Dust detection, transport and modeling.

Three talks:

1. First real-time detection of surface dust in NSTX
   C. H. Skinner, B. Rais (U. Provence), L. Roquemore, D. Mansfield, H. Kugel.

2. 3D reconstruction of pre-characterized lithium and tungsten dust particle trajectories in NSTX
   - L. Roquemore, J. Nichols (Cornell), D. Mansfield.

3. Modeling of dust transport in NSTX with DUSTT/ UEDGE code(remote) - R. D. Smirnov, S.I. Krasheninnikov, A.Yu. Pigarov (UCSD) A.L. Roquemore, D.K. Mansfield, C.H. Skinner (PPPL), J. Nichols (Cornell).

Motivation:

- High levels of dust are expected in ITER from more intense plasma wall interactions and longer pulse duration.
- Dust will have important safety and operational consequences:
  1. 670 kg is ITER limit on mobilizable 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).

Worldwide:

ITPA DSOL-21: *"Introduction of pre-characterized dust for dust transport studies in the div.& SOL."*

ITPA Diag. 4 initiative: "*ITER Dust and Tritium Measurement*"

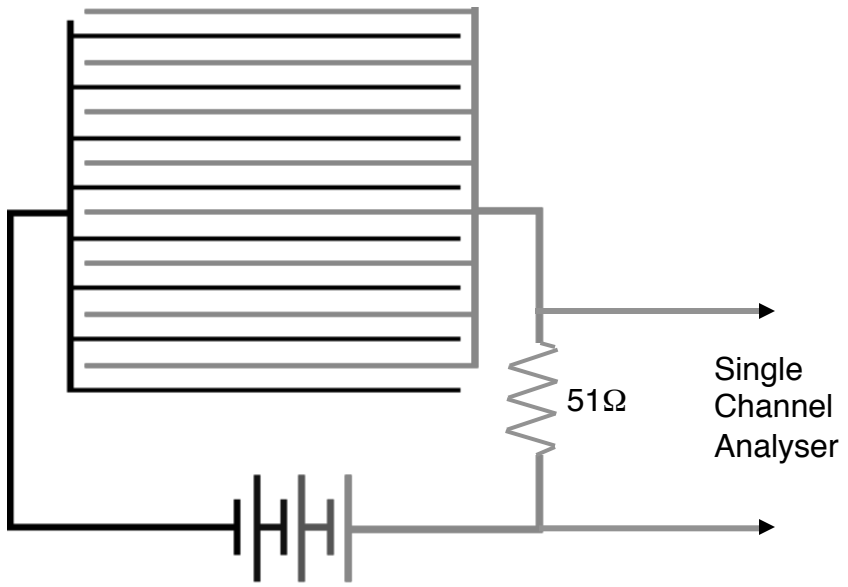
IAEA CRP: *"Characterization of the Size, Composition and Origins of Dust in Fusion Devices."*

3 EU funded activities on: '(i) Dust generation in present devices'; (ii) 'Conversion of co-deposits to dust'; (iii) 'Dust diagnosis in plasma'; dust test facility planned in Korea;
also PPPL collaborations with LHD, Tore Supra, ….

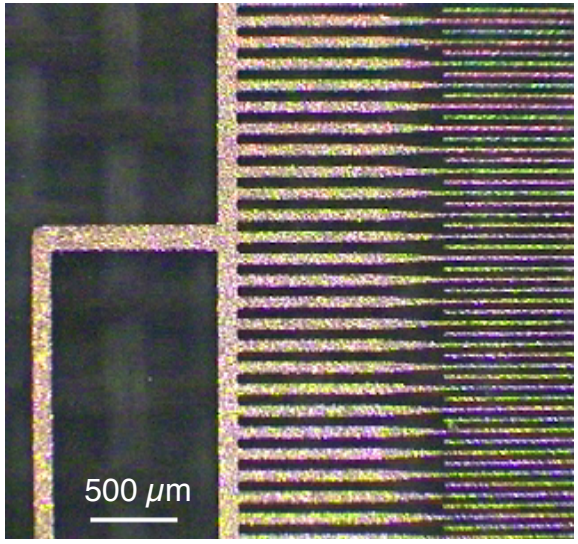
Electrostatic detection of dust settling on surfaces.

- A 30-50v 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 input to nuclear counting electronics and converted to counts.
- Number of counts is proportional to mass of dust.
- Current also vaporizes or ejects dust from the circuit board restoring an open circuit.
- Device works in air or vacuum.

