Electrostatic Detection of Stainless Steel Dust Particles for Fusion Applications

P. Landy[1], C. H. Skinner[2], H. Schneider[2]

[1] Cornell University, Ithaca, NY 14853

[2] Princeton Plasma Physics Laboratory, Princeton, NJ 08543-0451

Motivation

Dust is a safety concern for fusion devices.

- Dust accumulates in fusion devices from the erosion of plasma facing components, mechanical abrasion during maintenance, and other sources.
- This dust may be chemically reactive, activated, tritiated, and toxic. It also may pose an explosion hazard.[1]

A remote dust detection device is needed.

- Diagnostic tools will be needed for managing dust in fusion devices[1]
- An electrostatic detector design has been successfully demonstrated in NSTX,[2] Tore Supra[3],and in the laboratory with carbon particles.[2,4,5]

LHD generates carbon and steel dust particles.[6]

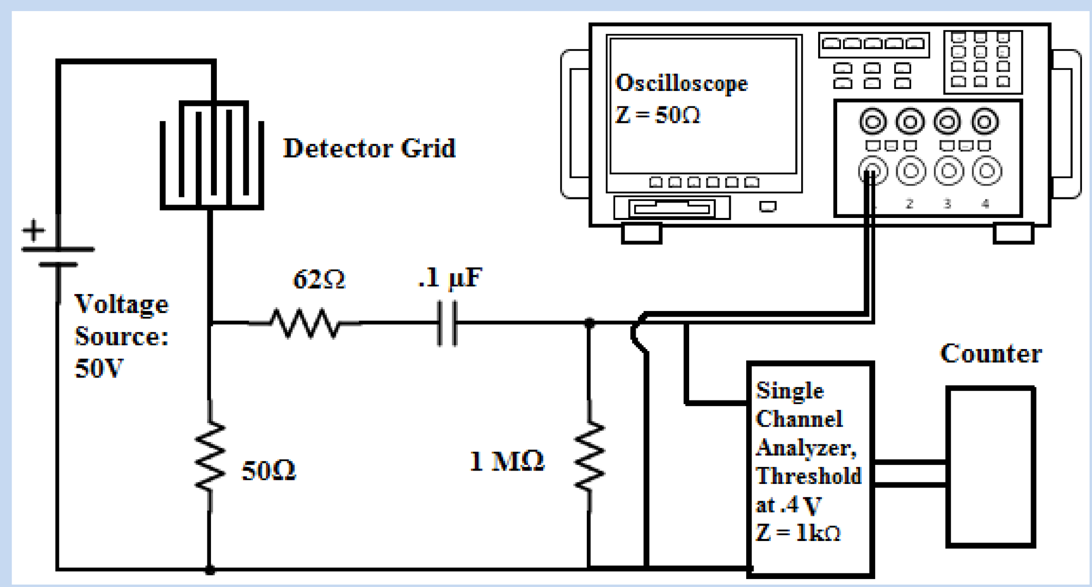
Challenges of stainless steel particles:

- Past results[7]suggest that metal particles may melt or burn up on the detector, causing permanent short circuits or damage

