CMS Preshower Leakage Currents Measurements and Observations

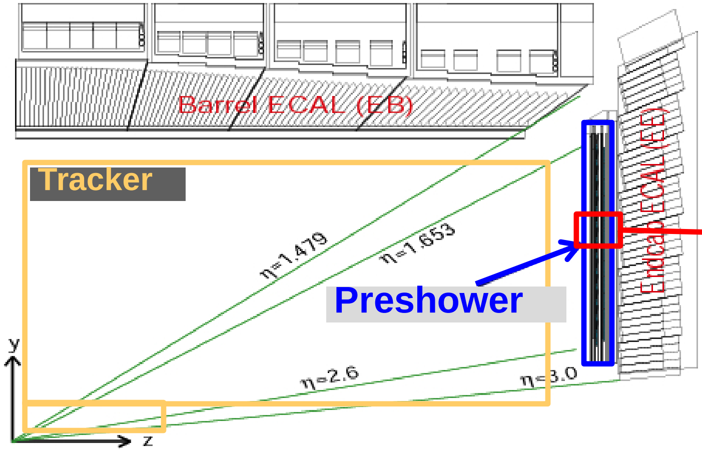
Alan Honma
on behalf of the CMS Collaboration

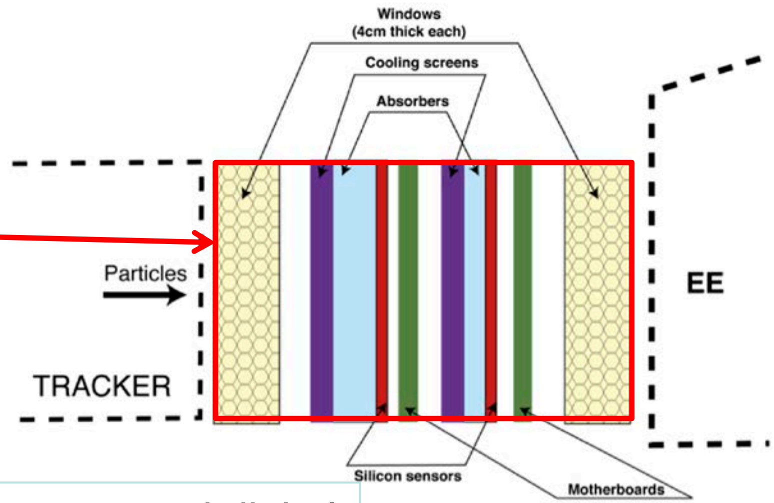
Outline

1. Description of the Preshower detector
2. Leakage current measurements
3. Simulation and estimation of fluence and annealing
4. Anomalous large leakage currents
5. Summary

The CMS Preshower detector

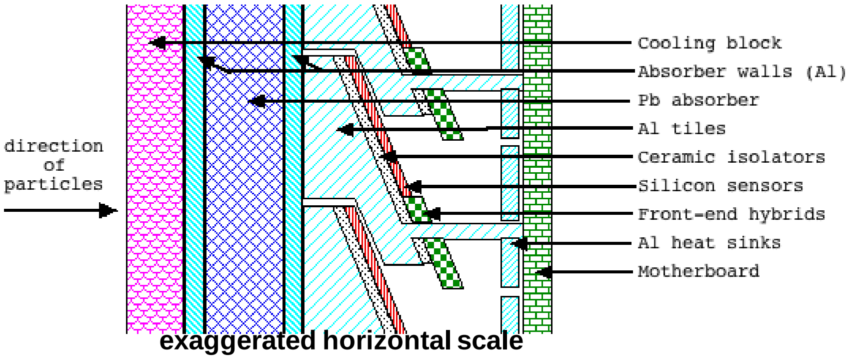
The Preshower detector is part of the endcap electromagnetic (EE) calorimeter providing position and energy measurements for electromagnetic showers.



