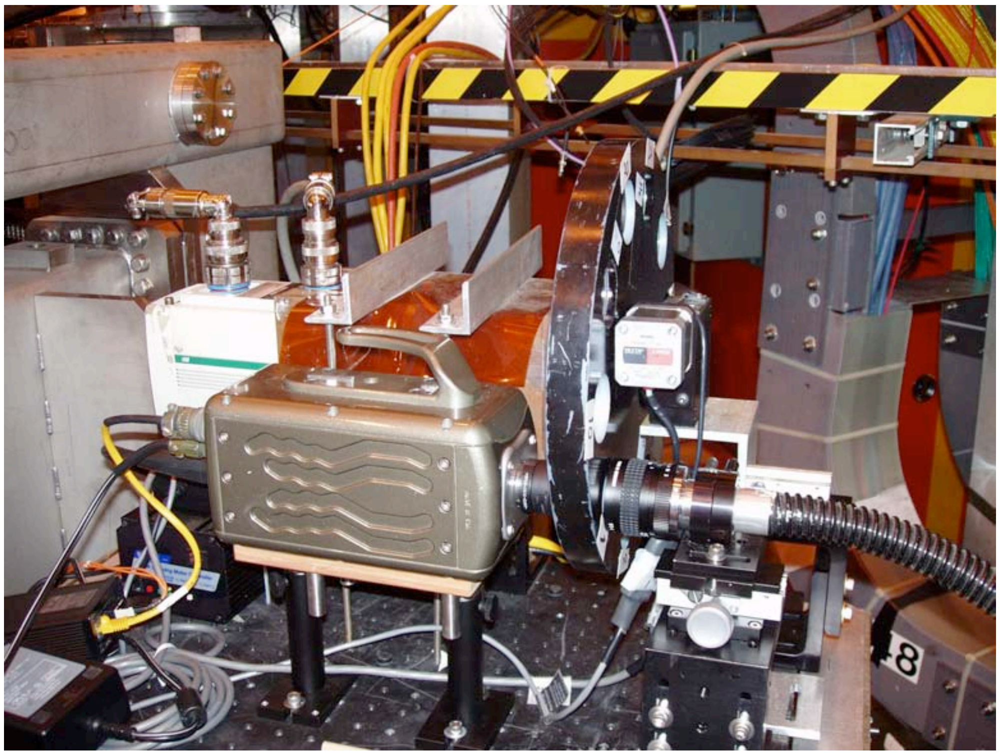
Camera Views on NSTX





Six tangential views on or near the midplane(above)
One tangential divertor view (right)
One vertical divertor view(right)

