First real-time detection of surface dust in a tokamak

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Motivation:

- In-vessel dust has important safety and operational consequences for ITER.
- Amount of dust in ITER is high due to more intense PMI and longer pulse length.

1. 670 kg is limit on mobilizable cold dust (public safety).
2. 6 kg is limit on W, Be, C hot dust
   - (vacuum vessel integrity - really a 4 kg H_2 2 bar overpressure limit)
3. Transport of W dust could prevent fusion burn (limit unknown).
4. Dust could obscure diagnostic first mirrors (limit unknown).

- Tritiated dust can levitate
- Is more hazardous than HTO vapor.

ITER plans:

- Diagnose dust inventory from divertor erosion measurements (laser rangefinder).
- Plus local dust monitors (so far not demonstrated in tokamaks).

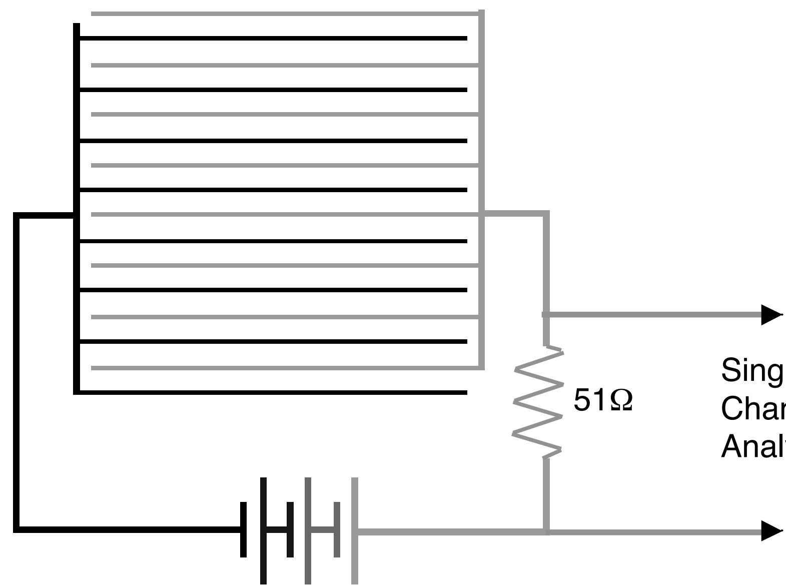
Outline of talk:

- Electrostatic surface dust detector developed at PPPL.
- Large (~ x10,000) improvements in sensitivity.
- First demonstration in NSTX.

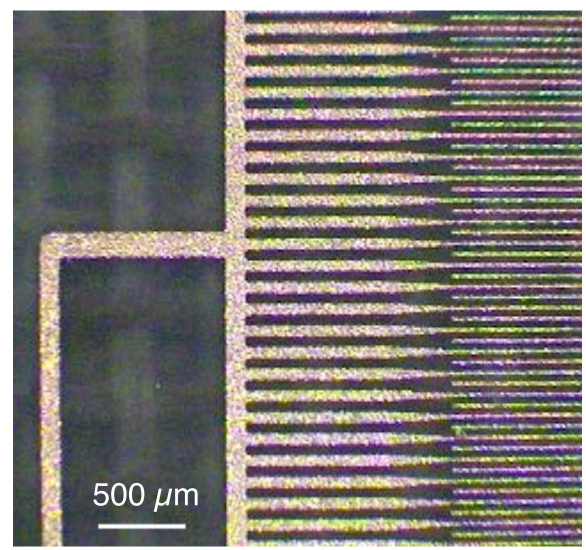
Electrostatic Detection of dust settling on surfaces.

- 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



Grid with 25 micron spacing



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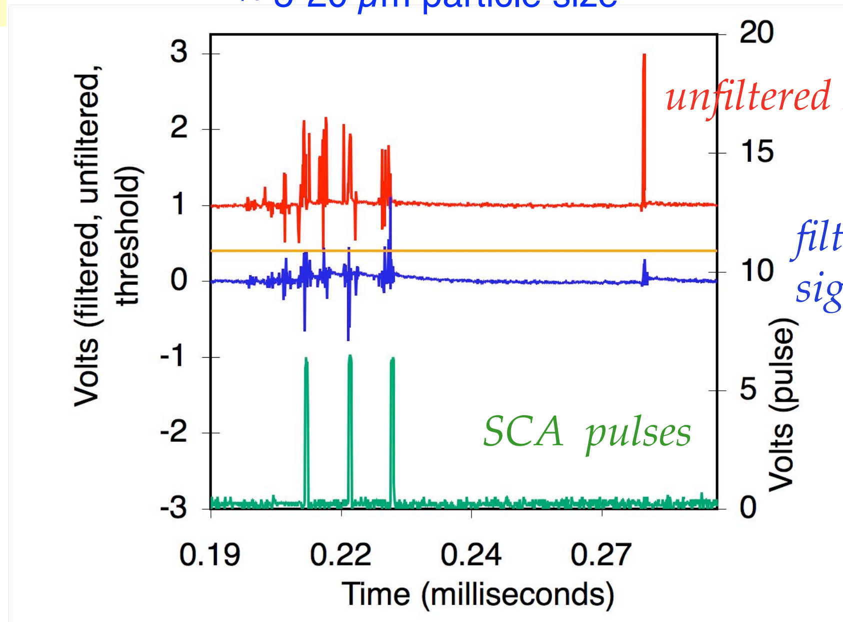
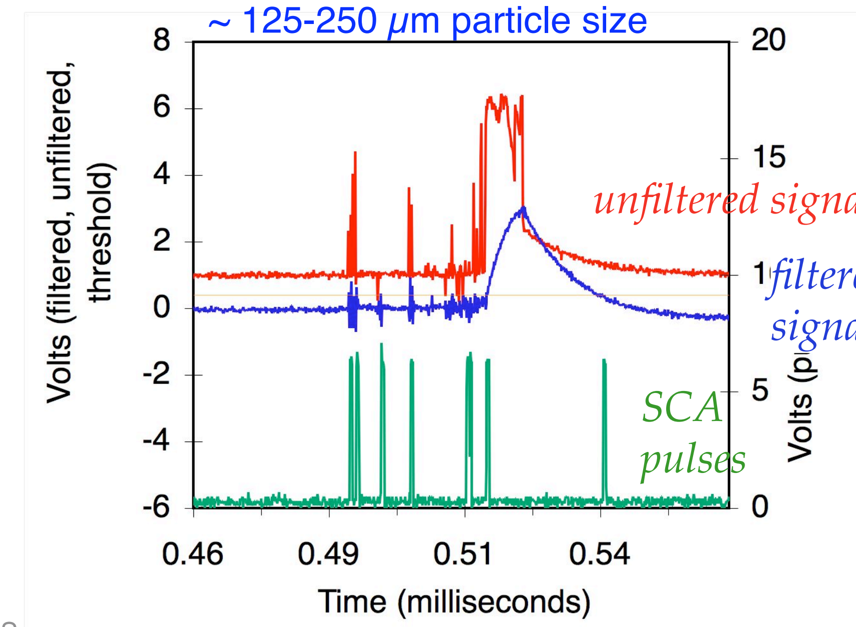
Electrostatic Dust Detector in action