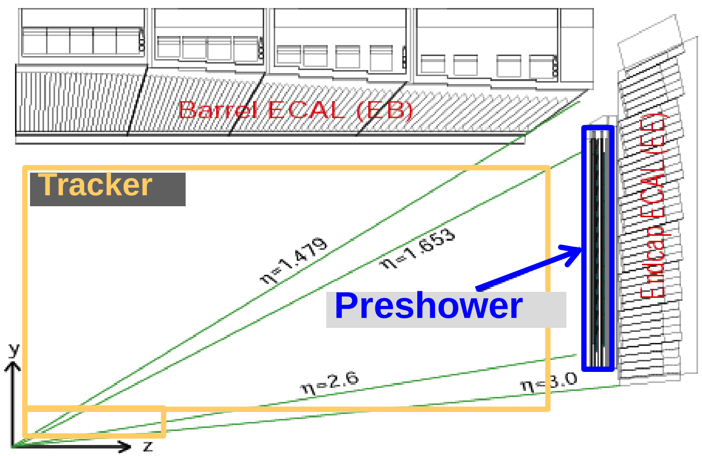


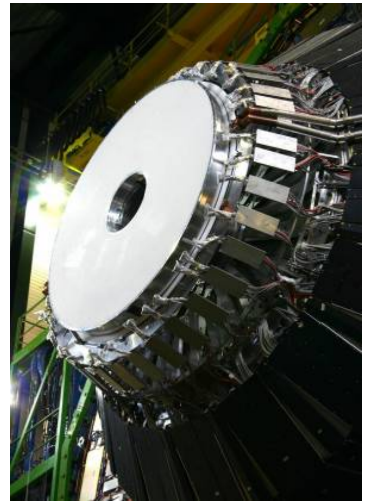
2 layers of lead absorbers each followed by Si sensors and digital electronics at Z ≈ ±3m and 45 cm < R <121 cm (1.653 < η < 2.6).

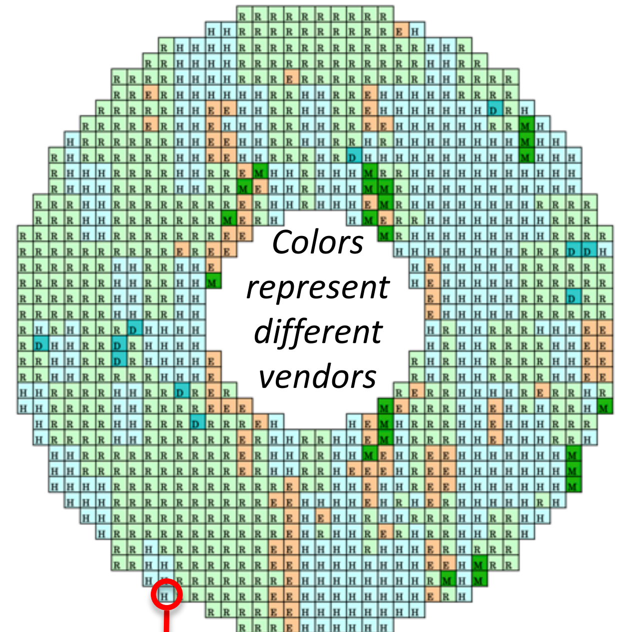
Very efficient cooling of the absorbers
Provides good heat evacuation from the electronics. Si temperature 2°C above the absorber temperature, stable and uniform over the whole surface to 0.5°C

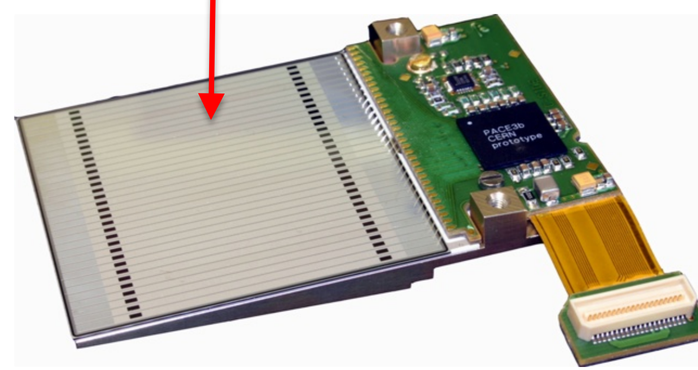


The CMS Preshower detector









Si sensors:

p-on-n , DC coupled, 63×63×0.32 mm^3, 32 strips each 1.9 mm wide.
4288 total, 1072 per absorber plane. A total of ~16m^2 of silicon sensors.

