Dust trajectories in the National Spherical Torus Experiment

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ABSTRACT

Production of dust particles is a common occurrence in nuclear fusion reactors of today. Studying the behavior of these dust particles during plasma discharges within the reactor may facilitate in improving present and future fusion reactors for research and widespread commercial energy purposes. In the current study, dust particle trajectories were recreated using data from the National Spherical Torus Experiment (NSTX) at the Princeton Plasma Physics Laboratory (PPPL). Dust particles were observed via two high speed cameras. Three dimensional trajectories of individual particles were reconstructed using a series of python codes. A crucial part of the analysis was the calibration and determination of the transformation functions from the camera to the NSTX reference frame. Due to the complex method involved in recreating these tracks, only 1 track from both shot 130376 and 130377 were recreated thus far. This was the first step to a complete analysis of all the data taken with these camera views.

INTRODUCTION

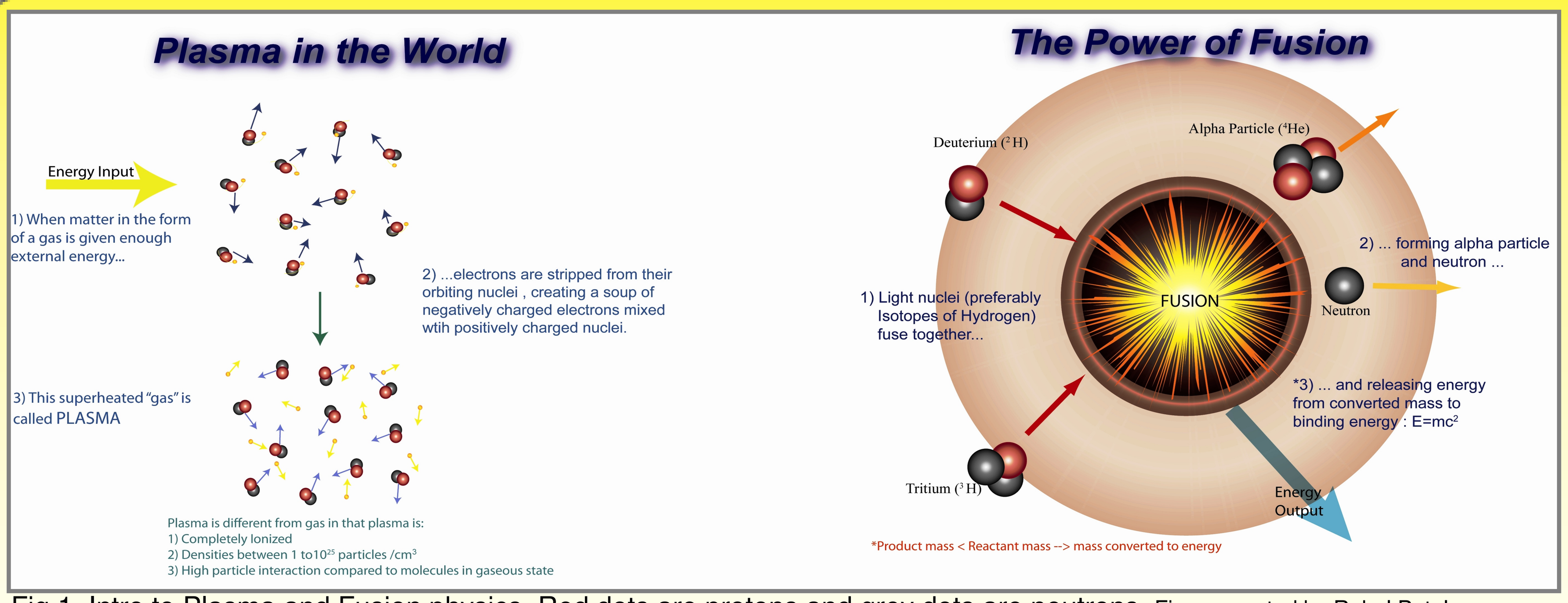

Fig 1. Intro to Plasma and Fusion physics. Red dots are protons and grey dots are neutrons. Figure created by Rahul Patel

Challenges in Fusion Energy Production

- High energy requirements to fuse two nuclei → need to overcome coulomb barrier (electrostatic repulsion)
- Enormous energy input required to achieve temperatures and pressures of such a magnitude
- Temperature to fuse Deuterium and Tritium: **100 million degrees Celsius!**
- Containment and energy production → no material can withstand such temperatures.

Dust and Fusion Reactors

- Confinement of high temperature plasma achieved via magnetic fields in Tokamak reactor like NSTX
- Contamination of plasma due to interactions with outer containment wall and evaporation of dust particles.
- Dust in plasma is impurity → safety issue.
- Dust particles may be lithium or carbon particles.

