NSTX

Supported by U.S. DEPARTMENT OF ENERGY | Office of Science

Lithium wall conditioning and surface dust detection on NSTX

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and the NSTX Research Team

PFMC-13
Rosenheim
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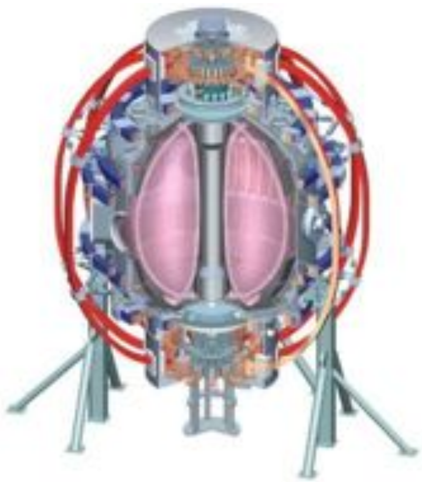

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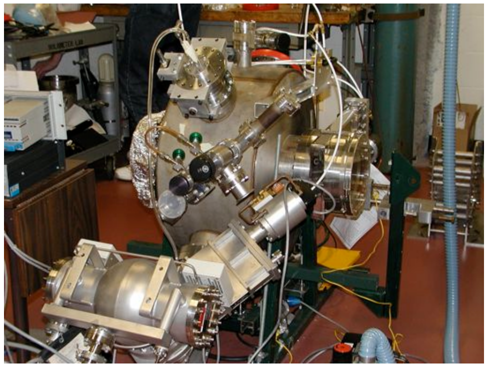
Outline:

1. Lithium research:
   a) Motivation, overview of Li research at PPPL.
   b) Recent results with Li on NSTX.
   c) Lithium surface chemistry.

2. Dust research:
   1. Electrostatic surface dust detection
   2. NSTX dust detection results
   3. Electrostatic dust removal

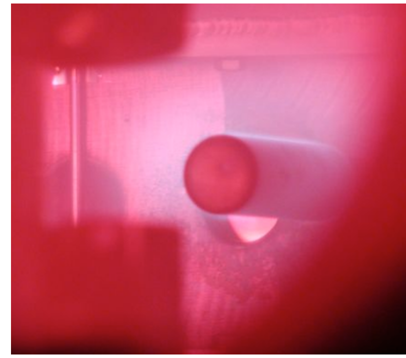
NSTX lithium research aims to assess Li PFCs for fusion



PFC test facility.

NSTX probe, Purdue collaboration, modeling…

LTX now operating:
Li evaporated into helium glow ->
All-metal walled comparison to NSTX.



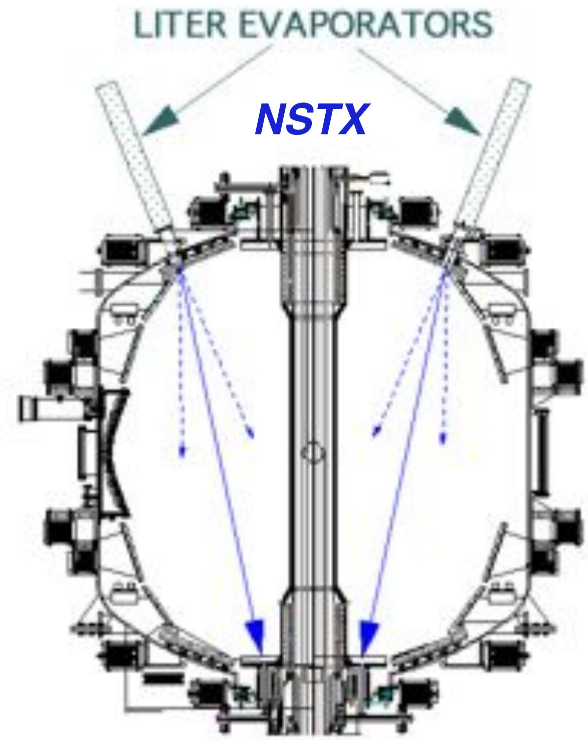
NSTX: Only diverted, NBI-heated tokamak studying Li.
LLD installed 2010.

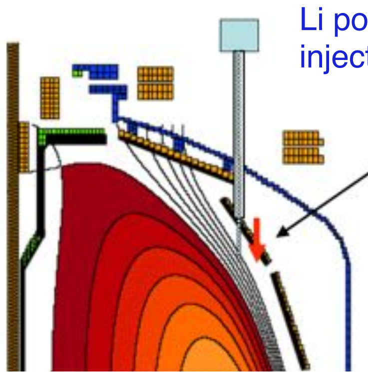
EAST / NSTX: Li collab. achieved H-mode !

NSTX Upgrade, Fusion next-steps.

Why lithium ?

- Long term potential benefits of liquid PFCs for fusion include:
  - No neutron damage and erosion lifetime issues for plasma facing liquids in future fusion reactors.
  - High-heat flux handling
  - Divertor pumping over large surface area for high flux expansion power exhaust
- Short term benefits in plasma performance.
  - TFTR: record $n * T * \tau$ on limiter machine
  - CDX-U: reduced recycling and improved confinement
  - NSTX: improved confinement, ELM suppression, lower H-mode threshold and faster shot cycle.