Phantom 7 Ultra high-speed camera



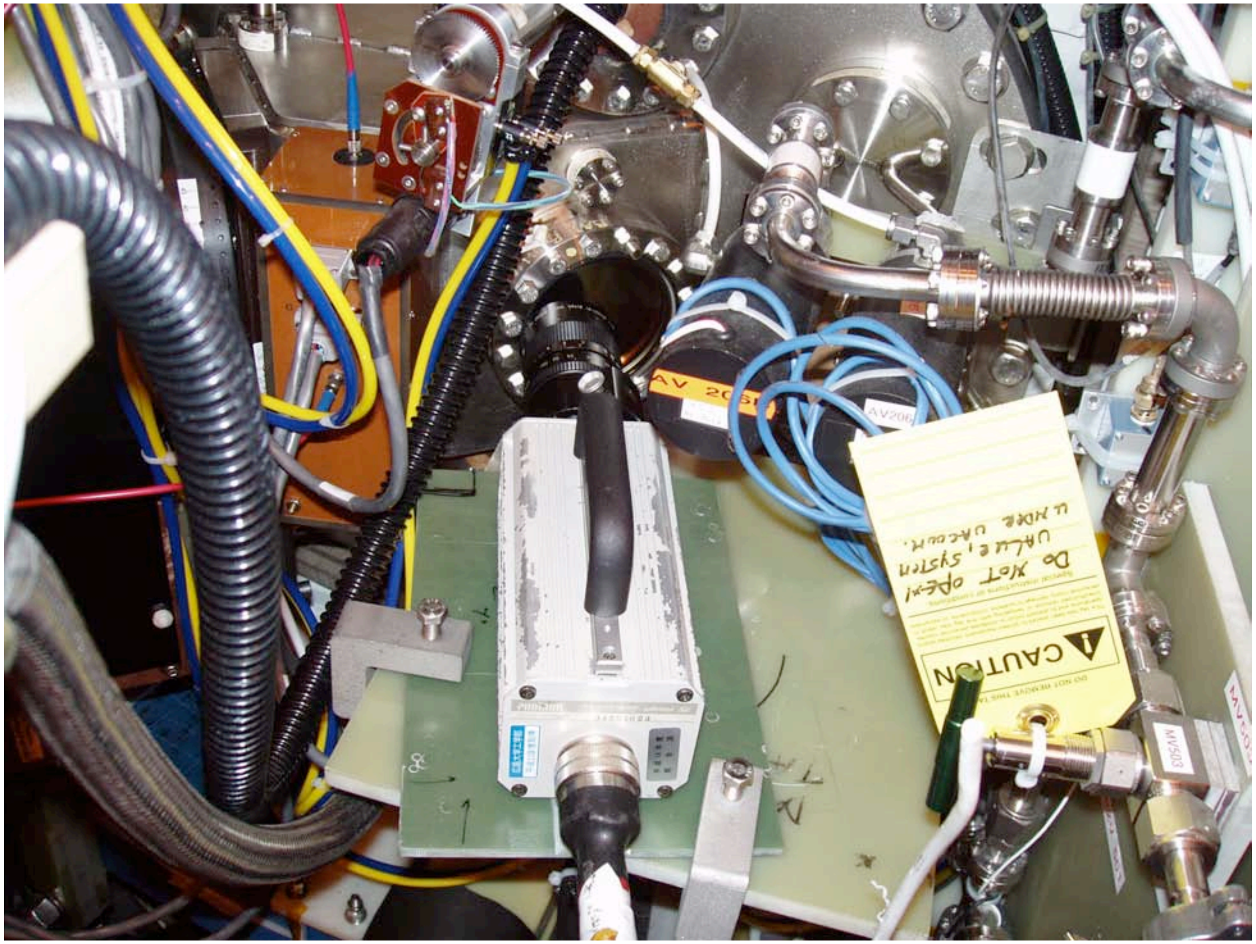
•SR-CMOS

•Most often operated at 68000 frames per second

•Requires FO coupling to prevent B-fld damage
to onboard camera computer.

•Camera has been applied to the divertor as an ELM diagnostic and in the mid-plane region to study Li pellet injection, super sonic gas injection, MARFESBLOBS in the
SOL as well as a dust detector

Photron Camera mounted at Bay B mid plane



•Typically operated at 2250-13500 fps to view dust.

•Slower Speed required in order to have enough light to see small particles.

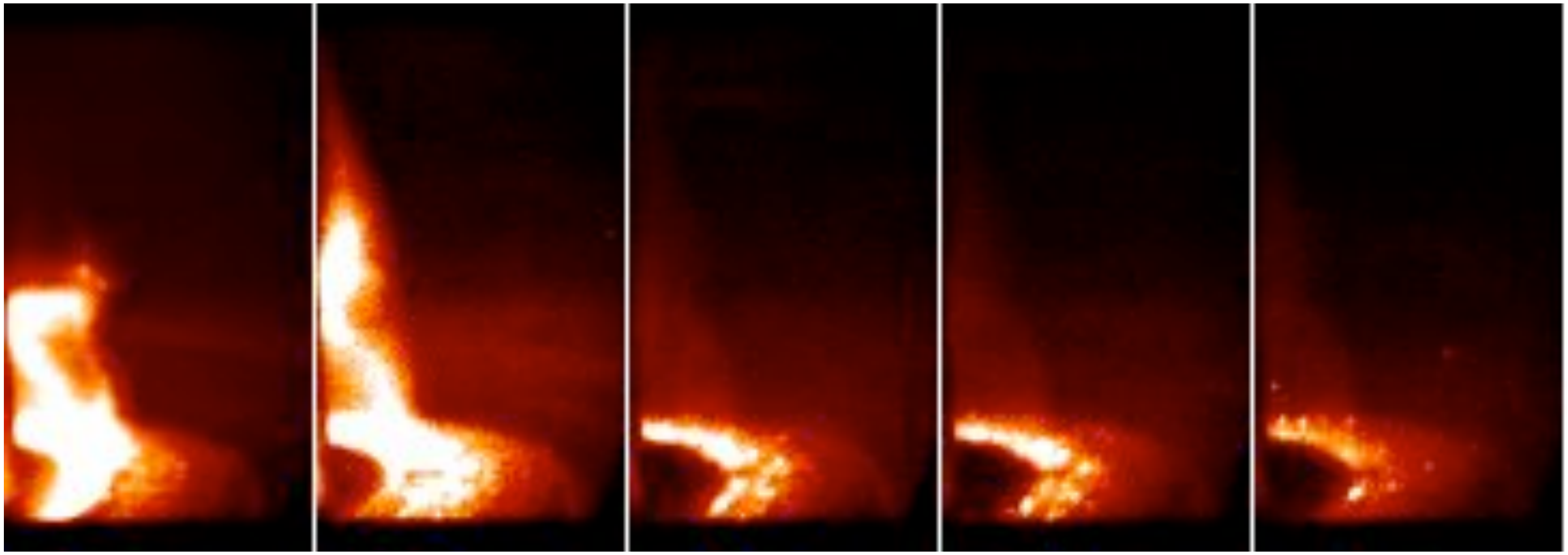
•Immune to B-field effects

Bay L Kodak Camera

- Typically operated between 250 -500 fps with 300 μs exposure time.
- Camera is too slow to capture fast dust particles. Upgrades are being discussed.
- Minimum required speed is 2000 fps but desire to operate at 10-20 times faster.