Schematic



Partial view of grid with 25 micron spacing



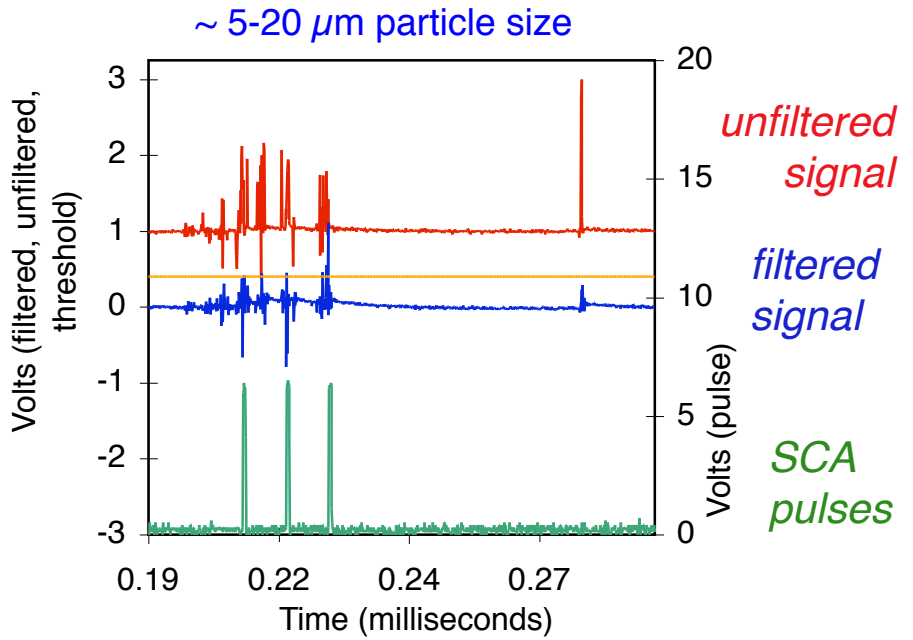
● 100 μm dia. of human hair

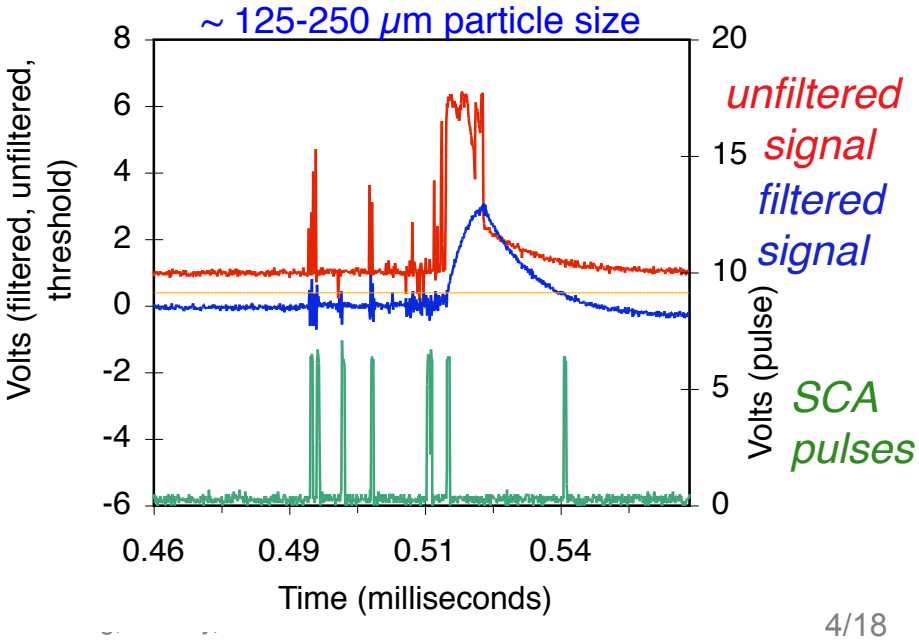
J. Nucl. Mater., 390-391 (2009) 1086,
Rev. Sci. Instrum. (2010) in press.

Electrostatic Dust Detector in action

- Complex waveform converted into counts by standard nuclear counting electronics.
- Larger dust particles take longer to vaporize and create signals with higher voltage and longer duration.

Waveform contains information on dust size





Development Path

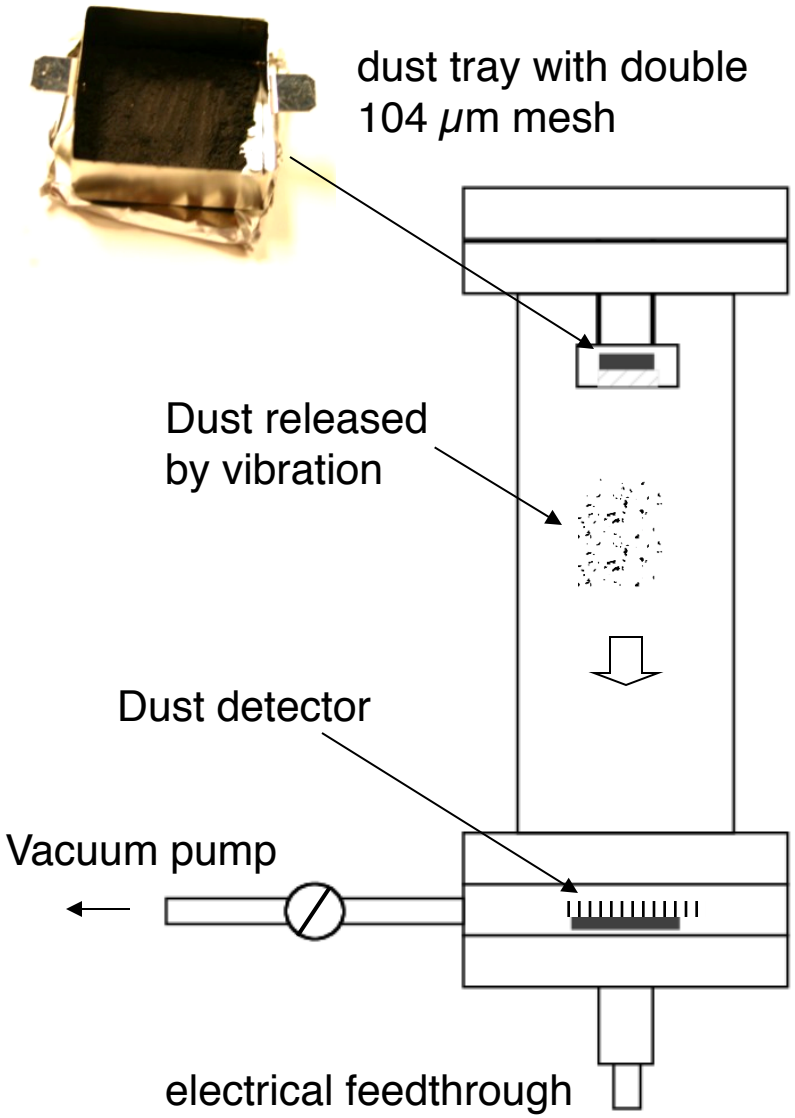
- First detector (2004) worked well in air and vacuum.
  sensitivity in vacuum: ~70 $\mu g/cm^2$ = 54 counts.
  However average dust level measured on NSTX (by weighing dust collected on slide) = 5.6 ng/cm^2/discharge.

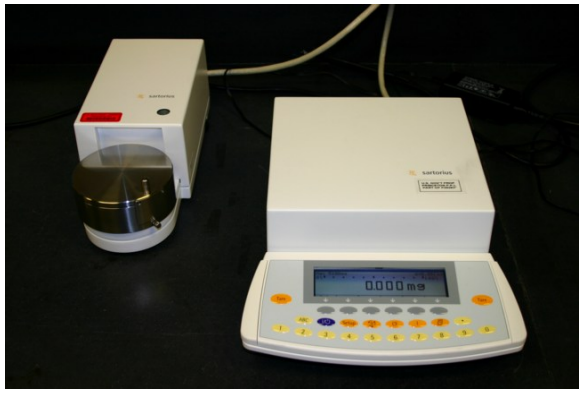
- **x10^4** increase in sensitivity needed to measure NSTX dust (not a problem for ITER dust levels).

  Strategy…
  1. Increase detector area
  2. Finer grids
  3. Upgrade electronics

Credit to National Undergraduate Fellows: A. Bader, D. Boyle, A. Campos, C. Parker, R. Hensley, C. Voinier

Laboratory Setup:



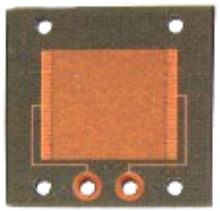


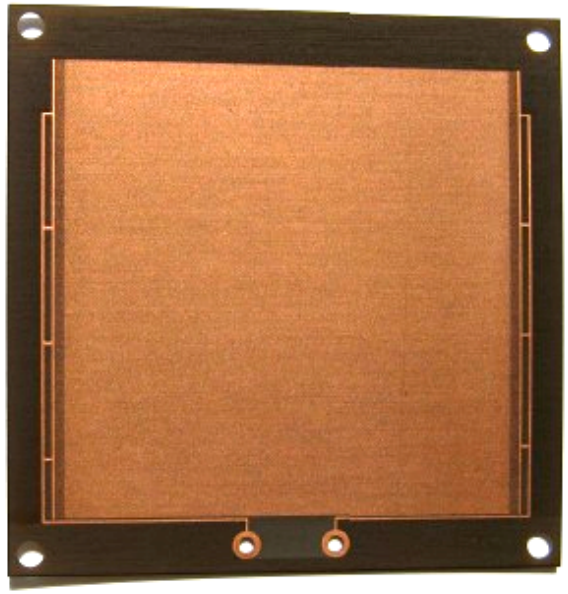
Microbalance to weigh dust before and after release.
5 g capacity 1 μg readibility
(fingerprint weighs 40 μg)