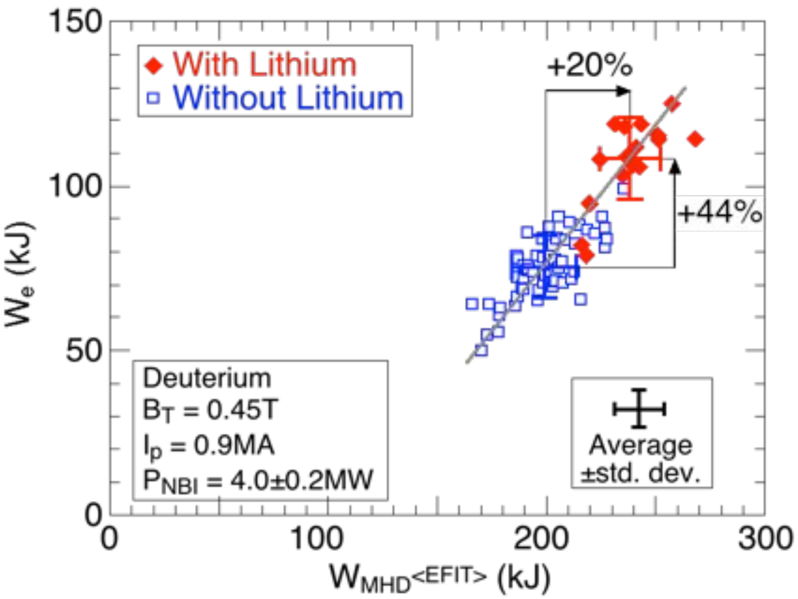




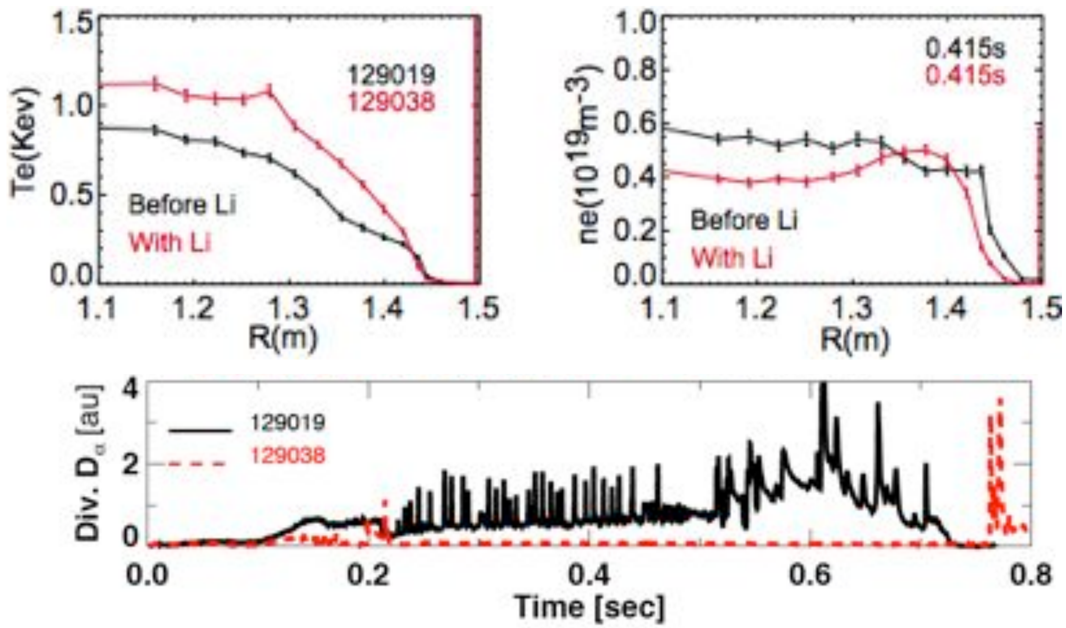
Stored energy increased and edge stability enhanced (ELMs suppressed) with Li conditioning

Stored energy (W_{MHD}) increases after Li deposition mostly through increase in electron stored energy (W_e)

Enhancement of edge stability with lithium. Preliminary stability analysis indicates reduction of edge n_e, P_e gradients responsible for stabilization of ELMs



M.G. Bell Plasma Phys. Control. Fus. 51 (2009)124056.

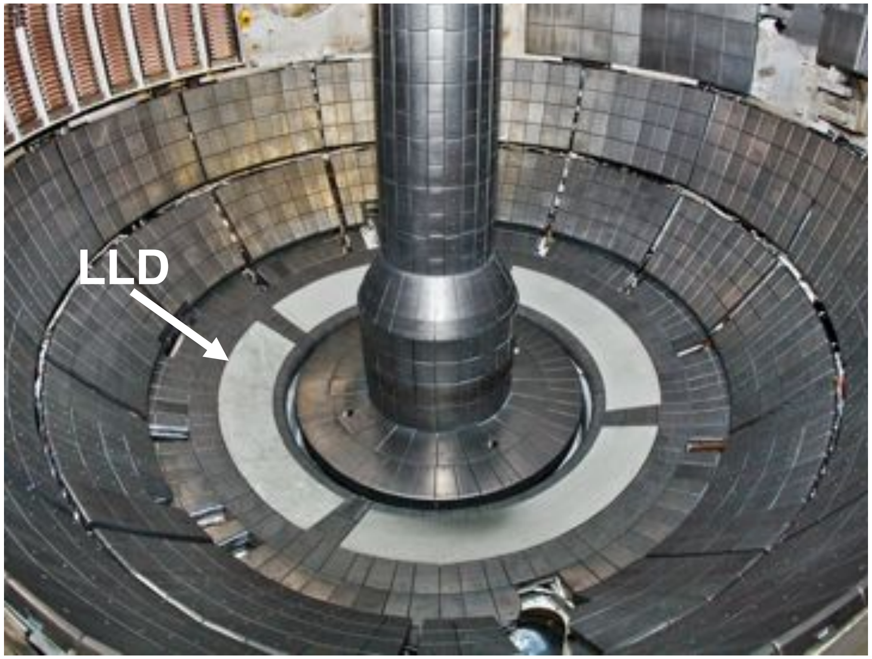


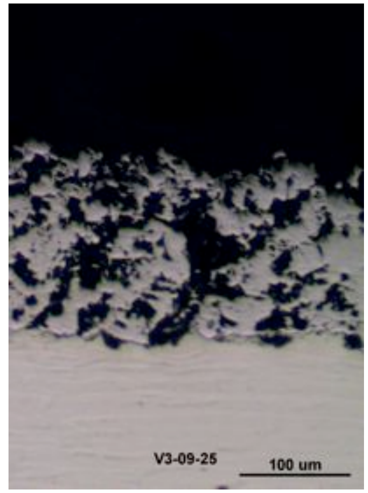
R. Maingi, 2009 Phys. Rev. Lett., 103 075001

Intershot He-GDC no longer necessary

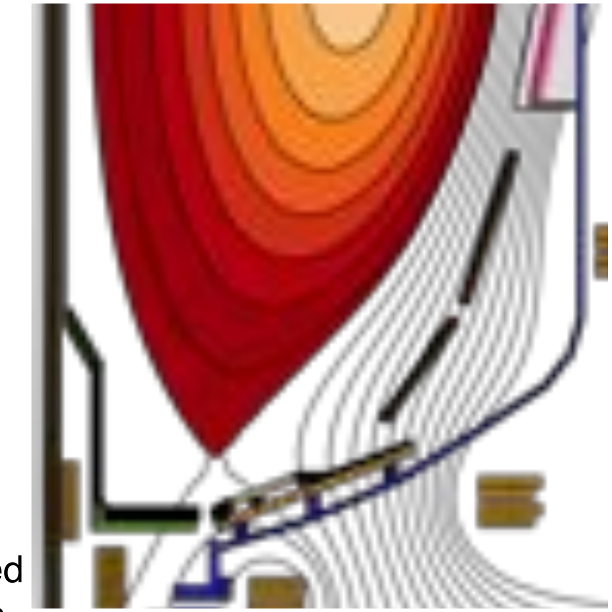
40% increase in shots / week.

Liquid lithium divertor tested in 2010





LLD surface cross section: plasma sprayed porous Mo on stainless with Cu backing plate