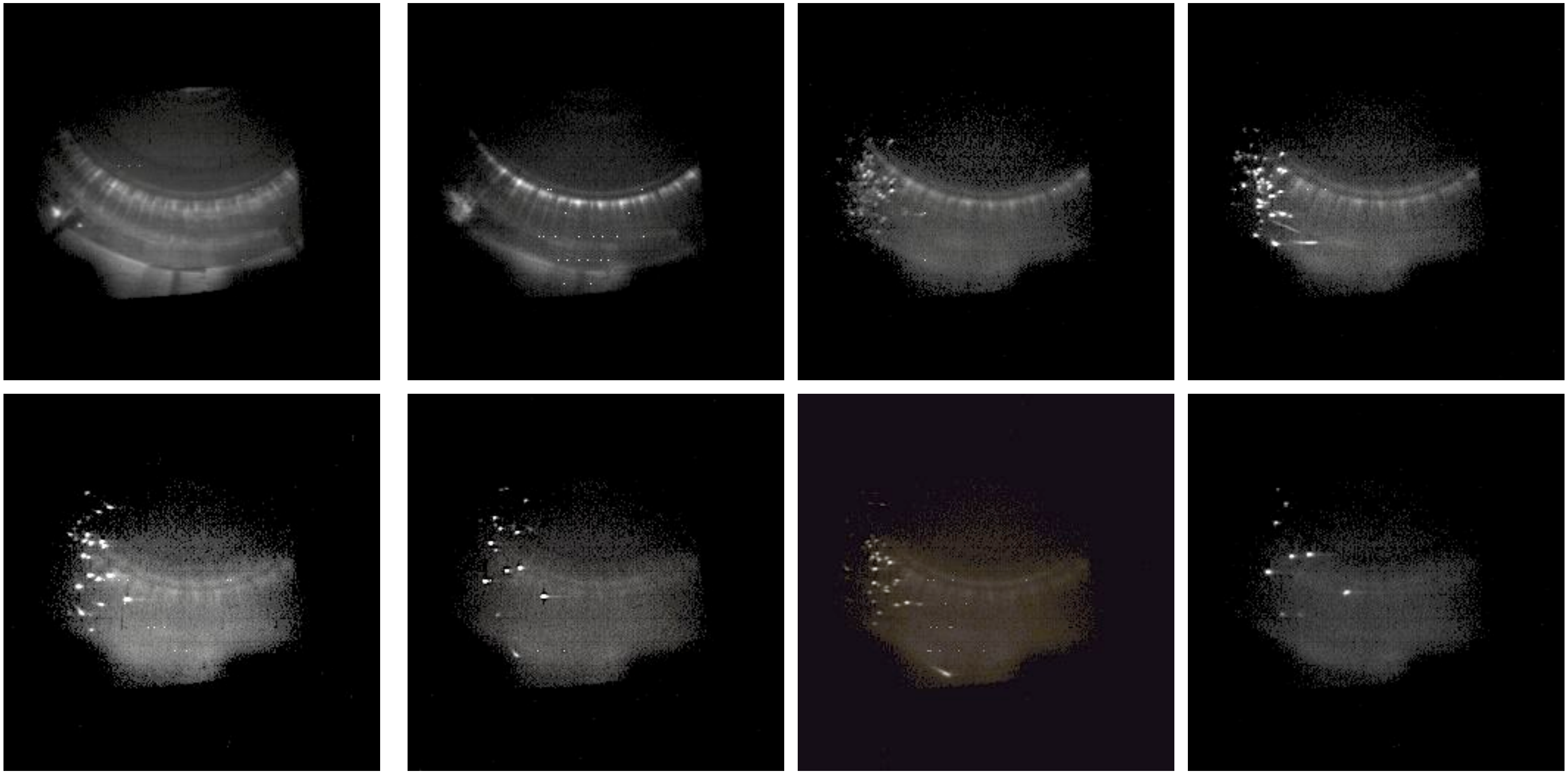
SOURCES OF DUST

Dust creation by ablation during Large ELM



Cascade of dust particles caused by Type I ELM.
Initial dust has almost total toroidal motion
Motion is in direction of flow at outer strike point
Centrifugal force causes particles to move radially.
(See associated movie)

Hot Spots may form at the end of a discharge



At the end of a discharge hot spots may form on the PFC's and eject a plume of particles. The Photron camera records the event at 4500 fps