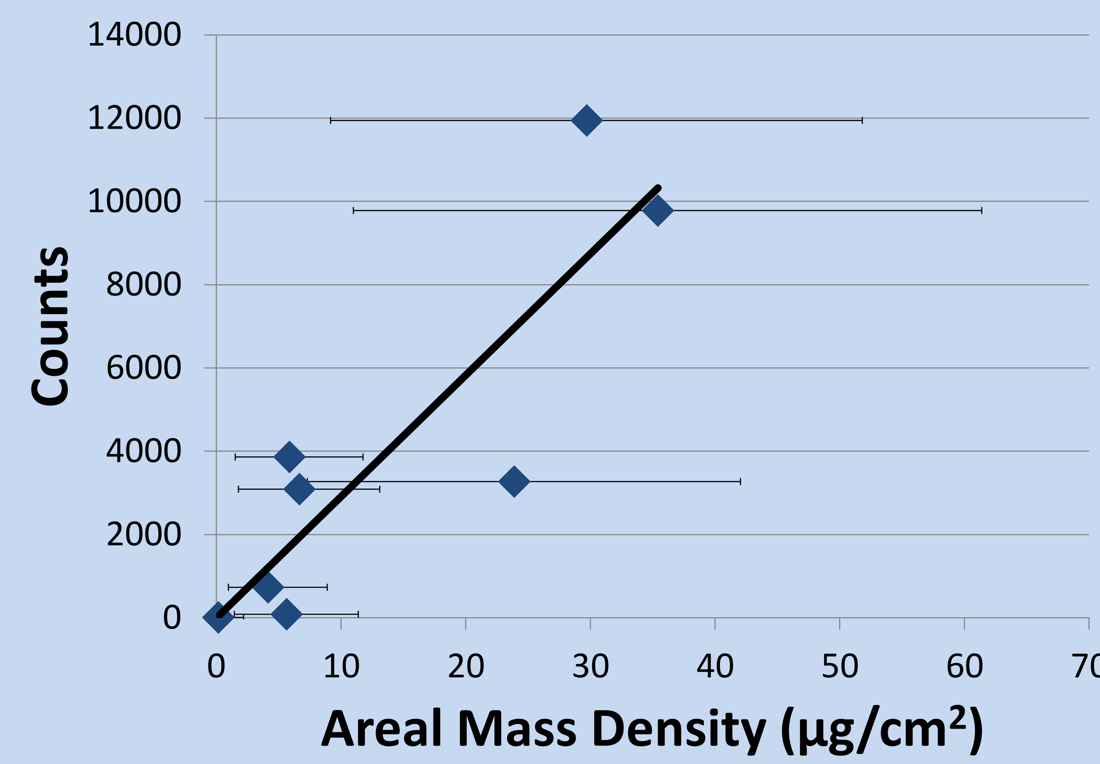
This work aims to characterize the response of the detector to stainless steel particles.

Electronics

Voltage pulses from impinging dust particles were detected using counting electronics[4]



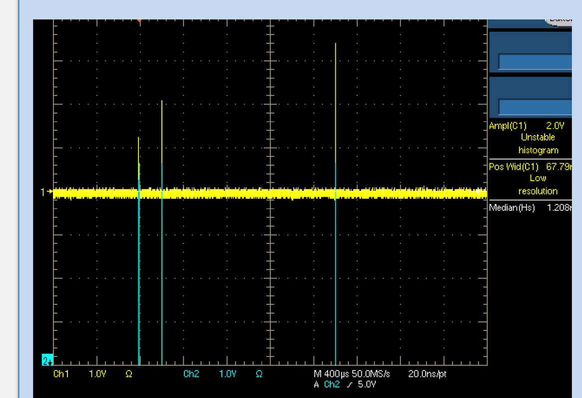
Carbon Sensitivity



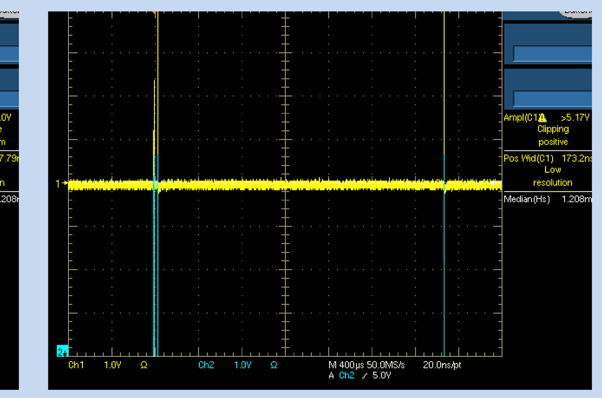
Carbon sensitivity, determined from a linear fit including the origin, is 291 counts/μg/cm², a result that compares well to a previous result of 239 counts/μg/cm²[5]

C/SS Dust Mixture Results

Carbon and stainless mixture produces waveforms representative of both materials:



Some isolated voltage spikes in the range of 1-4 V mimic behavior observed for carbon.