Waveform contains information on dust size

~ 5-20 μm particle size





Complex waveform converted into counts by standard nuclear counting electronics.

What it took to make this work on NSTX:

First detector (2004) worked well in air and vacuum 2004 detector
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.

Large increase in sensitivity needed to measure NSTX dust (ITER not a problem).

Problems:

- Tried lower SCA threshold - but noise increased also.
- Higher bias resistor - but noise increased also.
- Lower bias voltage - more counts but more permanent shorts.
- Electrical pick up on NSTX from SPAs and RF made identification of dust signals ambiguous.

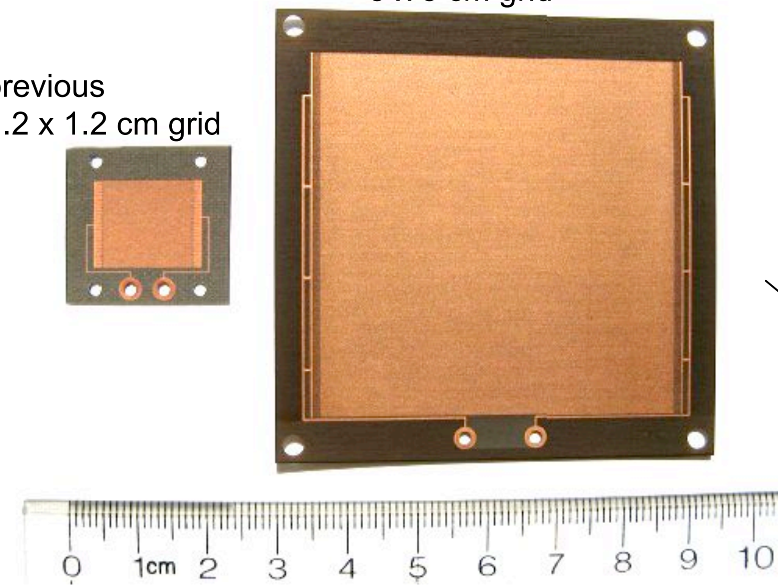
Ingredients for success:

1. Increase grid area from 12 x 12 mm to 50 x 50 mm: x16 increase in sensitivity
2. Decrease grid spacing from 125 μm to 25 μm: x 30 increase in sensitivity
3. Remove low pass filter: x 50 - x120 increase in sensitivity.
4. Installation of 'second blind' grid shielded from dust and sensitive only to pickup.
5. Differential detection electronics with high noise immunity (Bob Marsala).
6. Plus hard work by 6 summer undergraduate students.

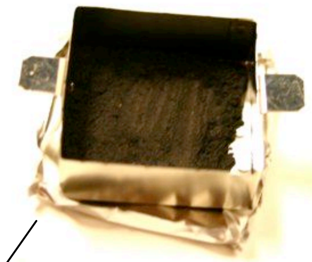
Lab tests of large area detectors:

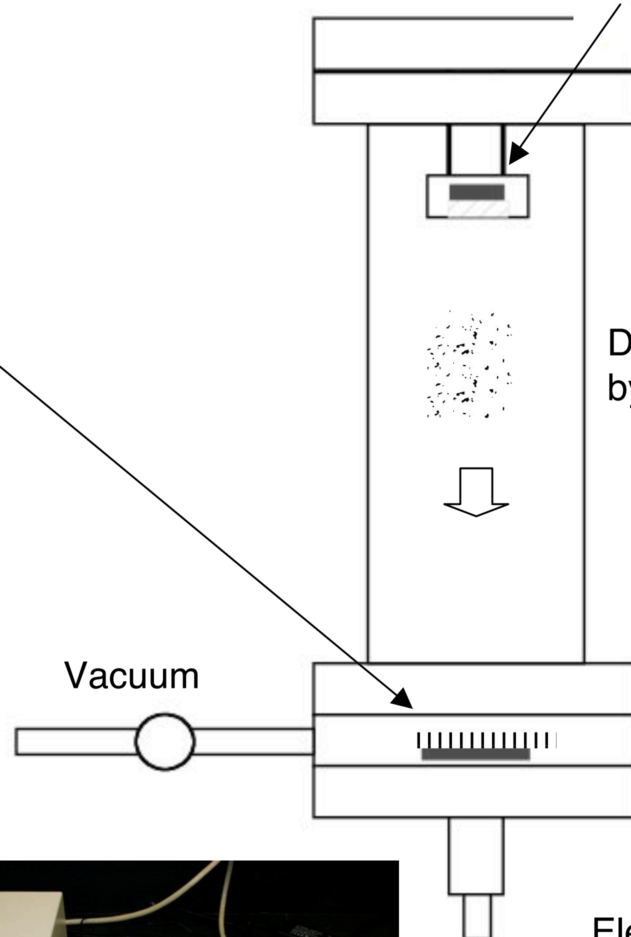
5 x 5 cm grid

previous
1.2 x 1.2 cm grid



Dust tray with double
104 micron mesh

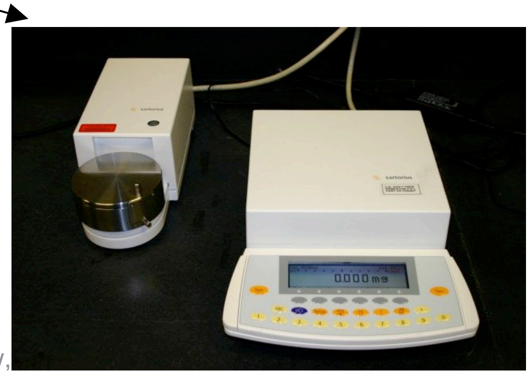




Dust released
by vibration

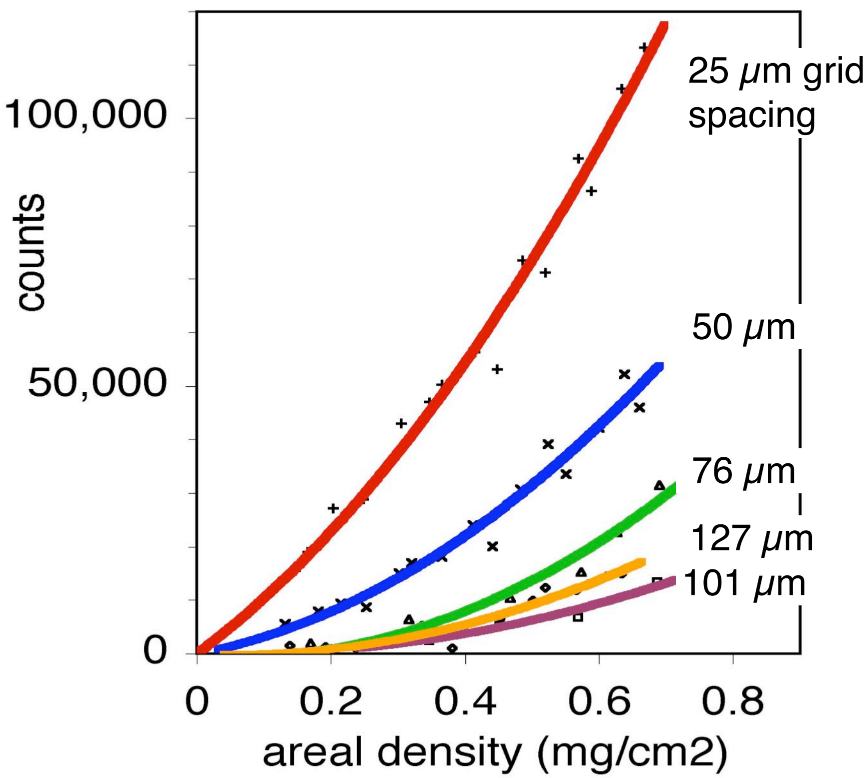
Electrical
Feedthrough

- 5x5 cm grid has 16 times larger area
- 25 μm trace spacing
- 100 times more sensitive balance
  - 5 gram capacity with
    0.000 001 gram readability
- Extreme precautions needed
  - (fingerprint weighs 40 μg)