Image of dust scraped from tile
count median diameter 2.14 μm
(cf NSTX dust: 2.06 μm)

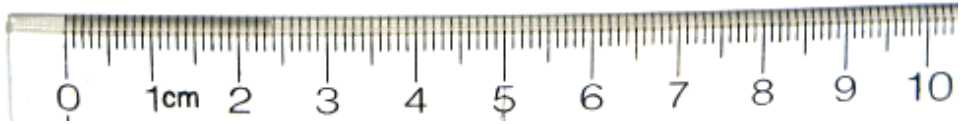
1. Increase detector area:

initial
1.2 x 1.2 cm
grid





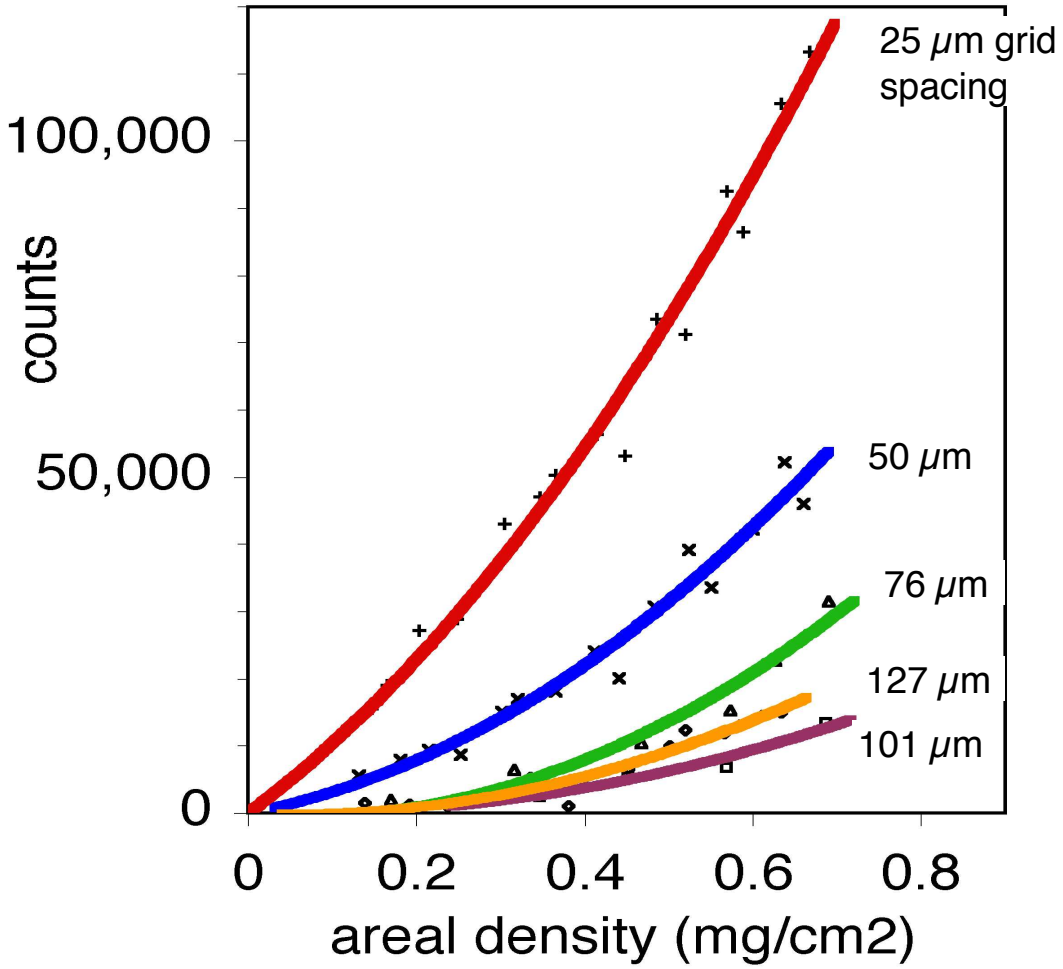
5 x 5 cm grid



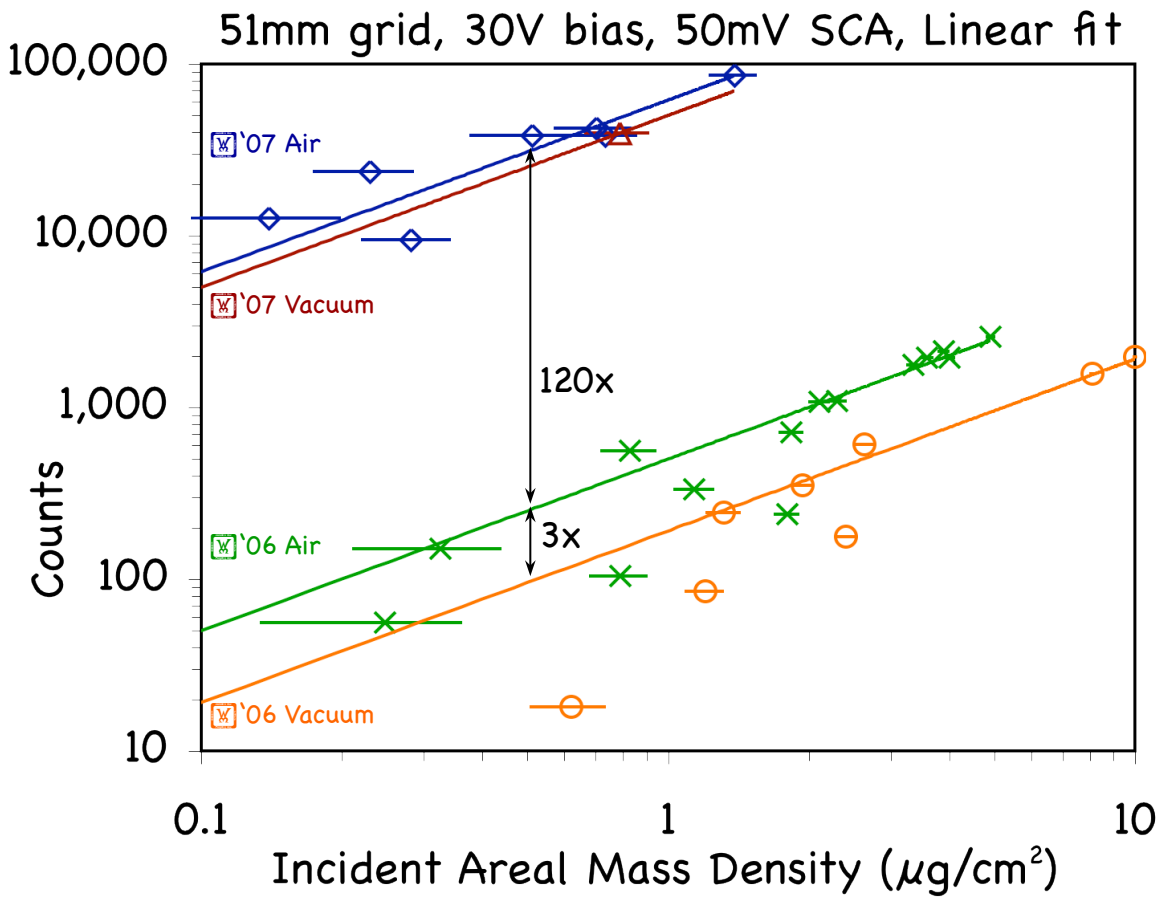
Both have 25 μm trace spacing.
5x5 cm grid has 16x area and
50 m of 25 μm spacing !