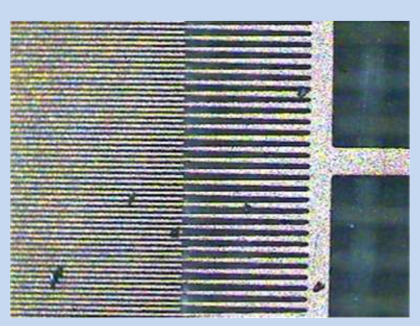
Some isolated voltage spikes exceeding 5 V mimic stainless steel particle behavior.

Numerical analysis of waveforms may yield counts for individual particle types.

Experimental Setup

Dust is detected when it creates short circuits between biased copper traces.

Traces are spaced 25 μm apart over a 1.27 cm square Ultralam substrate and biased at 50 V.[2,4,5]

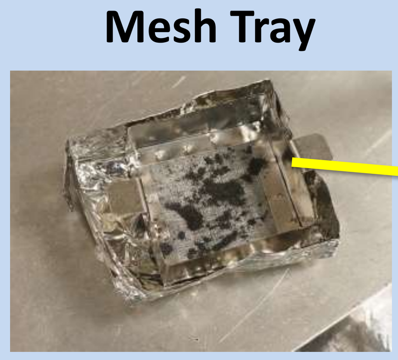


(Image courtesy of D.P. Boyle)

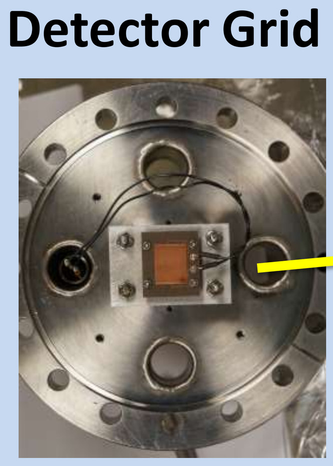
Dust was dropped on the detector through a mesh-bottomed tray with 86 μm openings.

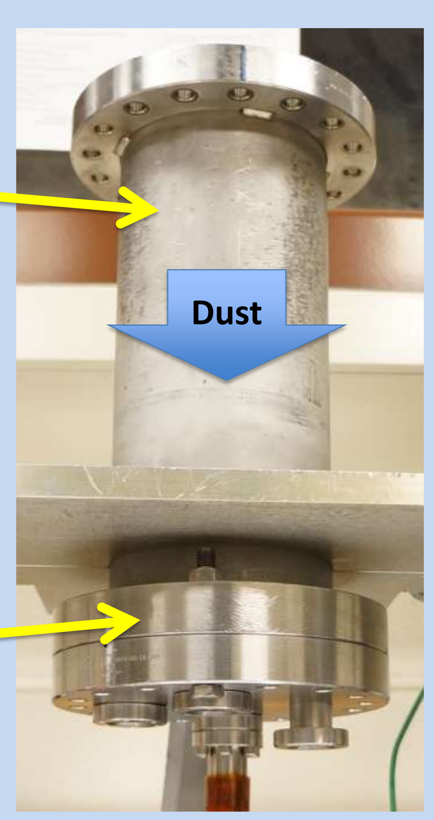
- A Sartorius ME 5-F Balance with 1 μm precision was used to measure the dust lost from the tray.
- The tray was tapped to release dust onto the detector.
- The detector grid was mounted on a 6" flange, that was bolted to the bottom of a metal tube.

Mesh Tray



Detector Grid





Dust Particle Size Analysis

Carbon particles scraped from a tile[8]	"PF-5F" Stainless Steel Particles[9]	"PF-15F" Stainless Steel Particles[9]

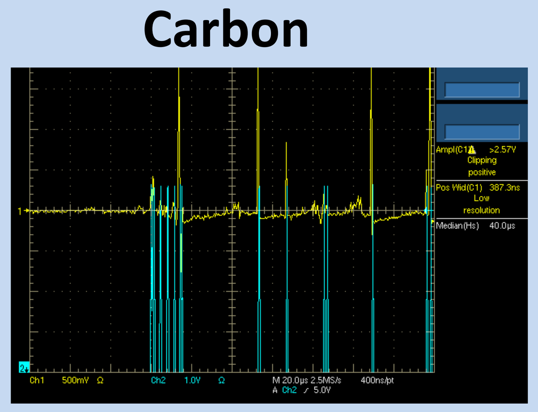
Count Median Diameter: 5.87 μm	Count Median Diameter: 4.78 μm	Count Median Diameter: 37.30 μm