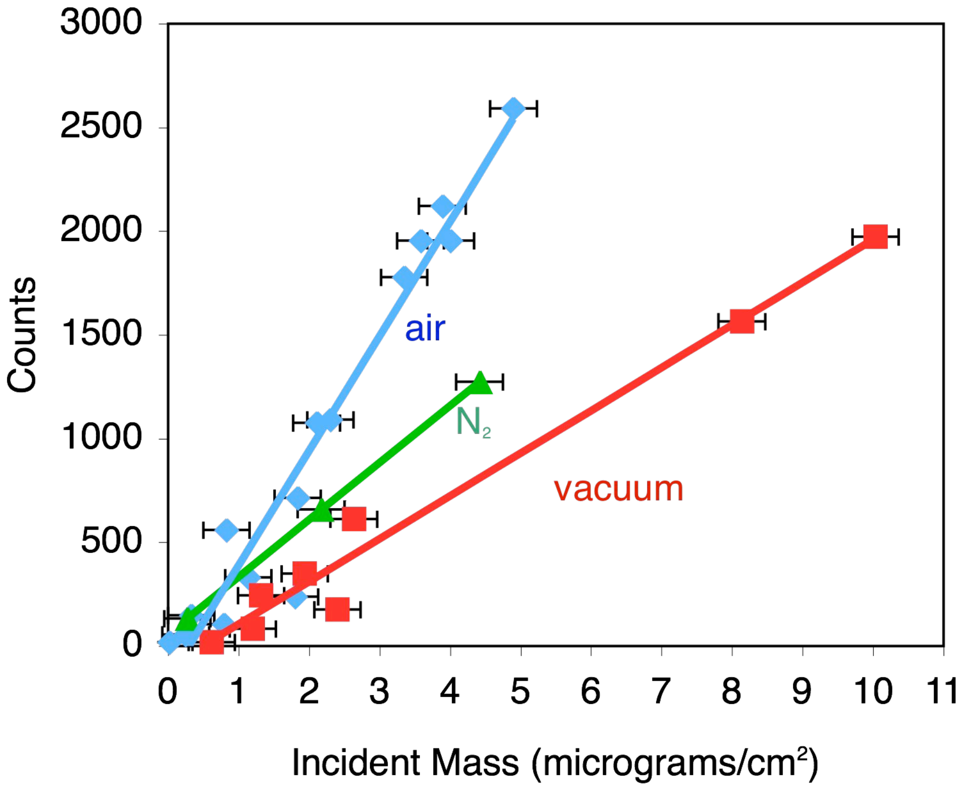


Optimization in laboratory

Sensitivity increased 30x with finer grids

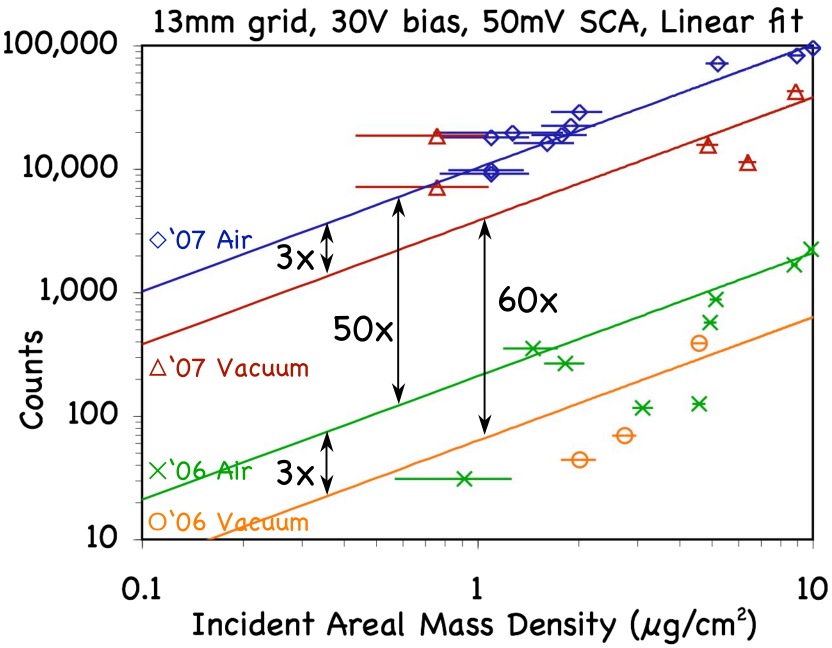


50 mm detector response linear down to ≈1 μg/cm²



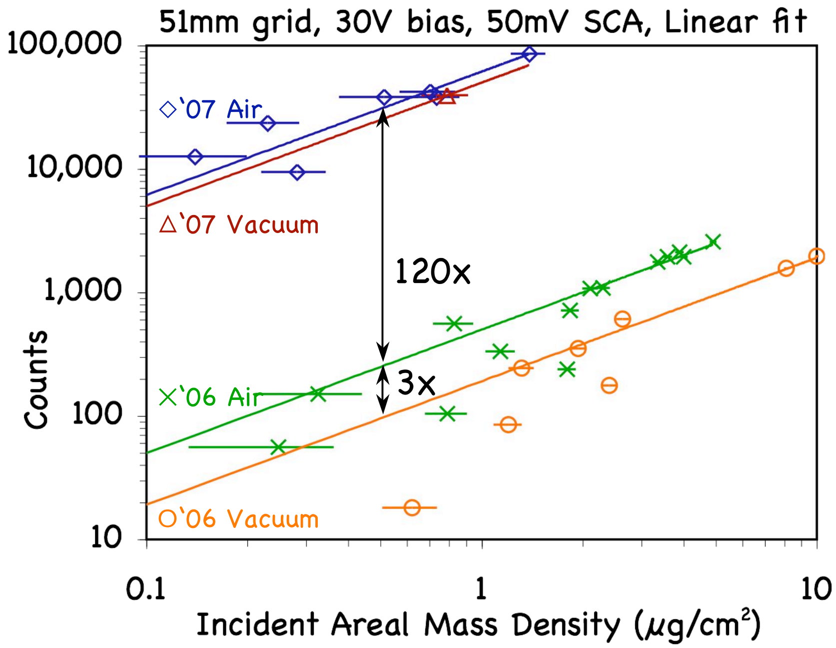
Overall detection threshold reduced 50-120x without low pass RC filter