2. Finer grids

Sensitivity increased 30x with finer grids



3. Remove low pass RC filter

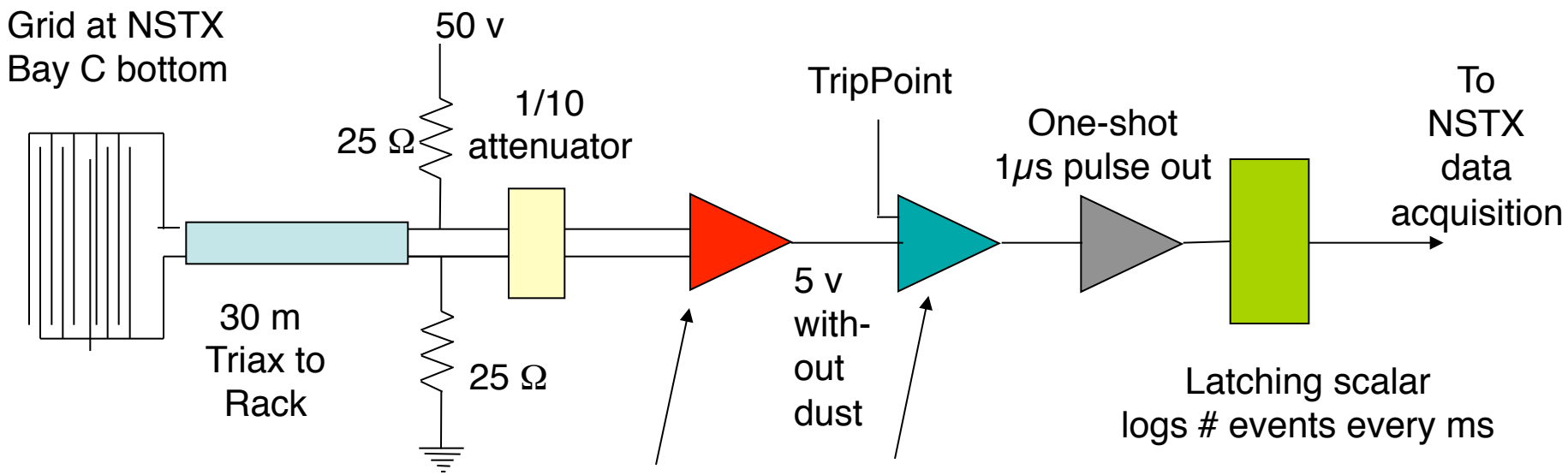


Detection threshold reduced 50-120x: now 4,000 counts for 100 ng/cm^2 !

But high sensitivity lead to electrical pickup in NSTX environment.

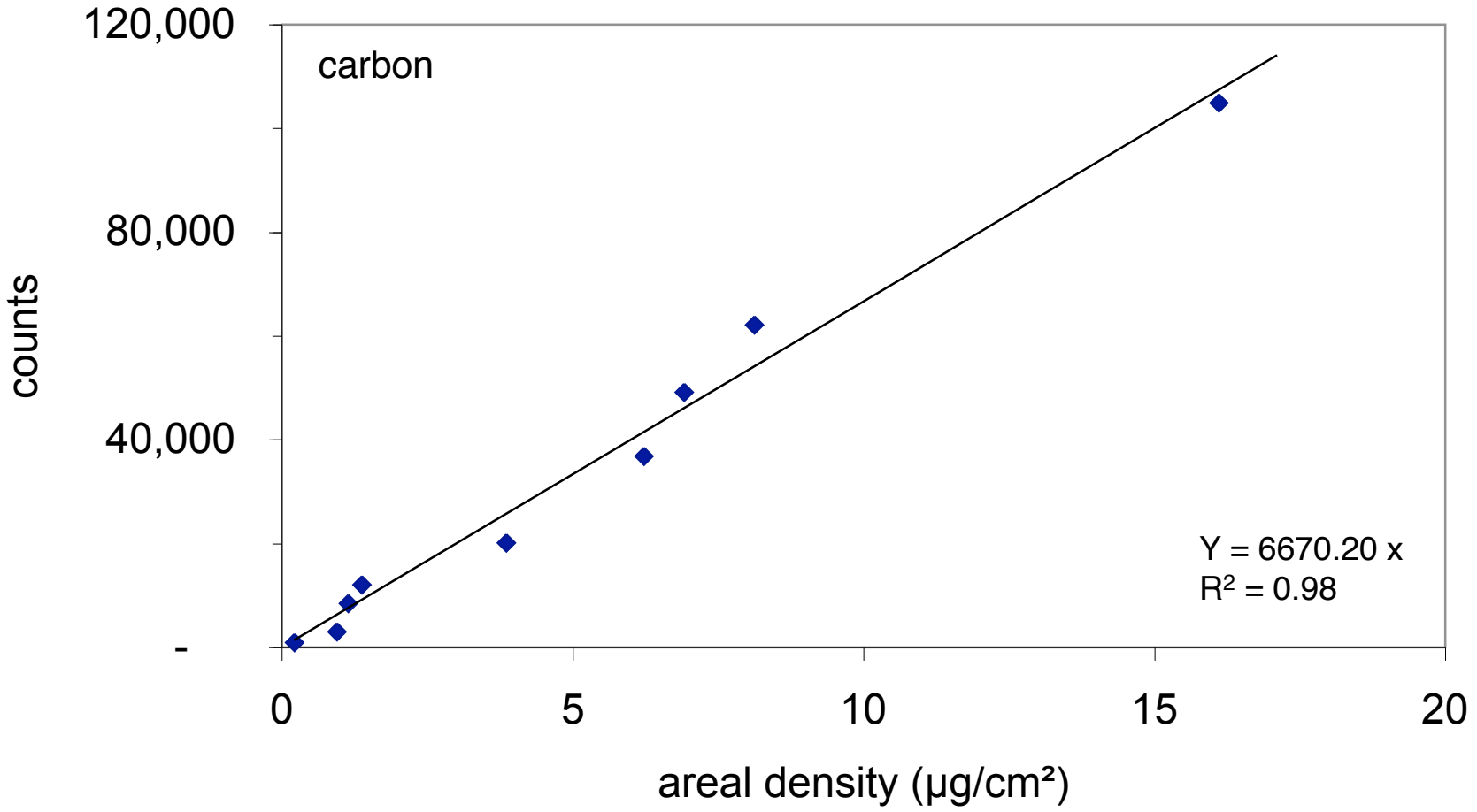
Differential detection electronics

SPAs and RF antenna are a powerful source of noise on NSTX.
New differential circuit has high immunity from electrical noise pickup.