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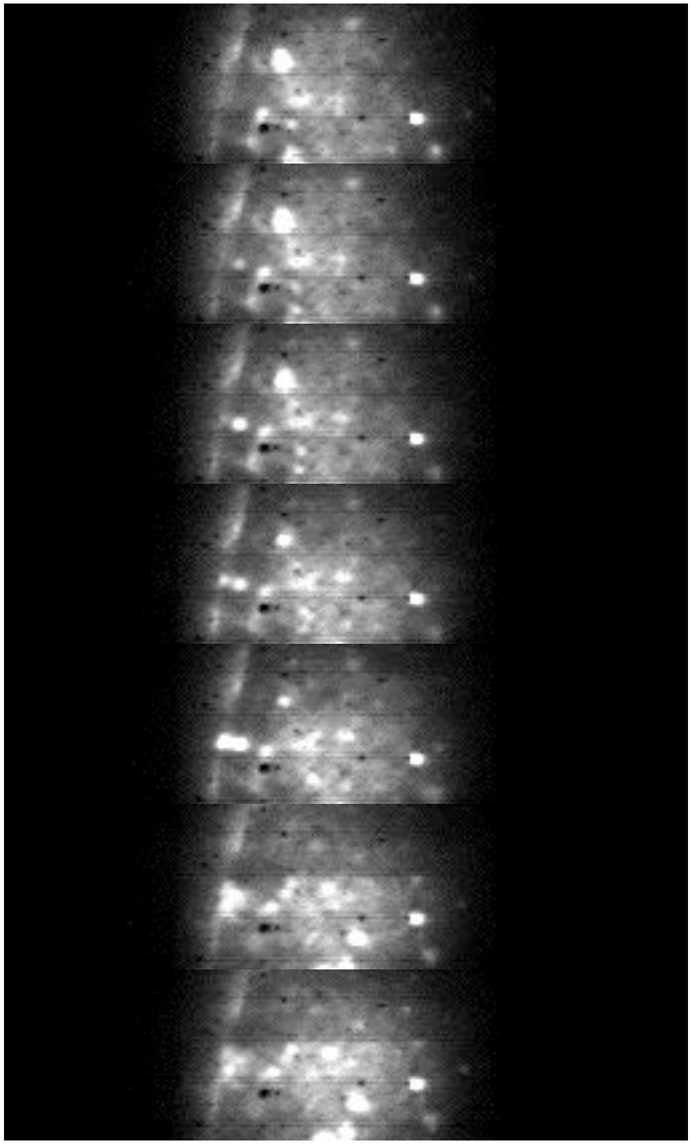
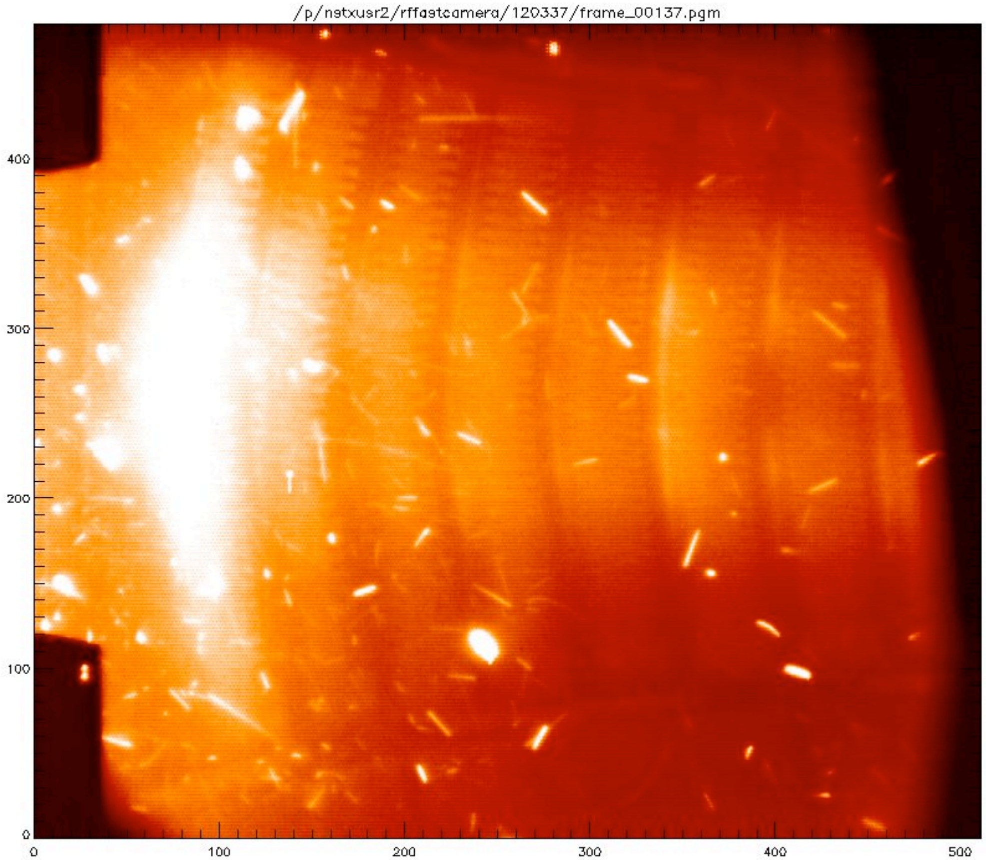
Injected Dust



•Li dust is injected from the impurity pellet injector. The pellet ablates and particles are trapped in the sheath.

•In the ‘07’ operating period a hypervelocity dust injector is being installed on NSTX to inject up to 50 micron sized dust particles at speeds up to 30 km/s.

Dust Particles in NSTX after a disruption



Disruptions fill the NSTX vessel with high-speed dust particles. This effect will be magnified by ~100 for next- step machines such as ITER.