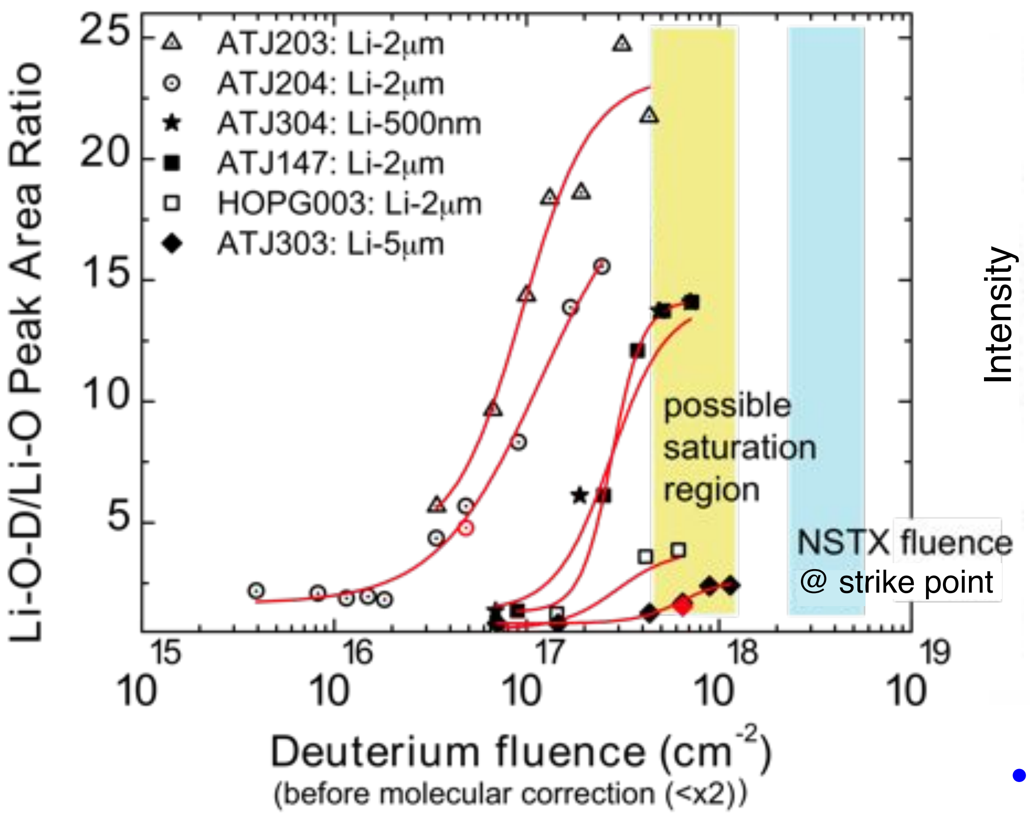


Outer strike point on LLD
EFIT02 142512 @ 547 ms

- Liquid Lithium Divertor (LLD) aims to provide volume D pumping capacity (> solid Li surface) for longer pulses with potential for handling high heat flux.
- LLD filled with 67 g-Li by evaporation. No surface damage with strike point on LLD.
- No major Li or Mo influx observed even with strike point on LLD.
- So far no systematic trend in D-alpha, wall inventory, or ion pumping with a transition above the Li melting temperature.

Lab analysis shows D binding on surfaces

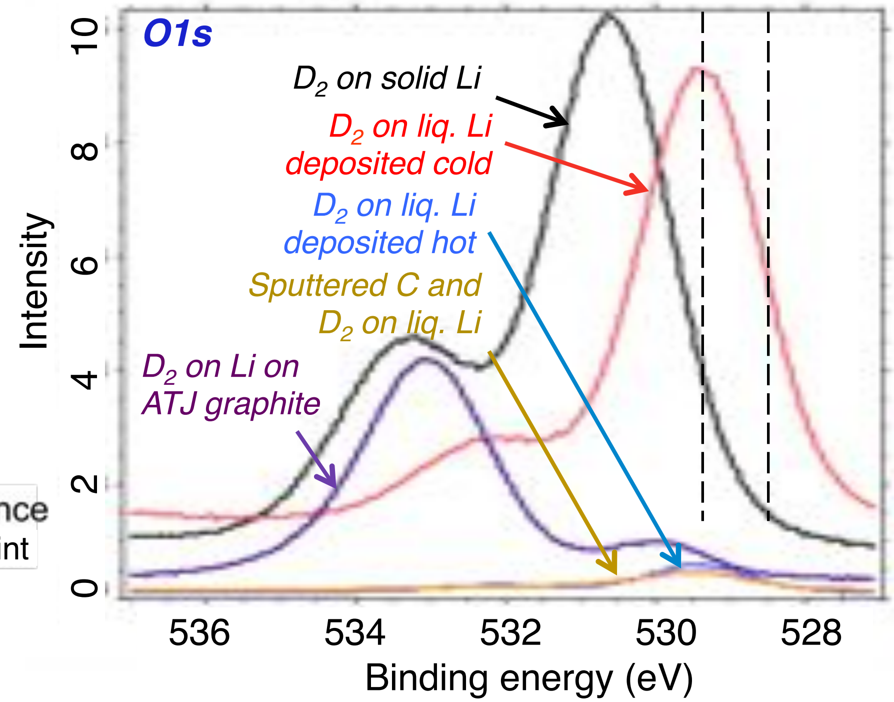
Possible deuterium saturation of Li



- Modeling showed the probability for D to bond to a Li-C complex is 3 x larger than to C (P. Krstic P28A)

XPS O1 spectra for the LLD samples

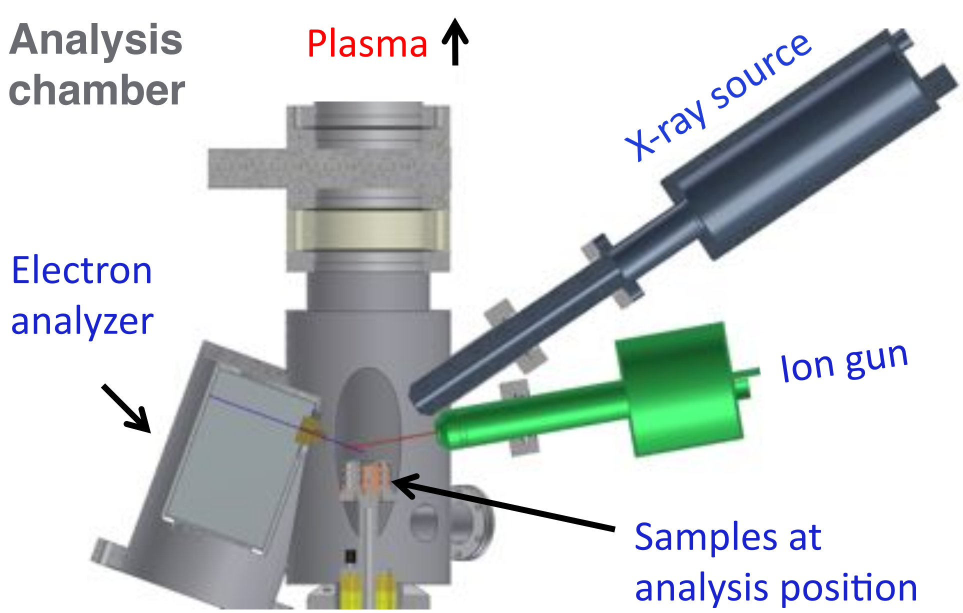
30 mins D_2 irradiation of Li on:

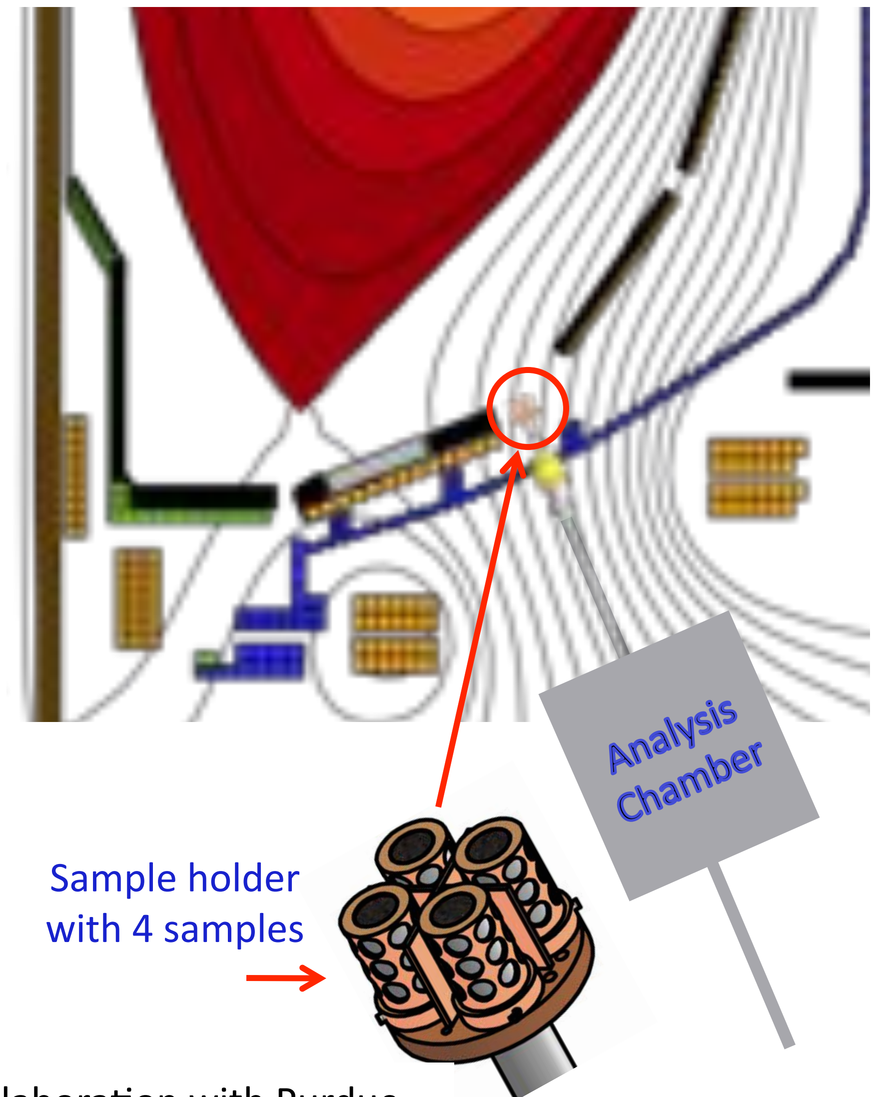


- XPS O1s spectra show changes in surface chemistry with D irradiation of Li deposited on cold / hot / C contaminated Mo and graphite.
- Suggests Li on Mo is interacting with D and D is diffusing into Li. (C. N. Taylor P09B)

In-vacuo surface analysis of plasma exposed samples

- Materials Analysis Particle Probe (MAPP) will be the first *in-vacuo* surface analysis diagnostic directly attached to a tokamak, capable of shot-to-shot chemical surface analysis of material samples (solid Li, liquid Li, Mo etc).
- Correlation of PFC surface chemistry with plasma conditions will point the way to improved plasma performance.





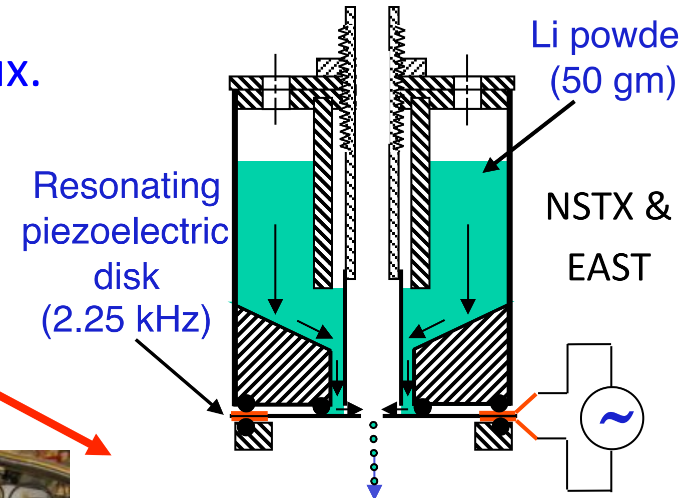
Collaboration with Purdue

EFIT02 142512 @ 547 ms

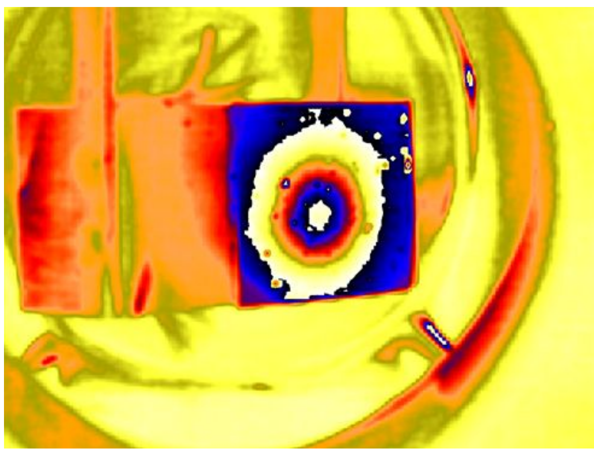
Li technology development supports tokamak applications

- R&D continuing for LLD performance at high heat flux.
- Continuous Li replenishment systems:

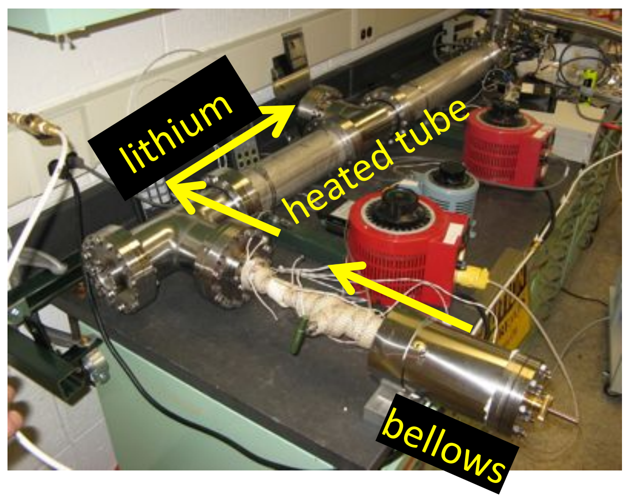
Li delivery by: powder
granules
liquid



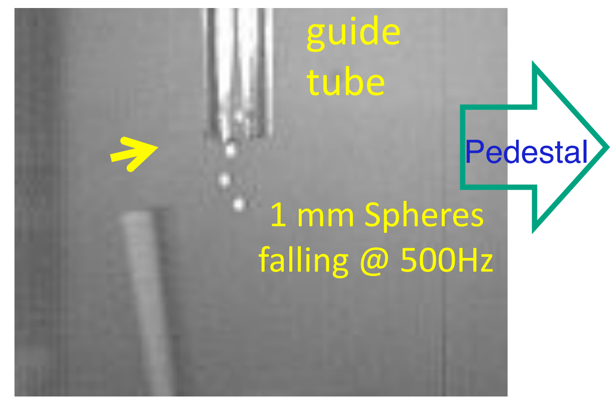
High heat flux test



IR image of LLD sample during NB exposure
T ≤ 225 °C @ 1.5 MW/m^2 - 3s.
Potential PFC for upgrade



10 g of molten Li moved 1.1m in vacuum and ejected 7.6 cm from nozzle



500 Hz Impeller Rotating @ 95 m/s

Midplane injection for ELM pacing

Surface dust detection needed for ITER

Motivation:

- High levels of dust are expected in ITER from more intense PMI and longer pulse duration.
- Dust will have important safety and operational consequences:
  1. 670 kg is ITER limit on mobilisable cold dust (public safety).
  2. Vacuum vessel integrity - (4 kg H_2 2 bar overpressure limit)
     leads to: 6 kg limit on W, Be, C hot dust
     or 11 kg Be, 230 kg W if C is absent.
  3. Transport of W dust could prevent fusion burn (dust limit unknown).
  4. Dust could obscure diagnostic first mirrors (limit unknown).

ITER strategy is to:

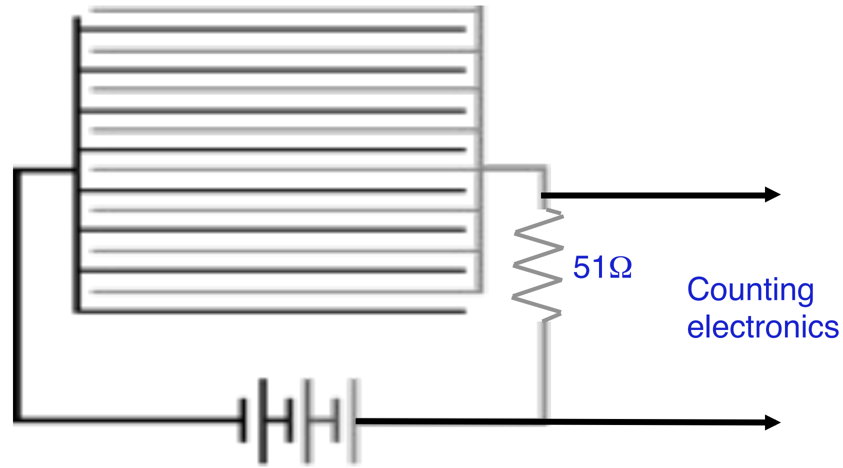
- Diagnose dust inventory from divertor erosion measurements (laser rangefinder).
- Install local dust monitors (presently undeveloped).