Small grid



'07 points without RC filter
'06 points with RC filter

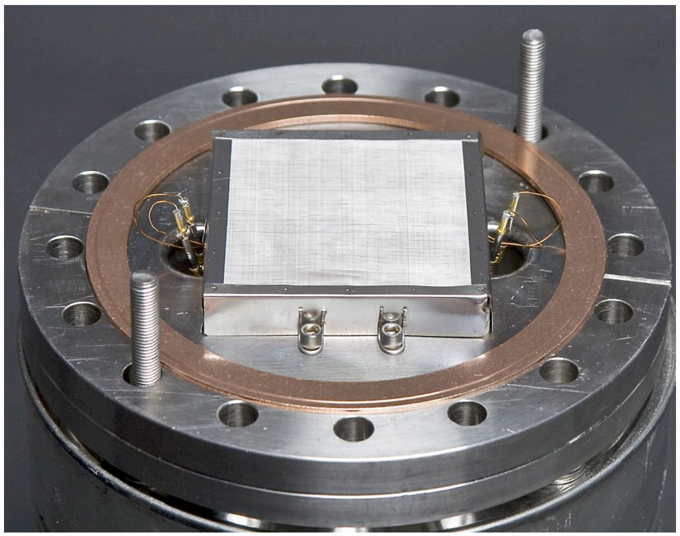
Large grid



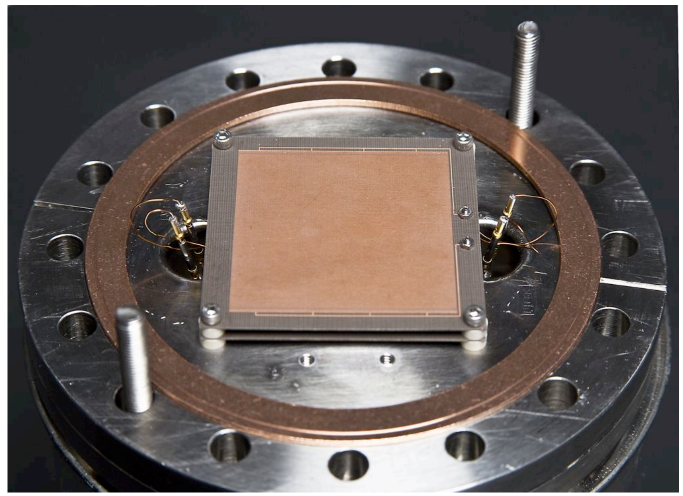
4,000 counts for 100 ng/cm2 !

Dual grid assembly

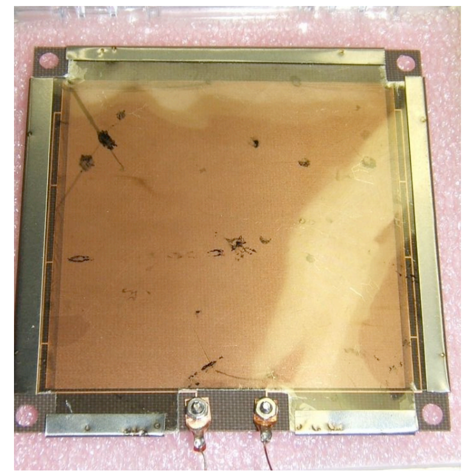
- Increase in sensitivity also increased pick up of electrical noise.
- Additional 'blind' detector implemented to assess contribution of electrical pickup (detector covered with mica to prevent dust settling).



Grid assembly ready for installation on Bay C bottom. Note mesh cover (125 μm pore size) to shield from fibers and large particles that could cause a permanent short.



Dual grid system.
Both grids in same electrical environment.
Only top grid (#1) exposed to dust.



Mica cover to shield bottom grid (#2).

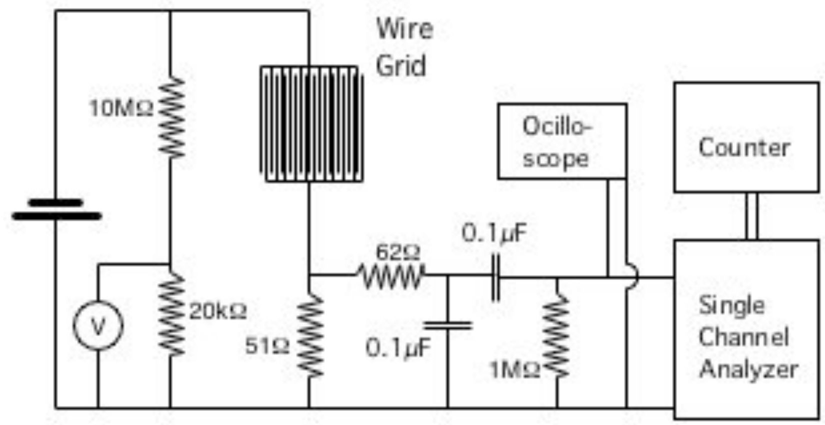
Differential detection:

SPAs and RF are a powerful source of noise.

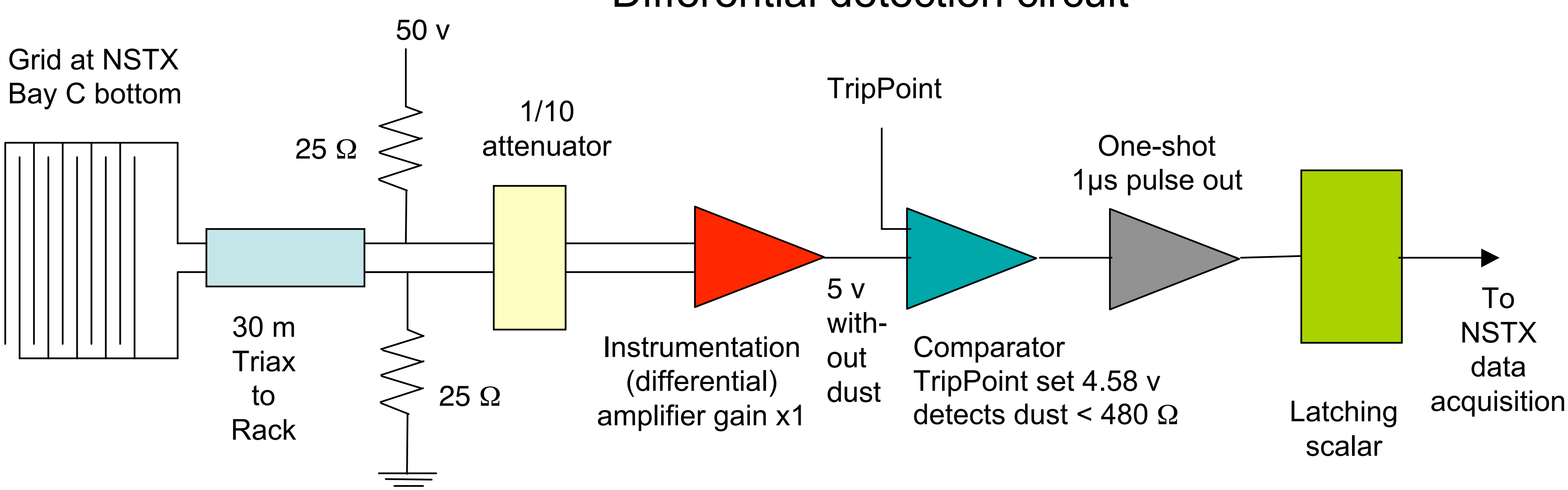
First detection circuit suffered from electrical noise pickup - - > .