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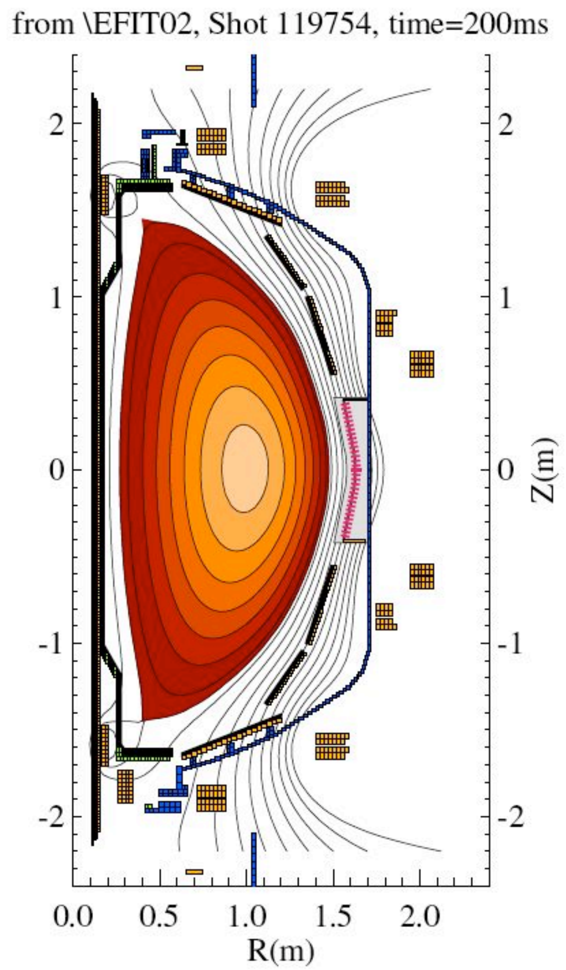
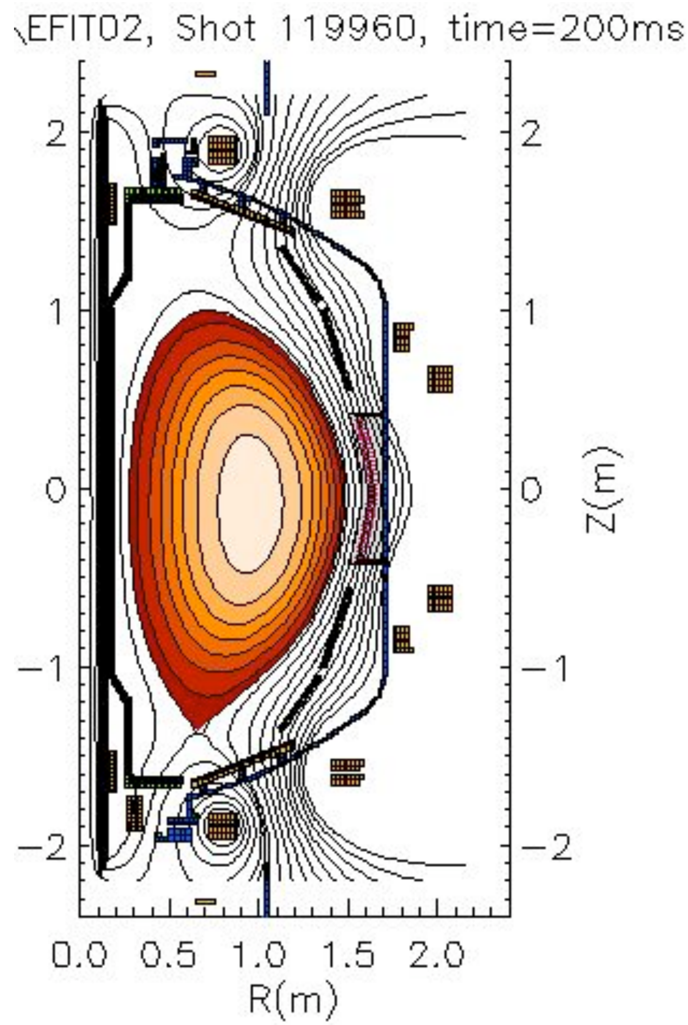
Results