Credit: Bob Marsala

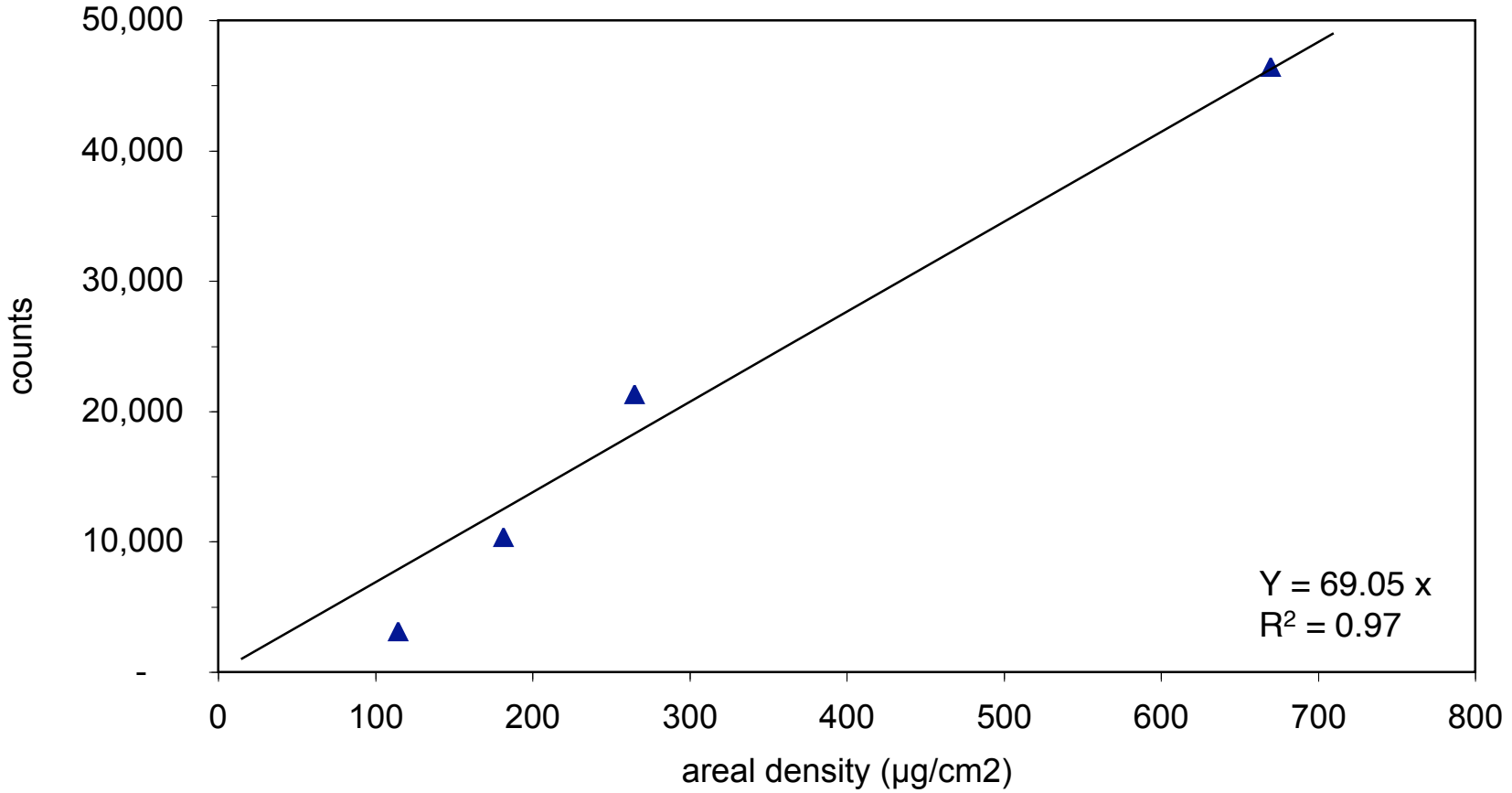
Calibration for carbon particles



Extremely sensitive: 0.15 ng/cm^2/count
(51 mm grid, 25 µm spacing, 50 v bias in vacuum)

Credit: Bilel Rais

Calibration for lithium particles



Lithium particles 40 µm diameter (used for wall conditioning)

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

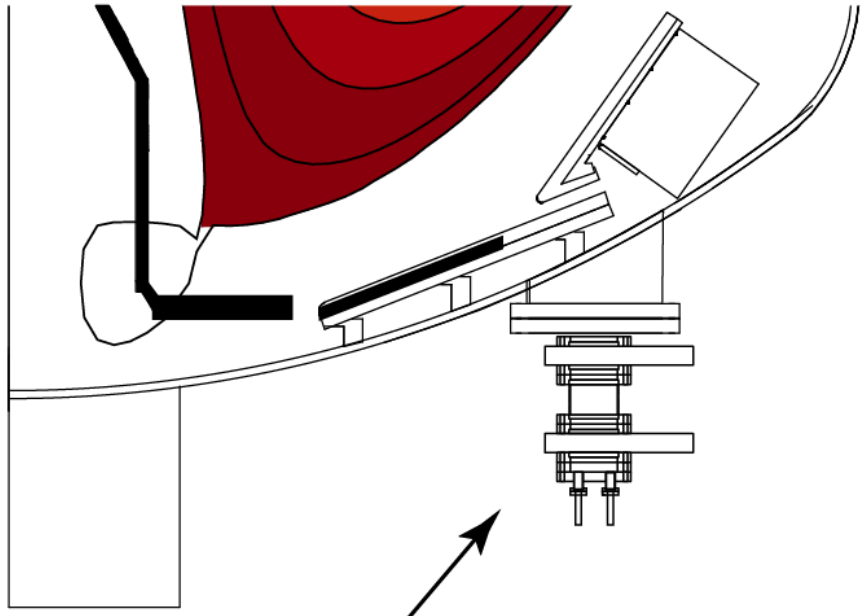
Threshold Sensitivity 14.5 ng/cm^2/count