Electrostatic detection of dust settling on surfaces.

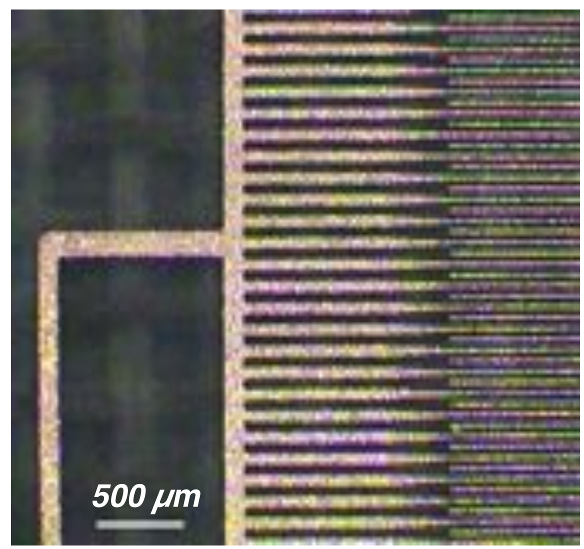
- A 50V bias is applied across a grid of interlocking traces on a circuit board.
- Impinging conductive dust creates a short circuit and current pulse.
- Current pulse is converted to counts that are proportional to flux of dust.
- Current also vaporizes or ejects dust from the circuit board restoring open circuit.
- Device works in air or vacuum.

Rev. Sci. Instrum. 81, 10E102 (2010)

Schematic



Partial view of grid with 25 μm spacing

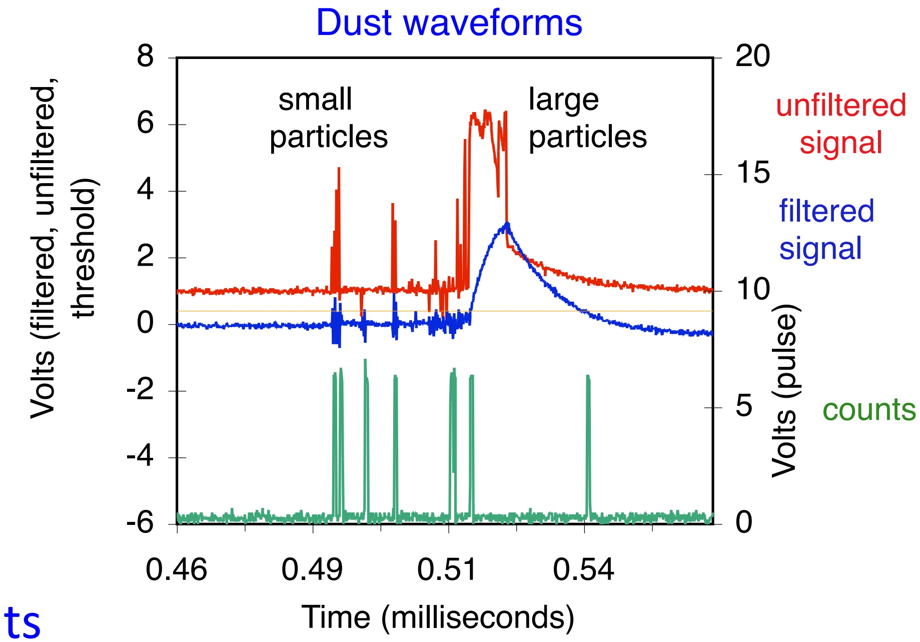


●

100 μm dia. of human hair

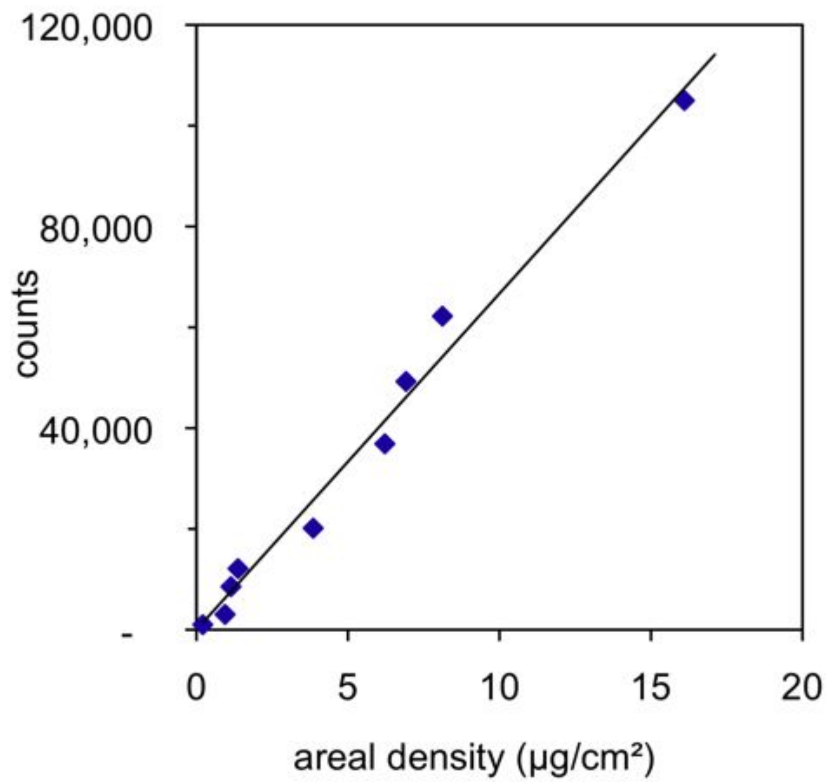
Sensitivity increased by x10^4

- Complex waveform converted into counts by counting electronics.
- Larger dust particles take longer to vaporize and create signals with higher voltage and longer duration.
- x10^4 increase in sensitivity over 1st results needed to measure NSTX dust (not a problem for ITER dust levels).
  Strategy…
  1. Increase detector area
  2. Finer grids
  3. Differential electronics to avoid EM pickup



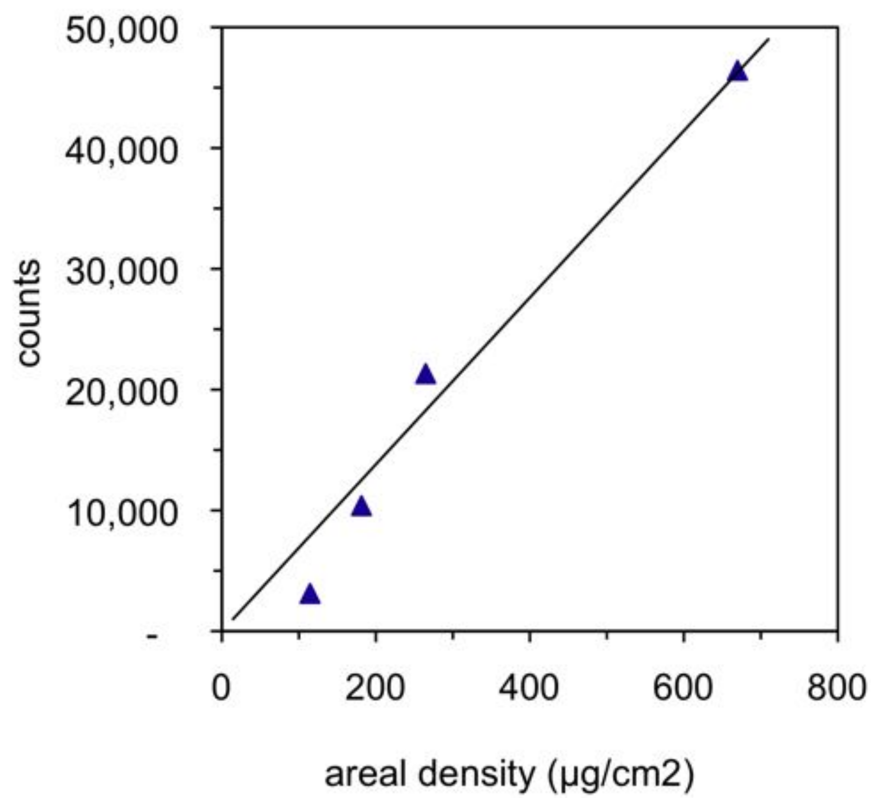
Very high sensitivity demonstrated in laboratory

Carbon particles



Lithium particles

(used for wall conditioning in NSTX
may be considered as proxy for Be particles in ITER.)