Strike point configurations

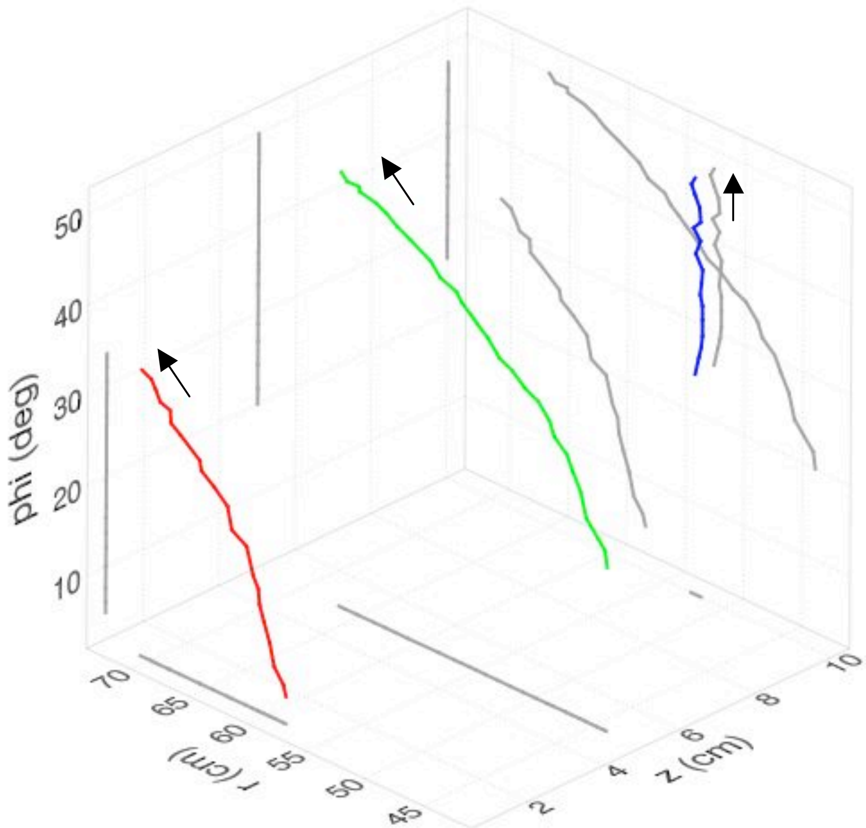


Clockwise particle rotation outboard of outer strike point



CCW motion for dust particles inside inner strike point

3-D trajectories of representative dust particles in the lower divertor of NSTX

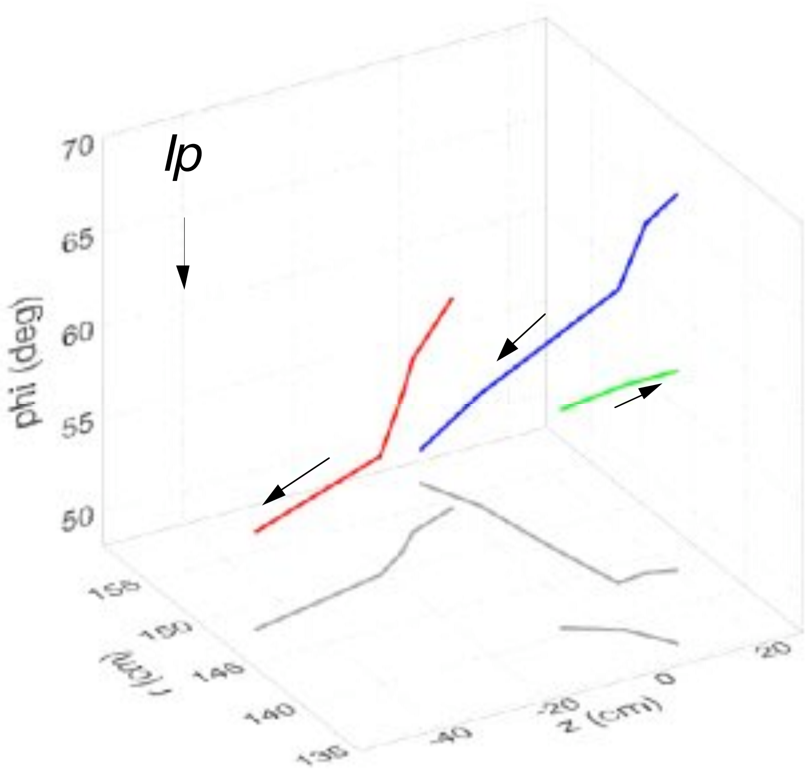


•The majority of dust particles hug the divertor plates so that the vertical component is constant.

•Newly spawned particles in the lower divertor tend to have the largest toroidal Component

•Toroidal motion is in the direction of parallel plasma flow. On NSTX this is clock wise outside the outer strike point and CCW inside of the inner strike point.

Main Chamber Particle Trajectories



•Main chamber particles most often move in the co direction.
Plasma boundary is at 143 for this shot.

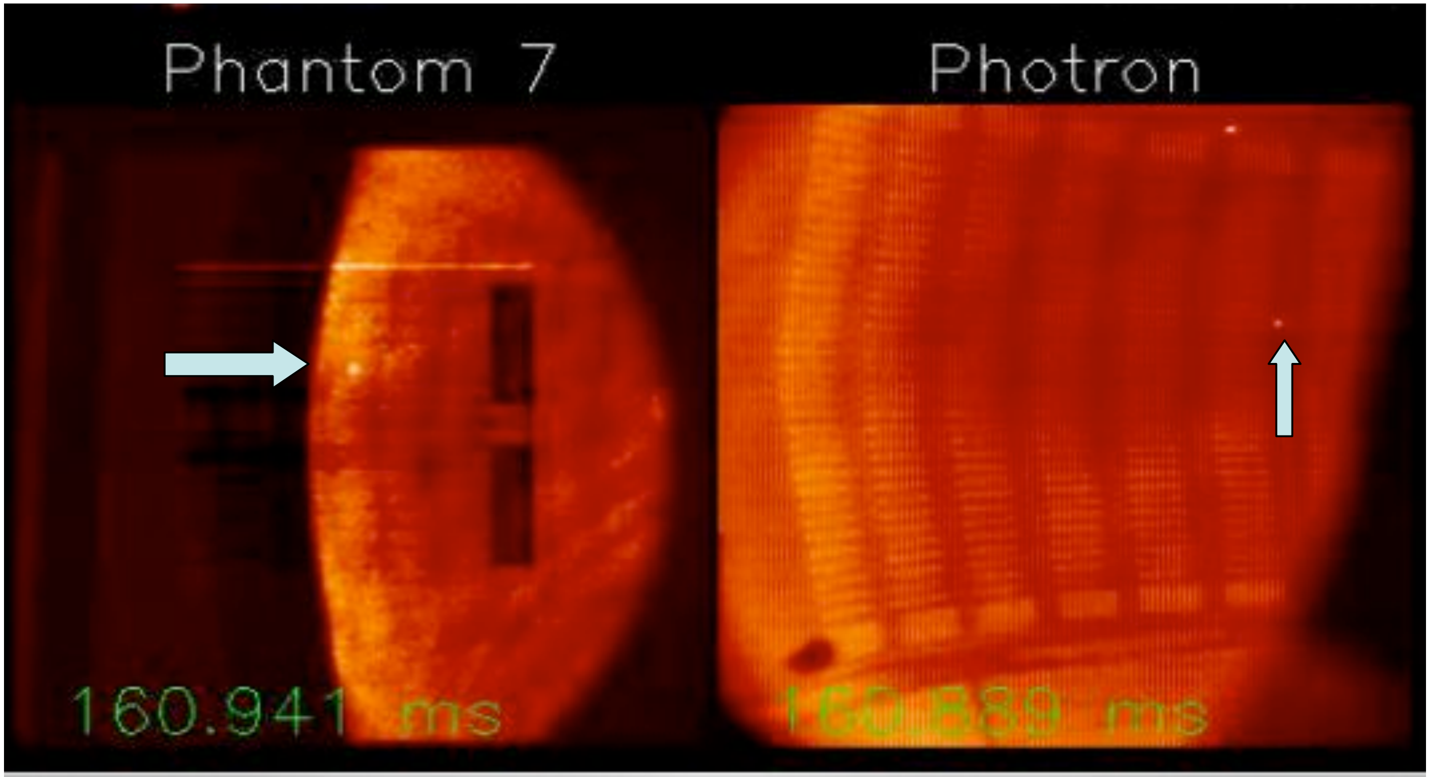
•Analyzed data is presently obtained for slow particles only using Kodak and Photron camera.

• Data using the Phantom 7 and Photron is presently being analyzed. (see movies).

•Particles do not appear to pass through the plasma edge. The are either deflected or vaporized.

•Most probable motion is in the direction of Ip and perpendicular to the magnetic field indicating the existence of an electric field.