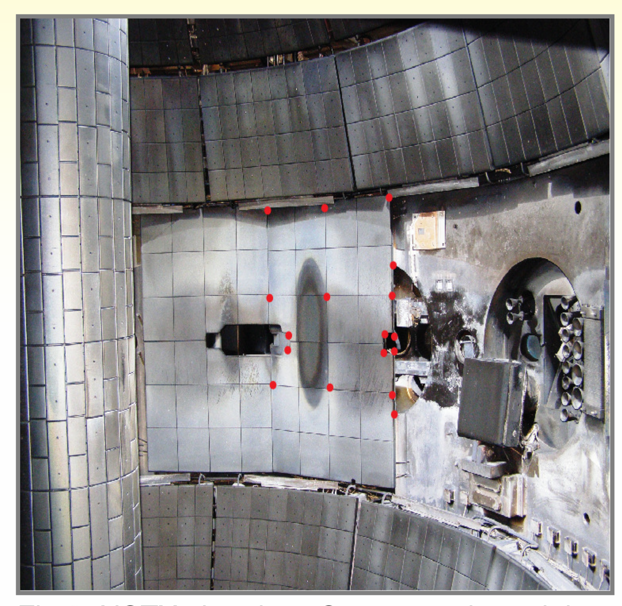

Fig 2. NSTX chamber. Center stack on right. Calibration points in red

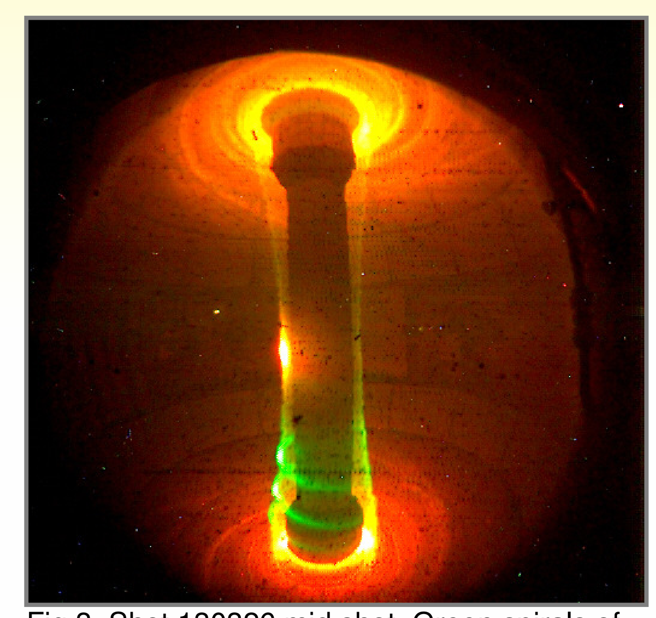

Fig 3. Shot 130326 mid shot. Green spirals of lithium particles. Red and yellow of He and H.

METHODS

Data Acquisition

- Dust tracks obtained at National Spherical Torus Experiment at Princeton Plasma Physics Laboratory, Princeton, NJ.
- Two high speed cameras used to record plasma discharges.
- Cam 1 at (43.6, 56.5, 0). Cam 2 at (-11.33,87.46,0) Recording rate of 7104 fps and 10000 fps respectively
- Shots (plasma discharge videos) were converted to JPEG frame images using Phantom camera program.

Tracking Dust Particles

Fig 4. Raw JPEG. Dust particles seen illuminated

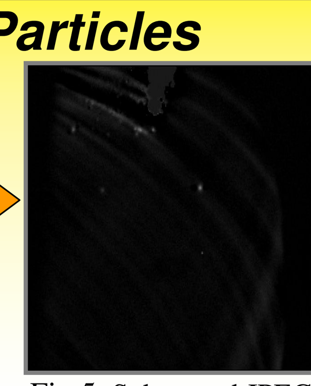

Fig 5. Subtracted JPEGs created.

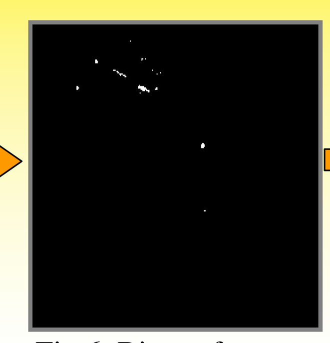

Fig 6. Binary frame: pixels below preset value set to black and above are set to white.

Fig 7. Final composite frame made by overlapping all images into one image, creating static tracks. Track in red.

- Images batch analyzed using python based software developed by Dr. Werner Boeglin and Rahul Patel