Sensitivity 14.5 ng/cm^2/count

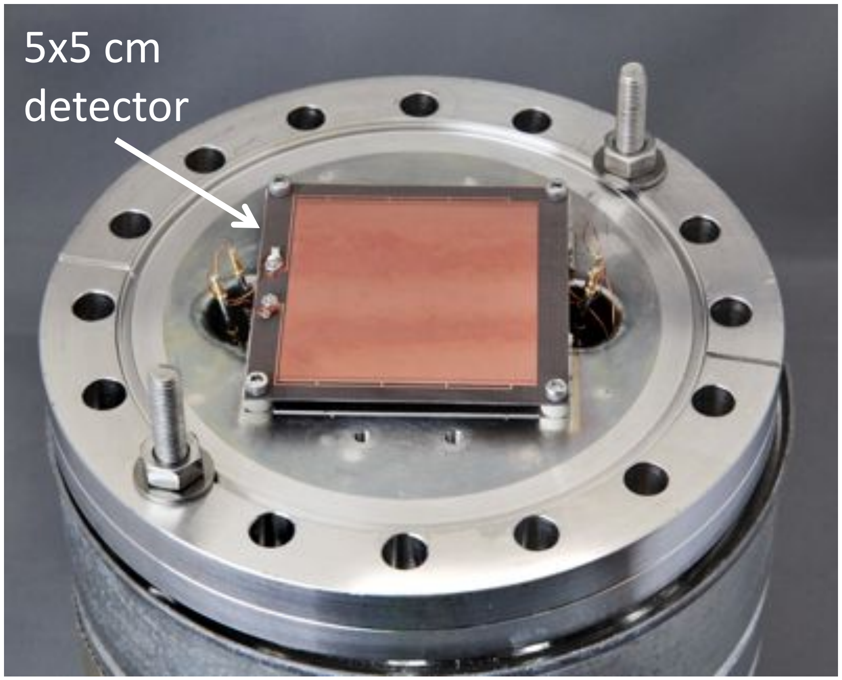
12 mm grid, 25 µm spacing, 50 v bias in vacuum

(40 µm dia. fewer particles than C for a given mass)

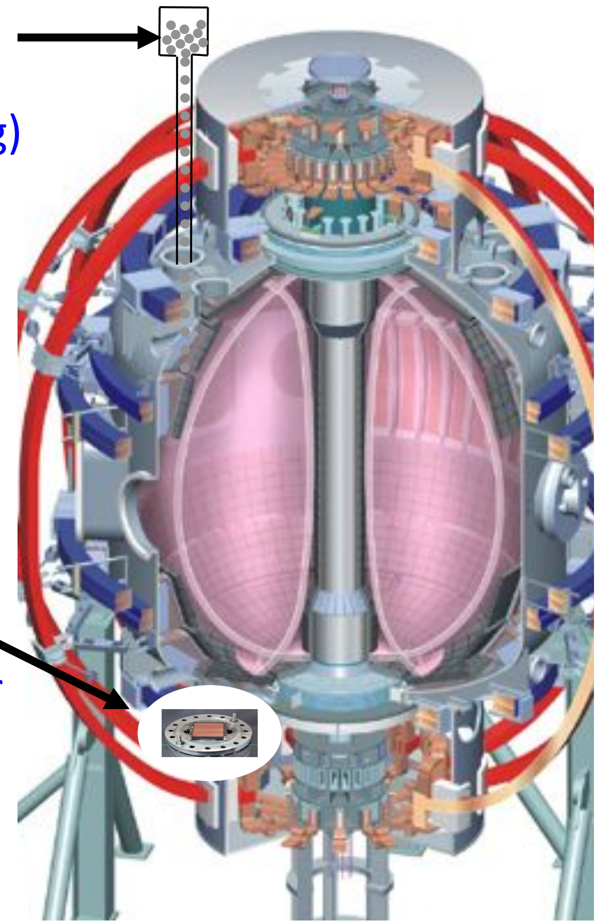
Extremely sensitive: 0.15 ng/cm^2/count

(51 mm grid, 25 µm spacing, 50 v bias in vacuum)

NSTX installation in lower port on NSTX



Li aerosol
(for wall
conditioning)