Microscope images analyzed with ImageJ[10]

- **Majority of particles < 10 μm in diameter**
- **Carbon dust contained relatively large flakes, some >53 μm**
- **Stainless Steel Dust tended to form clumps up to 100 μm**

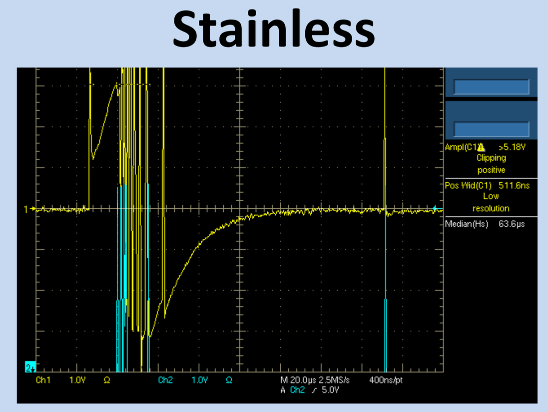
Waveform Comparison

Carbon



- 0.5 to > 2.5 V pulse heights
- Small negative amplitudes

Stainless

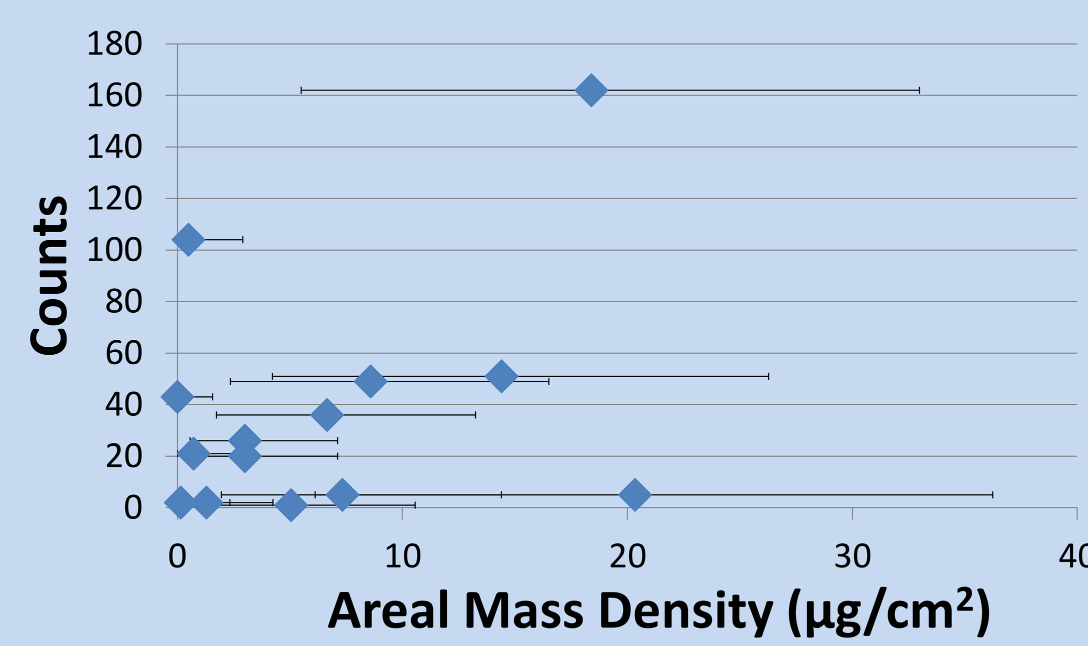


- Pulses usually >5 V
- Large negative amplitudes

Similarities:

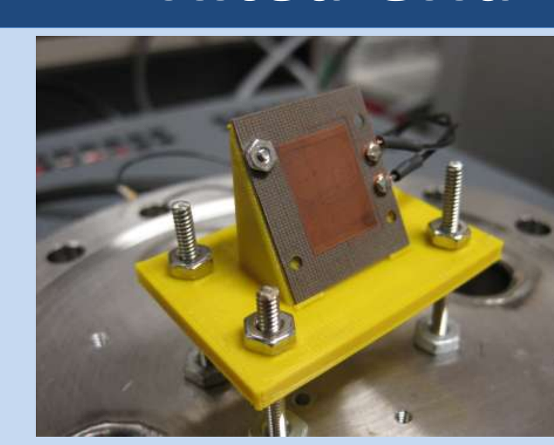
- For both particle types, isolated pulses and chaotic oscillatory behavior observed
- Duration of isolated pulses between 100 and 500 μs

Stainless Dust Detected



Trials used "PF-5F" stainless steel particles[9] dropped through a triple mesh. The power supply current limit was 2 mA and the SCA lower threshold was 0.4V. No clear correlation of counts with mass density was apparent. Approximated sensitivity: 4 counts/μg/cm²

Tilted Grid



60° grid mounting angle increased mass flux required for a short from dust pileup

- **Trials with the larger "PF-15F" stainless steel dust consistently short-circuited the detector.**
- **Angled grid stand was fabricated with a Maker-Bot 3D printer to reduce the areal density of incident particles and help eject particles[7] away from the traces.**
- **Tilted grid allowed the detector to produce counts from "PF-15F" dust[9] without short circuits from dust pile-up.**

Discussion/Conclusions

Detector produces counts for mass fluxes as low as several micrograms/cm².

Current limit successfully prevented grid damage.

- The grid sustains no observable damage from repeated stainless steel trials at a bias of 50V and current limits from 2 to 47 mA.

Data collected to date shows no observable correlation between counts and stainless steel areal mass density.

- Stainless steel counts vs. areal mass density did not follow a linear trend, unlike carbon. Approximate sensitivity was about 100 times lower than that for carbon.
- Many recorded waveforms reveal chaotic, oscillating waveforms, accompanied by numerous SCA pulses. These could be caused by bouncing particles or clumps breaking up, as observed in past work.[7]

Results from tilting grid and analyzing waveforms show promise for future work.

- Angled grid mount enables detection of relatively large particles.
- Pulse height analysis for carbon, stainless steel, and c/ss mixture trials could allow dust particles to be differentiated.

References

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[9]Epson Atmix Corporation, Aomori-ken, 039-1161Japan
[10]ImageJ Image Processing and Analysis Software, NIH

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Patrick Landy can be reached at pdl48@cornell.edu

Patrick Landy

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General Audience Abstract:

Detection of Stainless Steel Dust for Fusion Safety Applications

Dust accumulation in large-scale fusion devices such as ITER (International Thermonuclear Experimental Reactor) will pose significant safety concerns. Dust in ITER will be radioactive and toxic, and a maximum quantity of 1000 kg of dust will be allowed inside the device as a safety precaution. A remote dust detection device is needed to monitor dust levels inside both ITER and other fusion devices. An existing dust detector design has been tested with carbon dust particles inside the NSTX (National Spherical Torus Experiment) and Tore Supra fusion devices, but to date has not been evaluated with stainless steel dust. Planned dust detection experiments in the Large Helical Device in Japan will involve stainless steel dust particles. Work done during the summer 2013 SULI internship characterized the response of the detector to different varieties of stainless steel dust, in order to help prepare for dust detection experiments in LHD. It was found that the detector, when used with specific parameters, responds to both carbon and stainless steel dust particles with promising sensitivities. Working on this project strengthened skills in data analysis, oral and written communication, and project planning. It also enforced knowledge of oscilloscopes and multi-meters, amongst other lab equipment. Completing this project not only allowed for the invaluable experiences of documenting and presenting a complete research project, but enabled legitimate student contribution to fusion, one of society's most promising potential advancements in energy generation.