Particle Position in NSTX Reference Frame : Camera to NSTX reference frame

Line of Sight to Intersection in NSTX

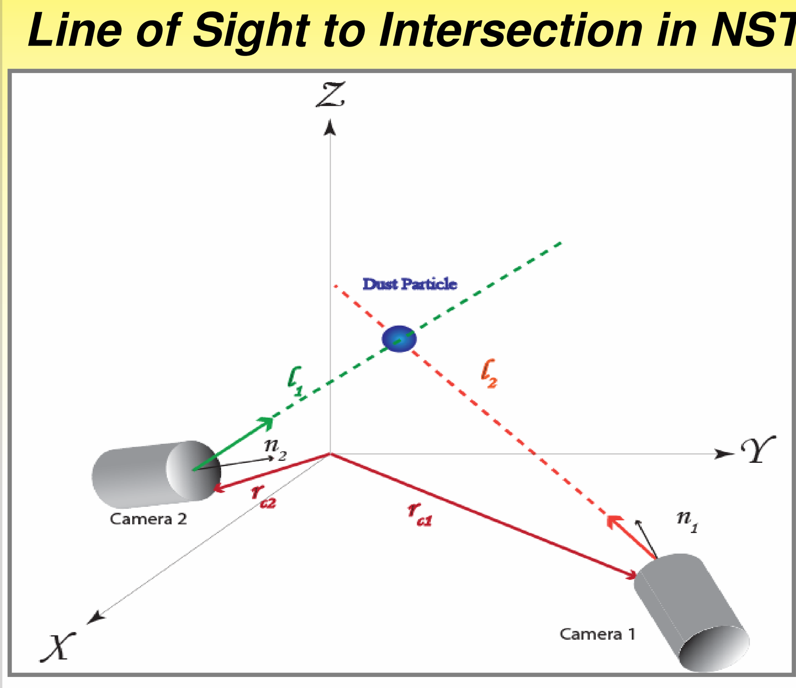

Fig 8. Configuration used to calculate position of particle in NSTX coordinate system. Each pixel position in camera refers to a line in space. Location of closest approach between two lines is calculated. Average of the closest approach positions along the sightlines is location of particle in NSTX reference frame

Figure by Rahul Patel

Initial Parameters and Parameter Calibration

- Initial Euler angles (α,β,γ) for coordinate transformation found using center pixel position on ccd chip and corresponding point in NSTX. Second point in view used to determine angle between line of sight of the two points.
- Initial ccd to lens distance also calculated (zcp)
- All 4 parameters refined using least squares fitting procedure.

RESULTS

- Only two dust tracks have been recreated thus far.
- Track 1, named "Loner" from shot 130377. Track 2, named "Hockey Stick" from shot 130376.
- Most of the dust seen due to injection of carbon coated lithium pellets into the fusion chamber during each discharge.
- Ready to reconstruct more tracks.
- More tracks coming soon.
- Any change in camera view will require a new calibration.

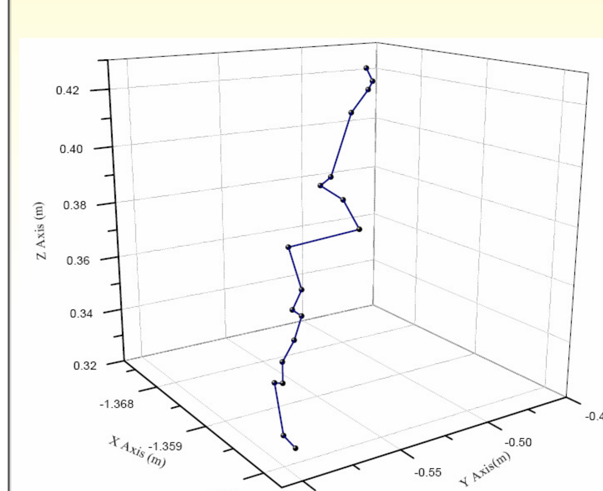

Fig 9. Track named 'Loner' reconstructed from shot 130377 in the NSTX Coordinate system

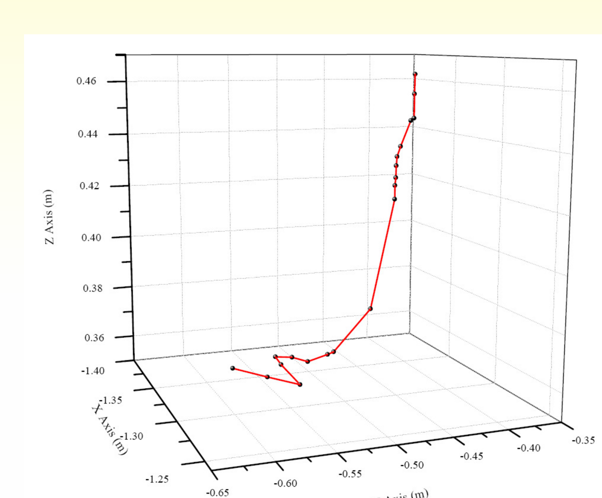

Fig 10. Track named 'Hockey Stick' reconstructed from shot 130376 in the NSTX Coordinate system

Conclusion and Future Work

Fusion reactors like the National Spherical Torus Experiment and the future International Thermonuclear Experimental Reactor face many challenges in keeping steady reactions for prolonged period of times due to instabilities in the plasma. The presence of dust particles can pose safety risks and impair optical diagnostic instruments necessary for the control of the plasma. The current study presents a method in reconstructing dust particle tracks. Laying out this method is crucial into reconstructing more tracks which provides important data to test and improve models of dust dynamics in fusion plasmas. Further work is being done to recreate more particle tracks.

References

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2. S.Eliezer and Y. Eliezer, Fourth State of Matter: An Introduction to Plasma Science, (IOP Publishing Ltd, Bristol, 2001).
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FIU Florida International University

PPPL Princeton Plasma Physics Laboratory