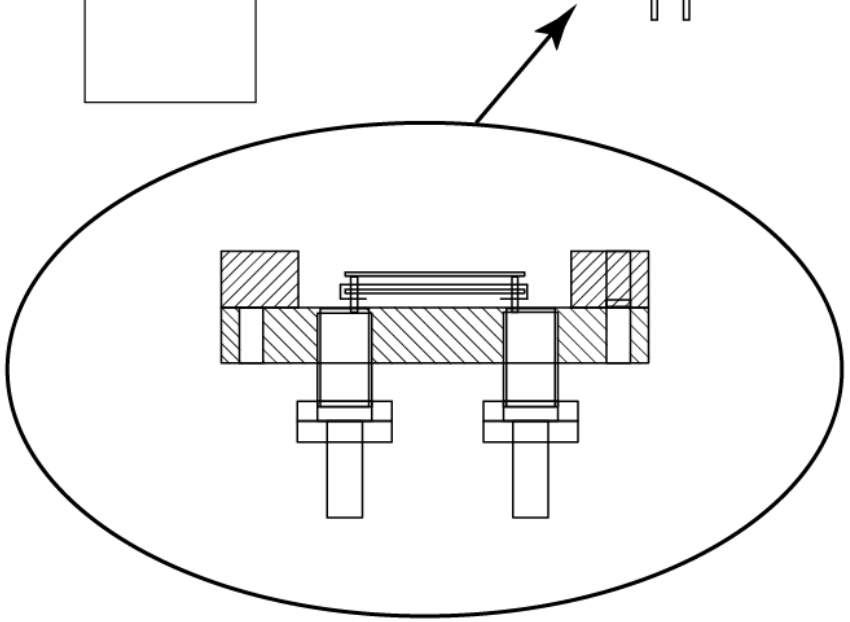
(fewer particles than C for a given mass)

Credit: Bilel Rais

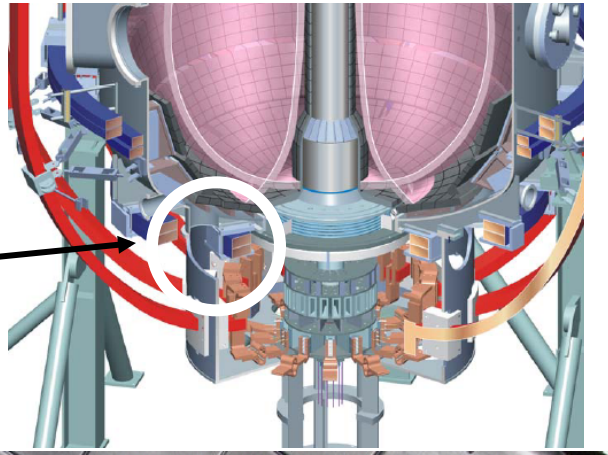
NSTX installation

Installation in lower port on NSTX.