Simultaneous particle tracking using two cameras



Bay B view

Bay L view

(see associated movie)

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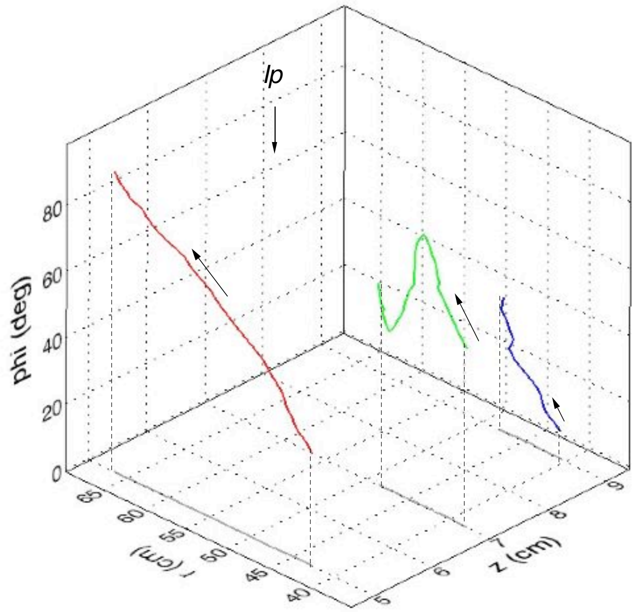
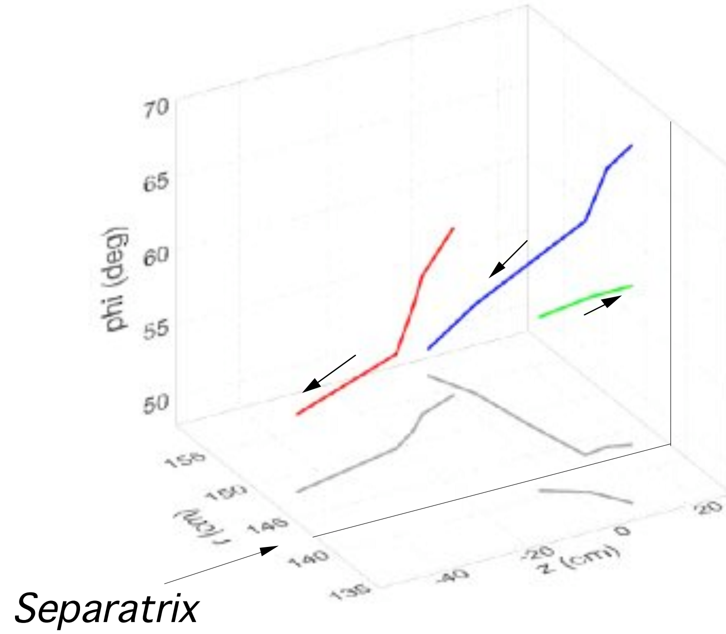
3D trajectories of divertor and main chamber dust particles





Divertor particle trajectories
Center stack radius *R*= 28 cm
(See movies)

Midplane particles
Separatrix at *R*=143cm
(See Movies)

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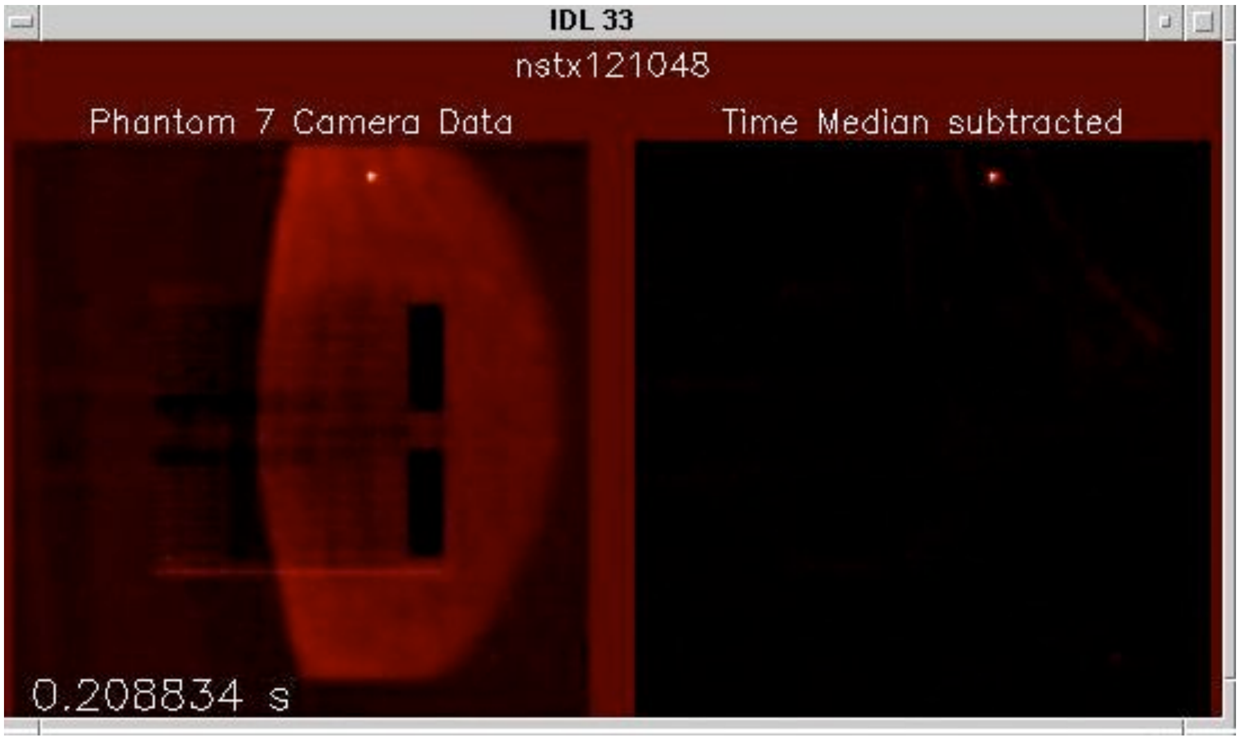
Observation of dust particles is enhanced by background and time median subtraction



- Background is average of first 10 camera frames.
- Subtract this from all subsequent frames.
- Select time window of ± 0.5ms
  around each frame.
- Take median value of this time window.
- Subtract median from each frame.
- Dim particles can be more easily observed with this method.