Differential circuit designed by Bob Marsala has high noise immunity.

First detection circuit

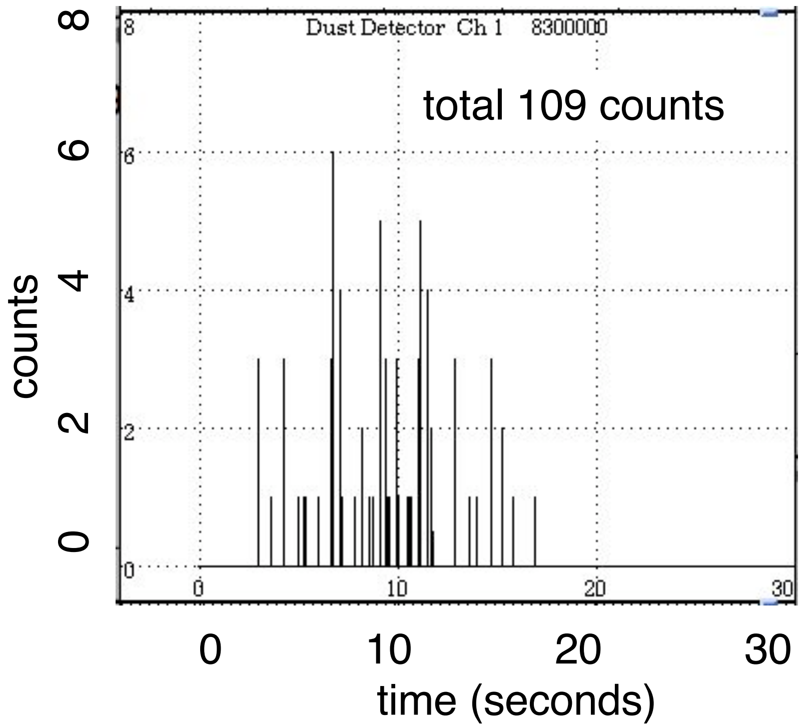


Differential detection circuit



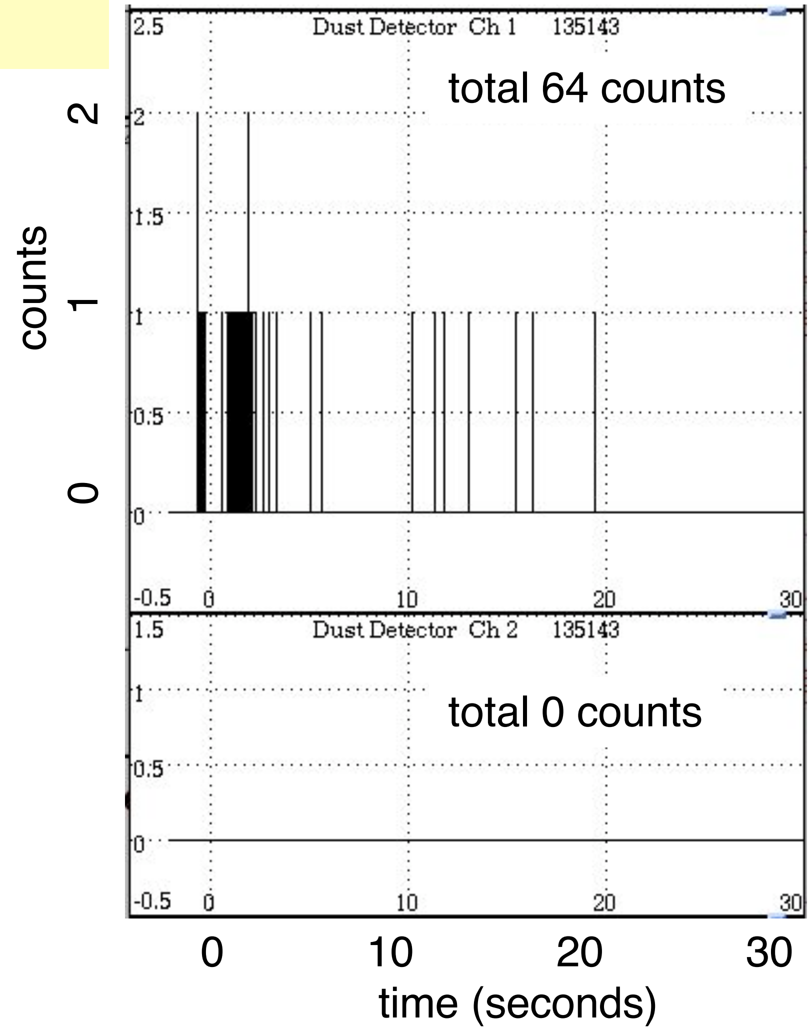
Detector signals from first day

Signal from lab dust source.



Signal from lab dust source recorded by first electronics, input to 911 latching scalar.
(12 mm grid, 25 μm grid, air, 30 v)
Note extended duration.

Example:
Signals from NSTX 135143.