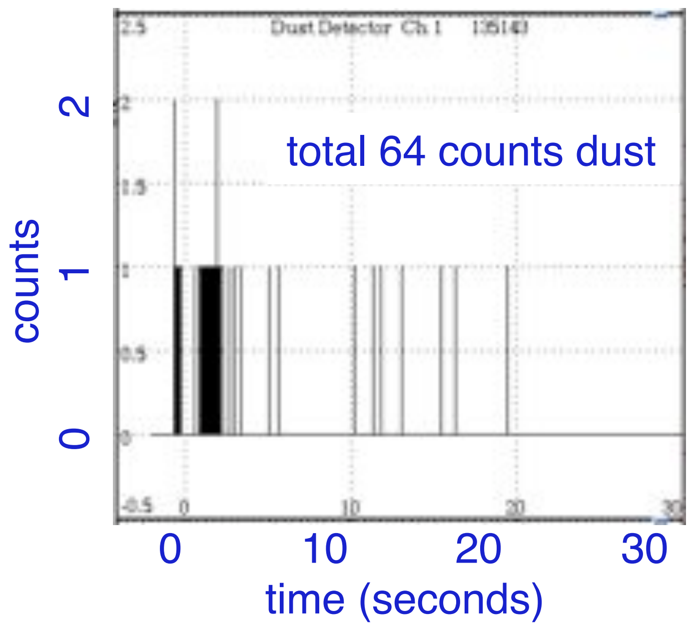


Dust Detector

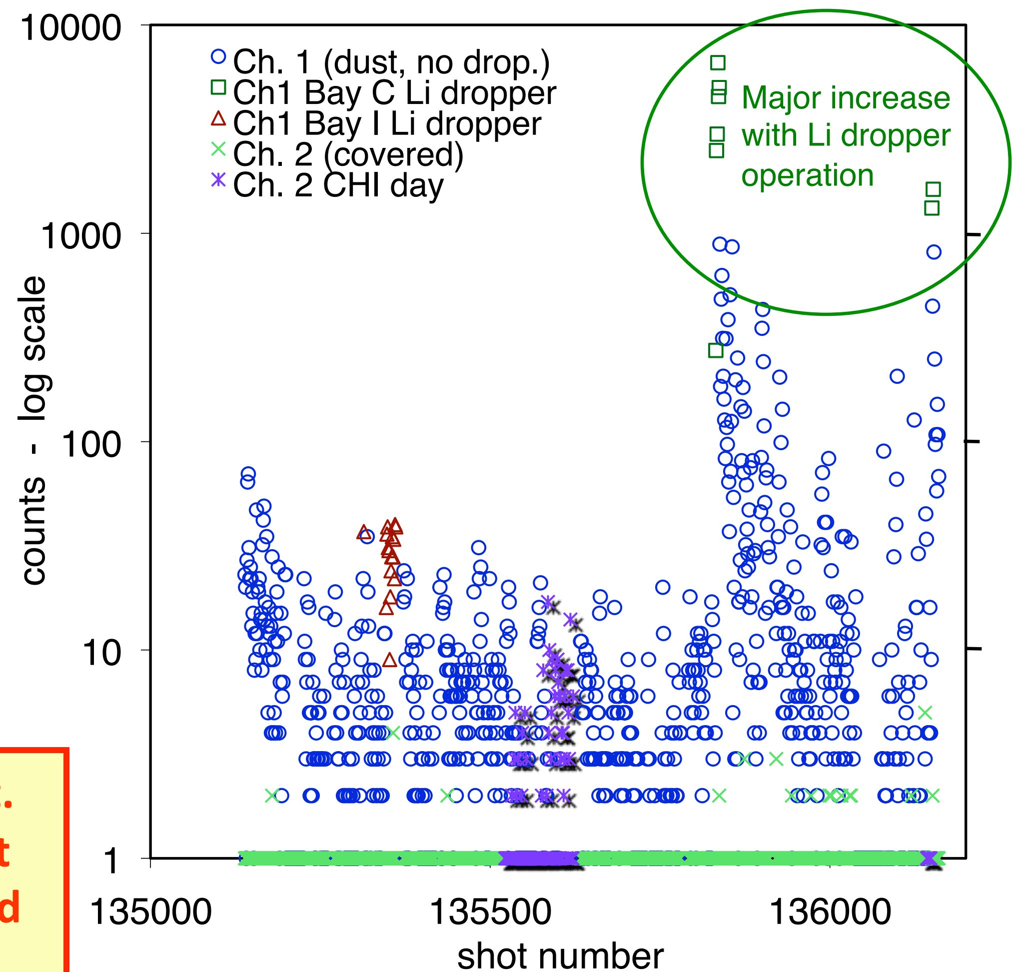
Two identical grids for noise discrimination.
Only upper grid exposed to dust.
Lower grid covered with mica detects only pickup
Mesh cover (90 μm pore size) (not shown) shields from fibers and large particles that might cause a permanent short.

First real-time measurements of surface dust on tokamaks

Dust signal from NSTX



Total dust counts per shot.

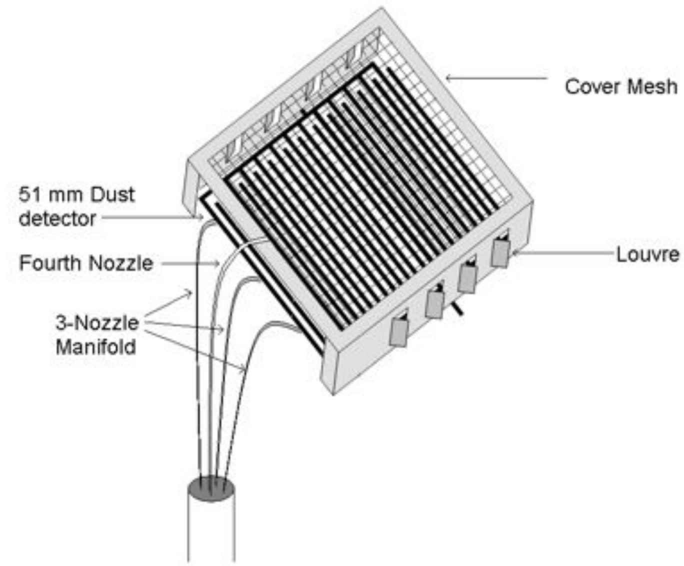


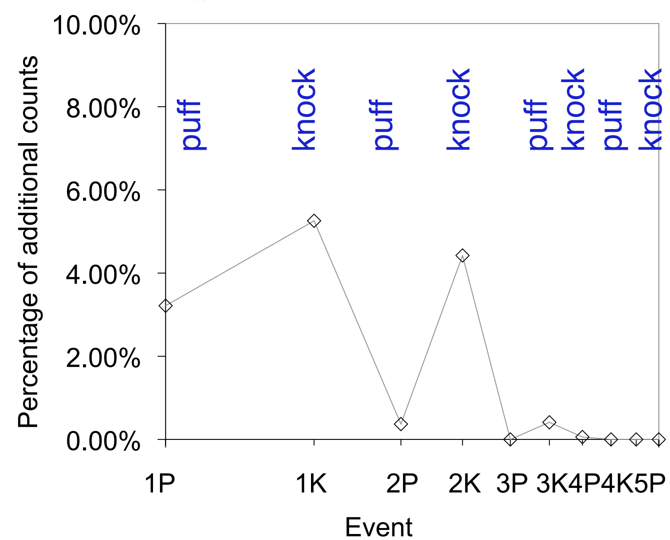
Disruptions are a significant source of dust. Of the 20 NSTX discharges with the highest dust signals, 15 discharges had experienced plasma disruptions.

Helium puffer developed to clear residual dust

- Up to 10% residual dust may remain on the dust detector after a pulse.
- A helium puffer was developed to clear this dust.
- Residual dust measured by mechanically disturbing detector.
- 99.9 % of dust cleared after two He puffs.