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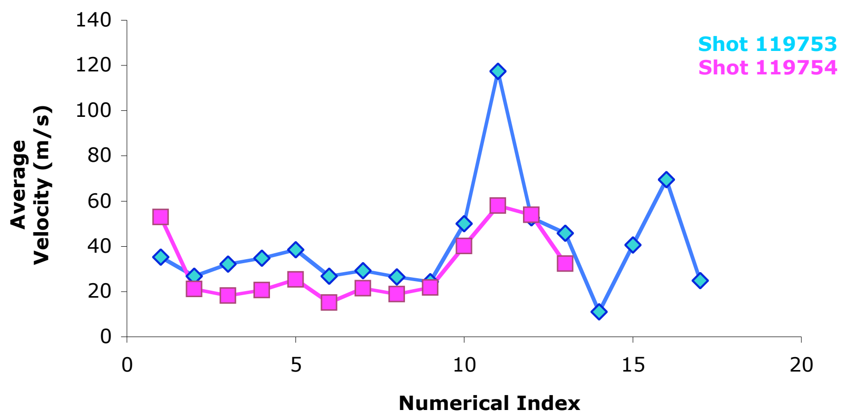
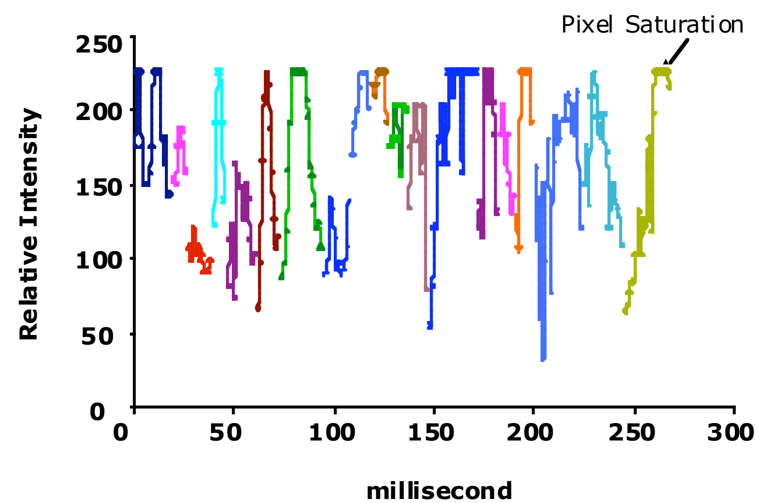
Divertor Particle Characteristics





Particle velocities averaged over lifetime

Frame by frame variation in the particle intensity using a near-IR filter

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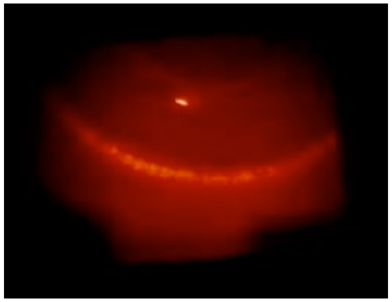
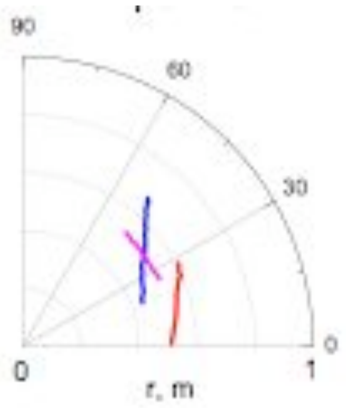
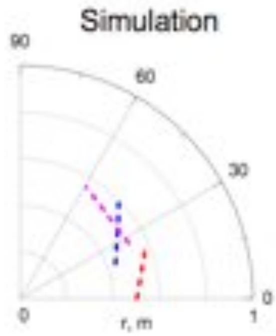
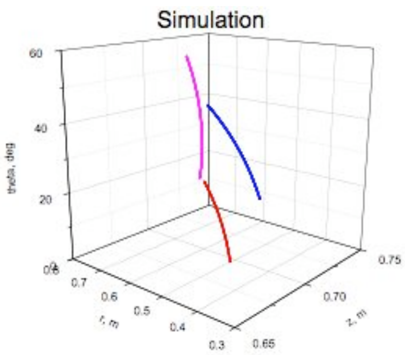
Comparison of observed particle trajectories with simulations from DUSTT









Results from fast camera views

Results from DUSTT

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Conclusions

- 3-D imaging of dust particles using two cameras has been accomplished for main chamber and lower divertor particles. Only low energy particles have been analyzed in the main chamber.
- Work is in progress to analyze recent data from the two fastest cameras.
- Image processing has been successfully applied.
- Velocity and light emission with time are obtained
- Improvements to the cameras and better access to the vessel view ports is in process.
- First results of modeling with DUSTT have been obtained for the lower divertor