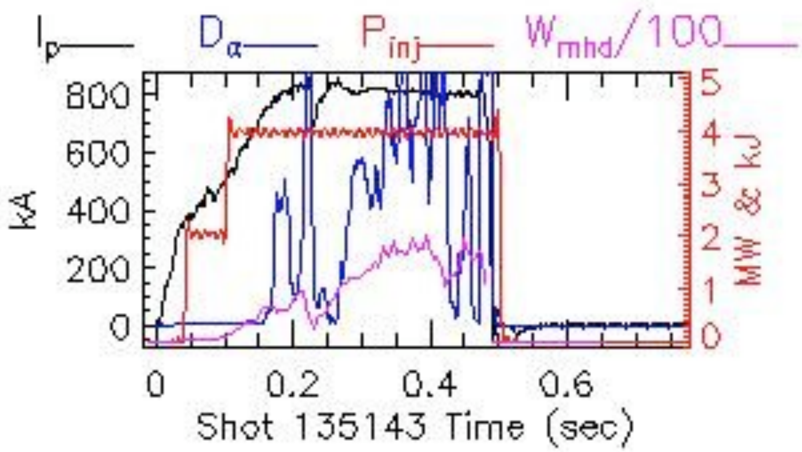


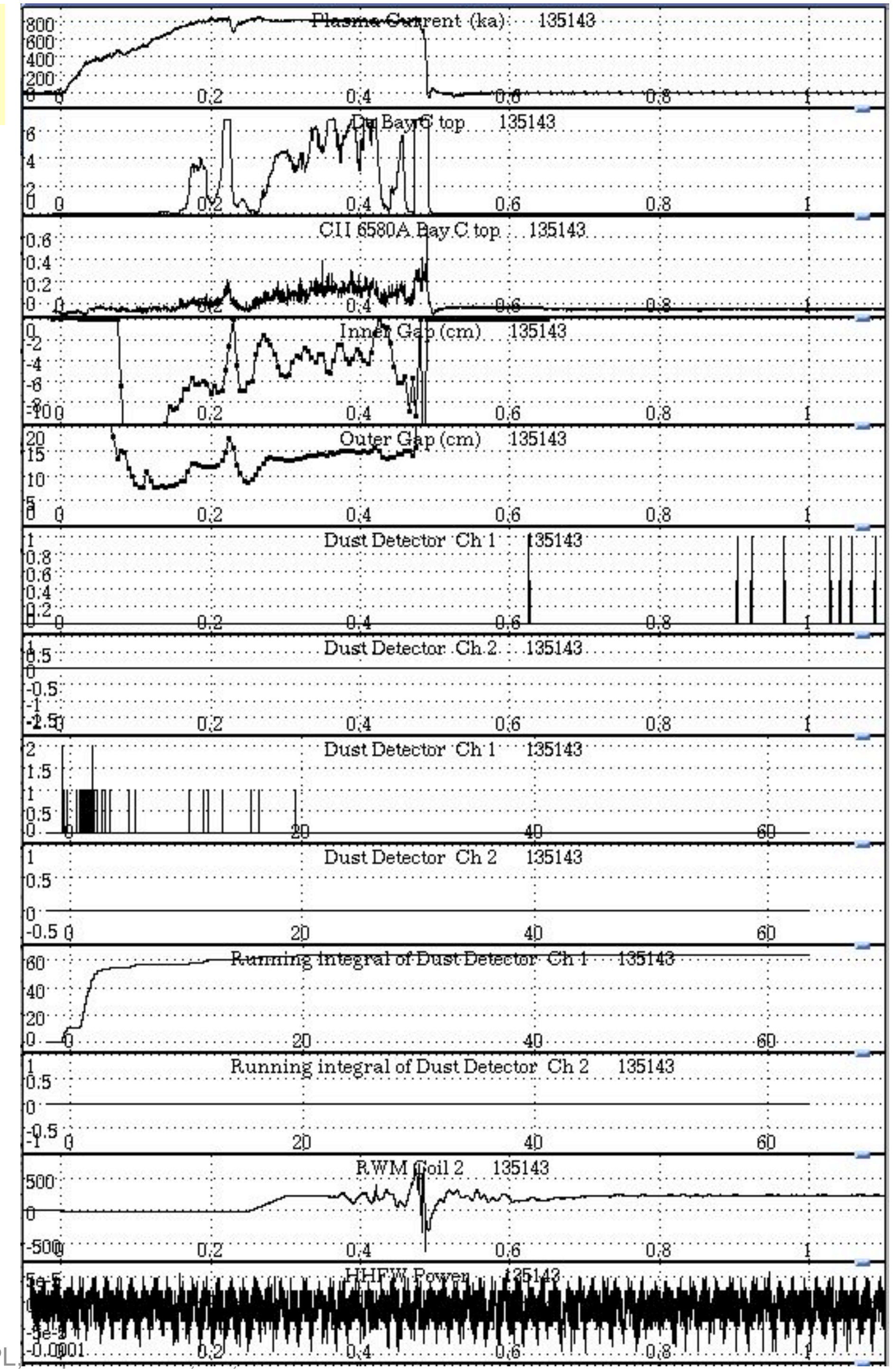
Signal from differential electronics to 911 latching scalar.
(50 mm grid, 25 μm grid, vac., 50 v)
Note zero counts on Ch 2 ‘blind’ detector.

More Signals from 135143

Signal on Channel 1
No pickup on 'blind' Channel 2 even with RWM coils

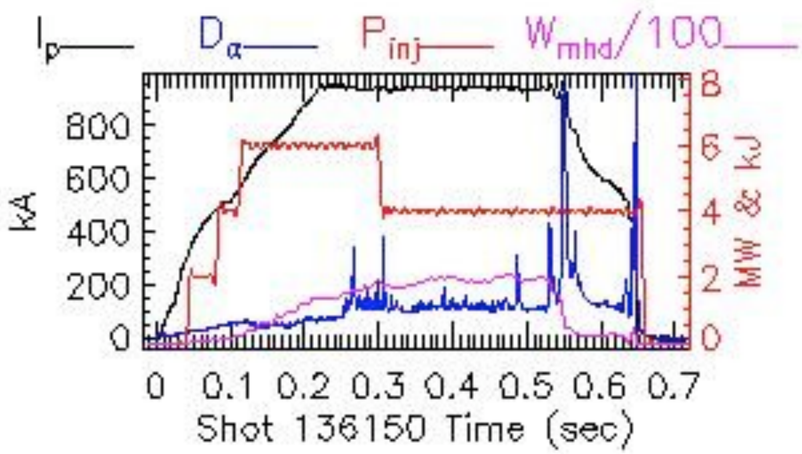
```
Logbook:
135143  XP#  942   BOUNDARY PHYSICS   Jul
21 2009 08:47AM   asontag
Reload 133886 which had strike point
control. Raise Ip to 800 kA and drop  Bt
to 4.5 kGauss. Drops out of H-mode @ 210
ms - gas too low
----------------------
135143  XP#  942   PHYS OPS           Jul
21 2009 08:48AM   MUELLER
Reload 133886, but Ip 800 kA, TF 4.5 kG,
This shot has lower outer strikepoint
control. A,B at 40, 80 ms, no C, CS 900 T
into H-mode around 150 ms, big ELM or
falling out at 220 ms
```