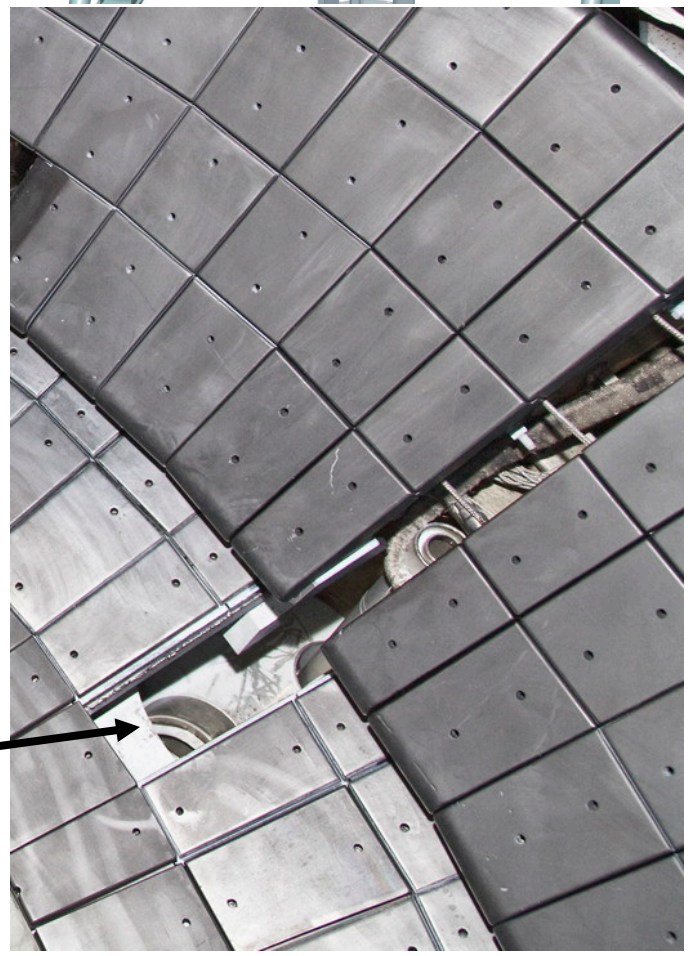




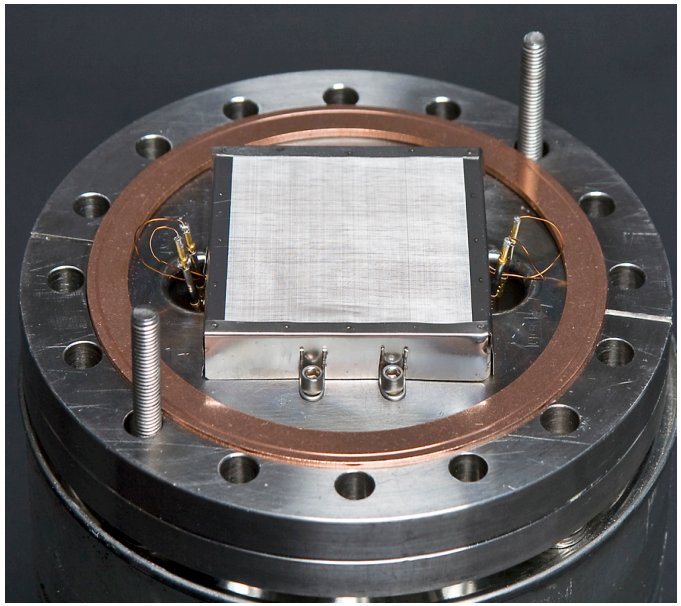
Location: in lower port



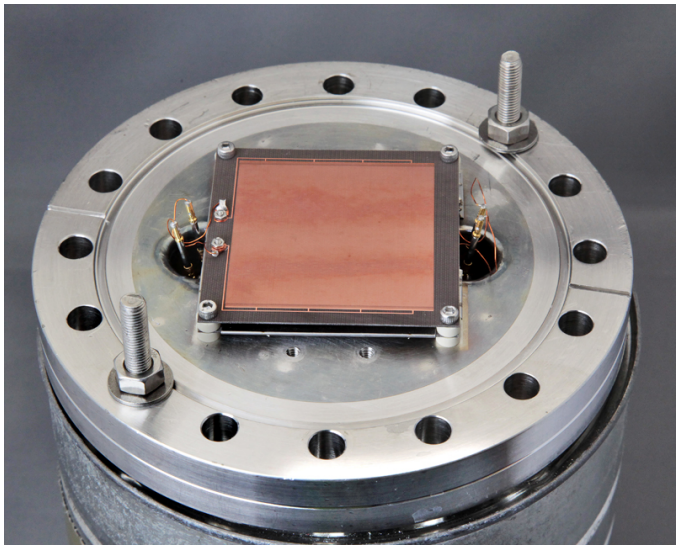
Detector below



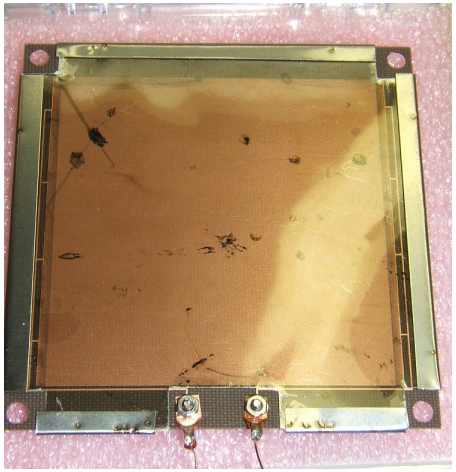
Detector in NSTX



Mesh cover (90 μm pore size) shields from fibers and large particles that might cause a permanent short.



Two grids in same electrical environment.
Only upper grid (Ch.1) exposed to dust.



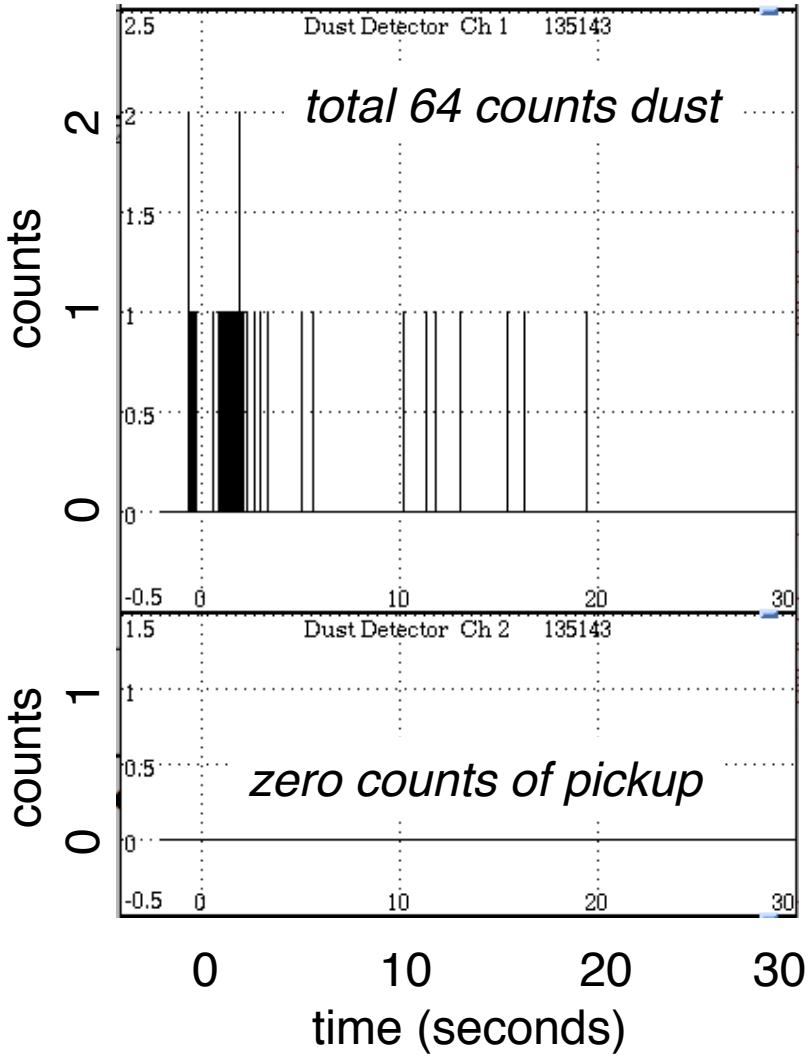
Mica cover shields lower grid (Ch.2).

Additional covered detector detects only electrical pickup.

Credit: Tom Provost

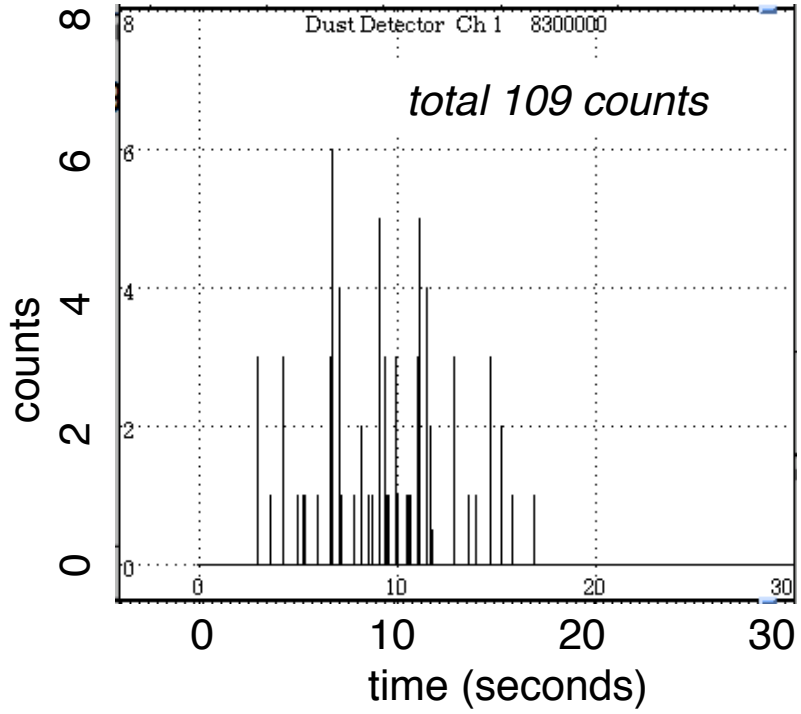
First tokamak dust signals:

Dust signal from NSTX



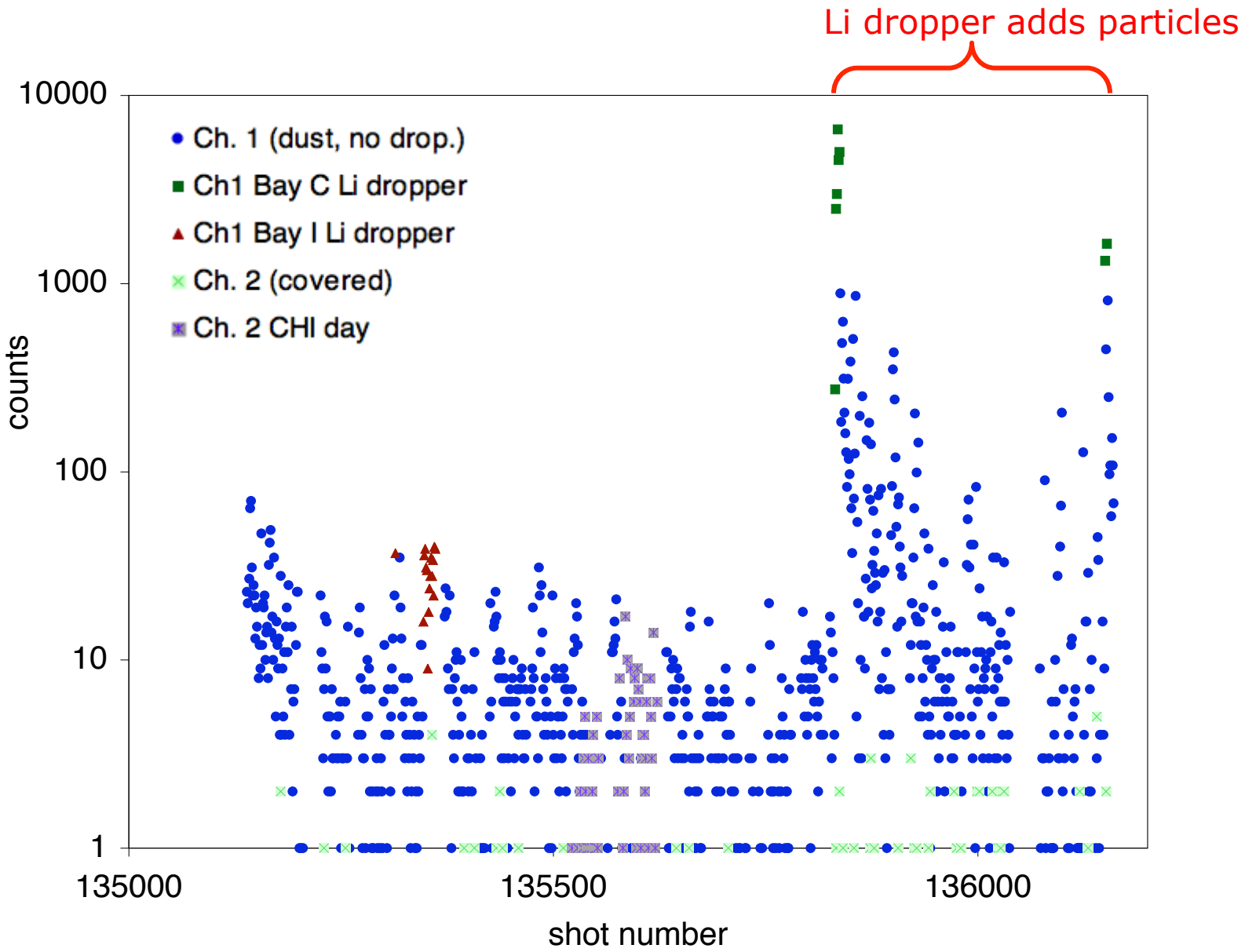
(50 mm, 25 μm grid, vacuum, 50 v).

For comparison:
signal from lab dust source.



Lab dust signal recorded by unipolar electronics.
(12 mm, 25 μm grid, air, 30 v).

Dust signals July-Aug, 2009:



Summary of part I:

- FIRST real-time measurements of surface dust in ANY tokamak.
- High threshold sensitivity to carbon dust
  0.15 ng/cm^2/count
  - suitable for contemporary tokamaks.

Measurements validated by:

1. NSTX signal similar to lab dust source.
2. No signal on covered detector as expected.
3. Large increase in signal with Li particles.

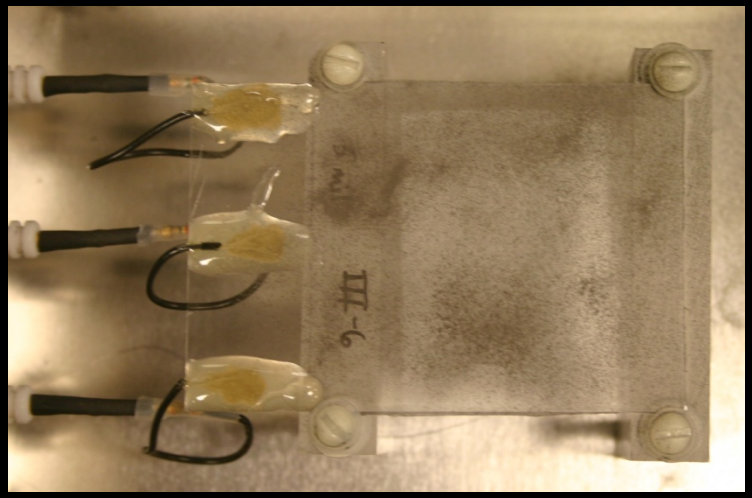
Further development needed for ITER environment (more rugged, less sensitive, radiation hardened…)

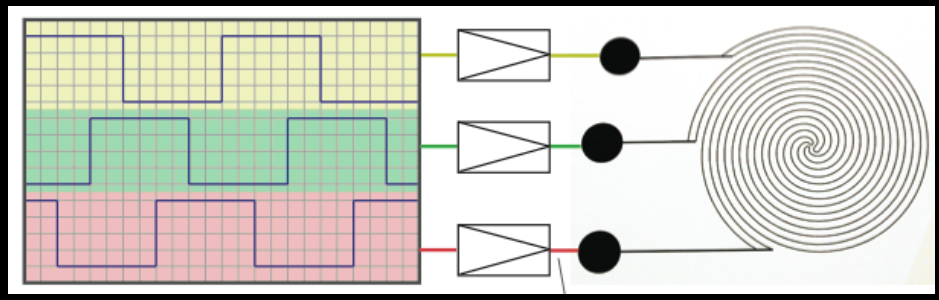
PPPL report 4517 available at: http://www.pppl.gov/pub_report/2010/reports-2010.html
accepted for Rev. Sci. Instrum. (2010).

1st results on dust removal with electrostatic travelling wave

Forrest Friesen, Grinell U, Brendan John, Swarthmore, Carlos Calle (NASA)

~5 μm W particles on dust conveyor





After:

- +500v pre charge for 10s
- 3000v, 50hz traveling wave