See poster P27A: *"Advances in Dust Detection for Tokamaks"*. B Rais et al.,



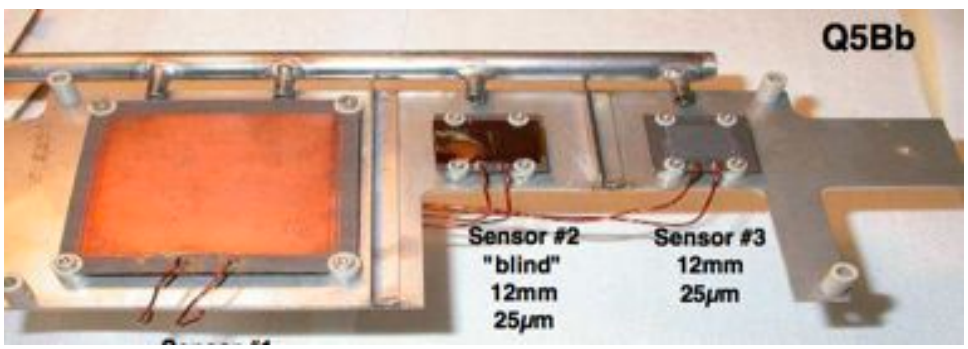


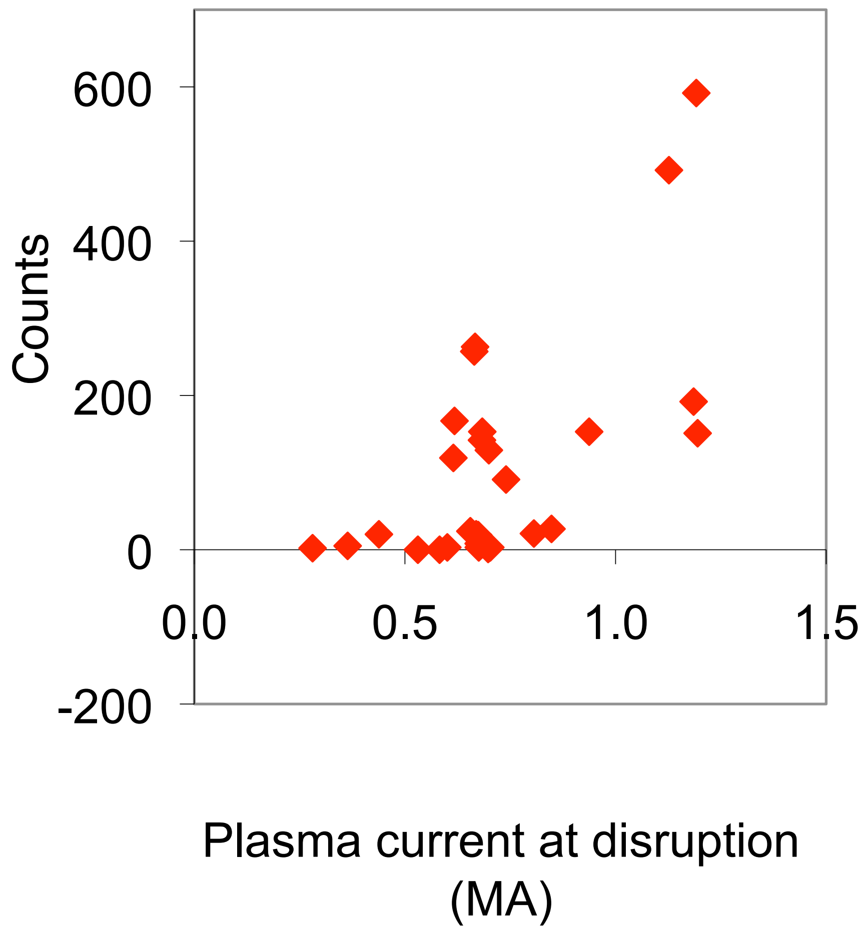
Dust remaining after helium puffs labeled 1P, 2P, 3P

Dust quantity correlated with disruptions on Tore Supra

- Electrostatic dust detectors installed on Tore Supra.
- Dust signals sorted by duration and voltage.
- Dust correlated with severity of disruptions.

See poster P26A: *“First results from dust detection during plasma discharges in Tore Supra”* H. Roche, et al.,



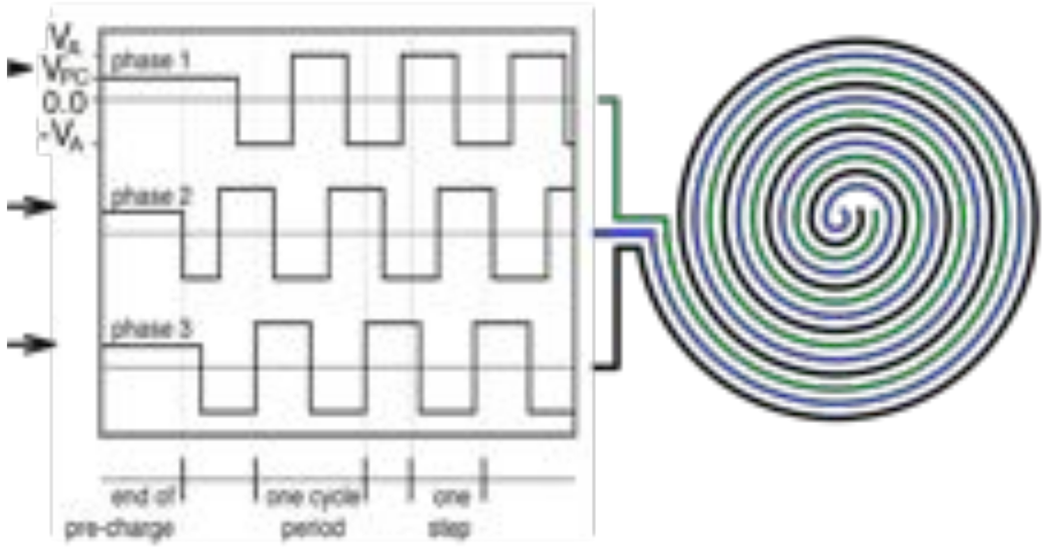


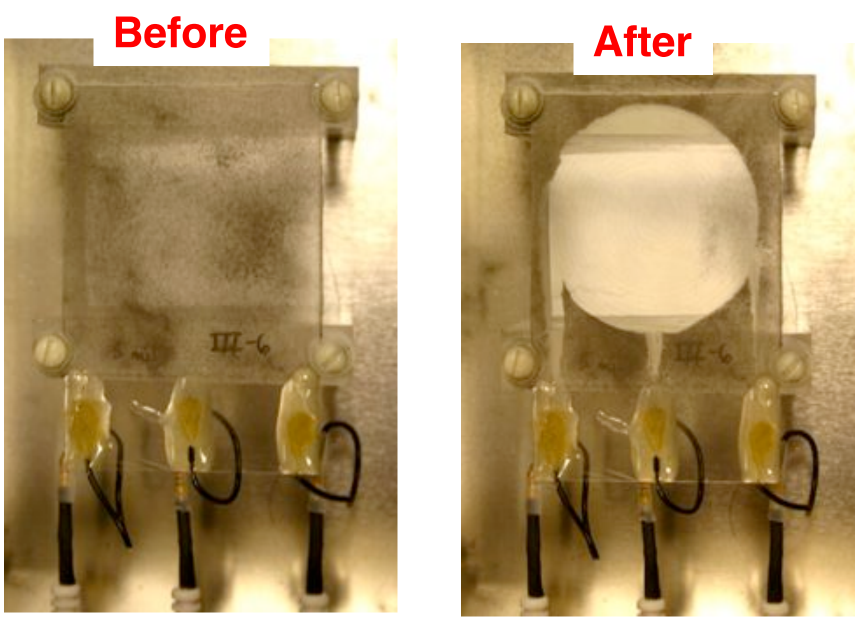
First steps in electrostatic dust removal for tokamaks

An electrostatic dust conveyor, originally developed by NASA to remove dust from solar panels of planetary rovers.

A spiral pattern of traces is biased to create moving electrostatic potential well.

Transport efficiency for tungsten, carbon glass spheres, and sand were measured.
Friesen et al., Rev. Sci. Instr. (2011) in press





Dust detection and removal demonstrated:

- Electrostatic detection of surface dust demonstrated on NSTX and Tore Supra.
- First steps in electrostatic dust removal demonstrated with C and W dust.
- Tests with W dust detection planned.
- Further development needed for ITER environment (more rugged, radiation hardened…)
  - B. Rais, et al., Rev. Sci. Instrum., 82 (2011) 036102.
  - F.Q.L. Friesen, et al., Rev. Sci. Instrum., (2011) in press.
  - C. H. Skinner et al., Rev. Sci. Instrum., 81 (2010) 10E102.

Don't miss posters:

- *"First results from dust detection during plasma discharges in Tore Supra"*
  H.Roche et al., P26A
- *"Advances in Dust Detection for Tokamaks"*
  Rais et al. P27A B
- *"Computer Simulations of Plasma-Carbon and Lithiated Carbon interface"*
  P. S. Krstic et al., P 28A
- *"Time dependent low-energy deuterium interactions with lithiated graphite…"*
  C. N. Taylor et al., P09B

Broad advances in lithium applications to fusion

- Li conditioning reduces recycling, suppresses ELMs and improves stored energy of diverted plasmas. Also enables faster shot cycle.
- LLD implemented in 2010 to test D pumping in liquid Li.
  - LLD surface temperature raised above Li melting temperature,
  - no significant Li or Mo influx.
  - So far D pumping / performance similar to lithiated graphite.
  - Spectroscopy indicates surface is not pure Li – this can affect D pumping.
- NSTX data linked to model lab experiments and fundamental chemistry calculations
  – insight into D pumping by Li-C complexes.
- Lithium technology being developed

Plans for 2011/2012:

- Investigate D pumping, plasma performance and surface chemistry including *in-vacuo* surface analysis by MAPP probe
- Assess Mo tile performance with Li.

Postdoc available