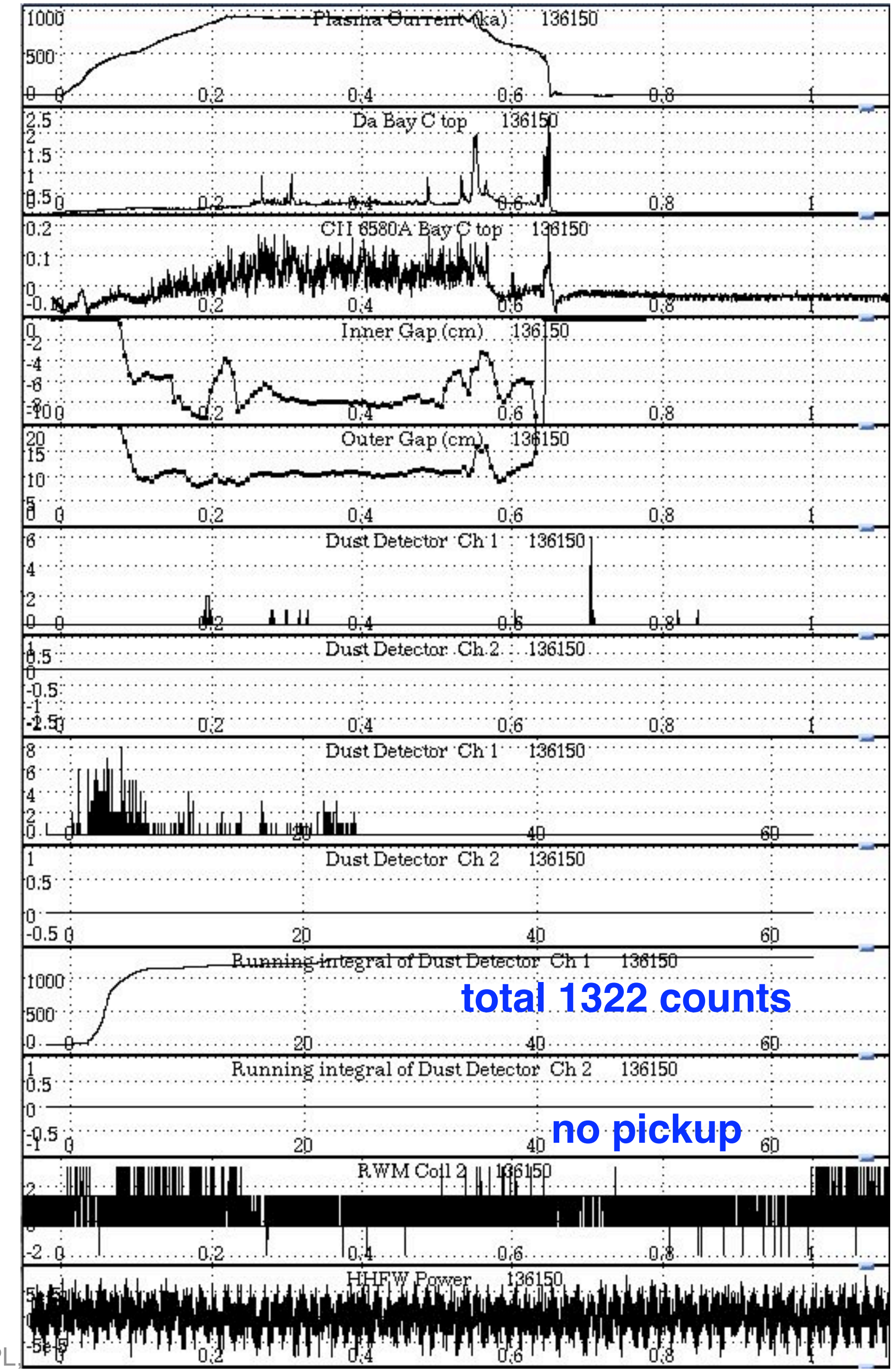




Last day of run with Li dropper

```
136150   XP#  955   PHYS OPS   Aug 14 2009
11:37AM    MUELLER
Repeat with Li dropper (5V 45 mg 1.3s
starts -970 ms Bay C only)
No EFC or n=1 feedback. )K
------------------------------------------
136150   XP#  955   IMPURITIES   Aug 14 2009
11:43AM    spaul
Steady rise of hollow Pad profile, but
large reconnection events at .264 at .306
sec.
```





Summary:

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- FIRST real-time measurements of surface dust in ANY tokamak.
- Up to 100 counts without Li dropper,
- Up to 6589 counts with Li dropper.
- Blind channel registers zero or few counts.
- Time resolution ~ 10-20 s.
- Vibration can cause existing dust to register counts.

Future work:

- Lab calibration of ng/cm^2/ count with new electronics.
- He puffer to remove dust.
- 3-phase grid to demonstrate dust removal.
- Rugged radiation resistant version for ITER.