Produced by 6 vendors from Russia, India, Japan, Taiwan and Greece.

Leakage Current Measurements

For 2010-2011, had 192 HV channels for the 4288 sensors.

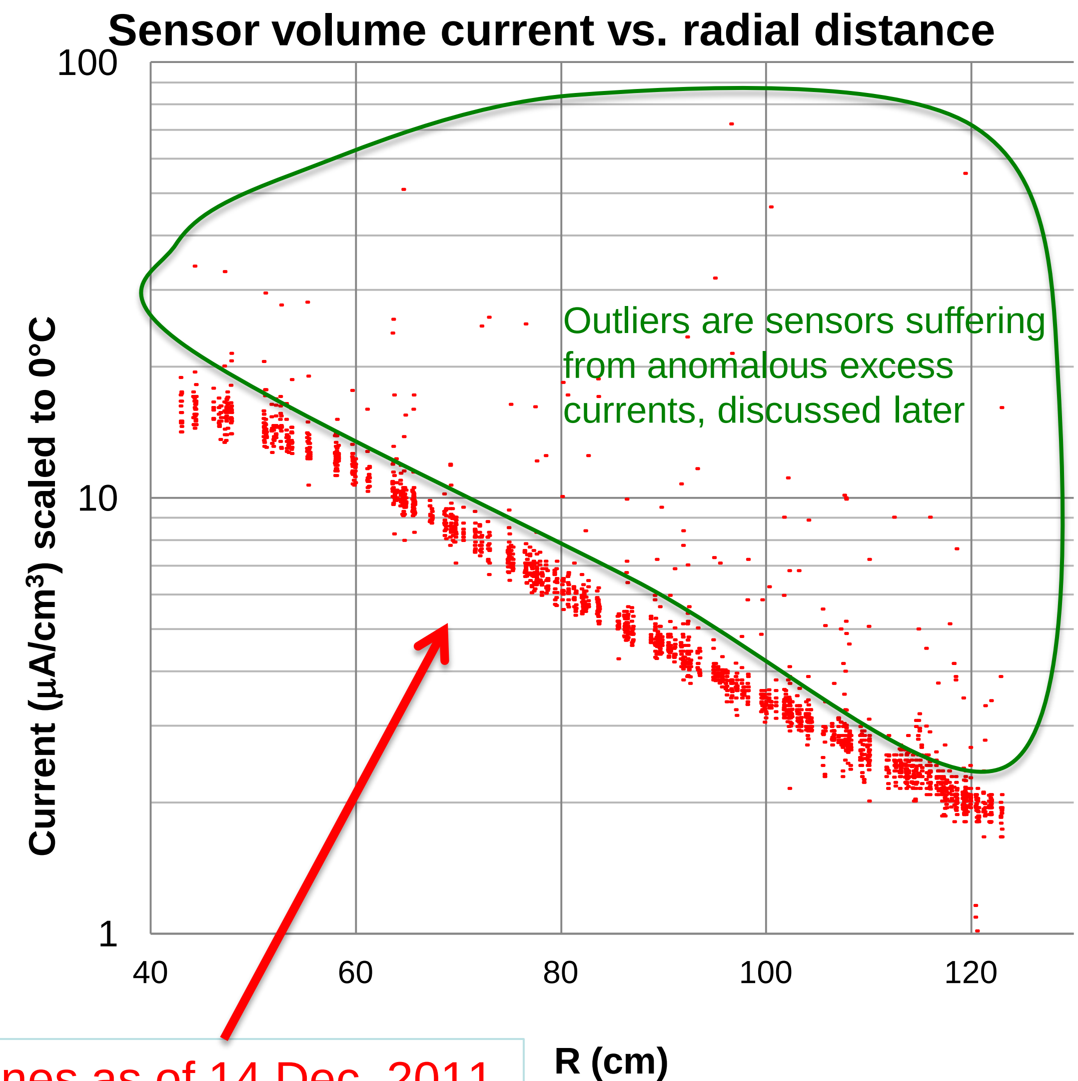
However, there are 2216 HV lines going from the HV patch panel to the detector.

Most lines go to a pair of adjacent sensors and a few lines go to a single sensor.

Thus one HV channel powers 6 to 35 sensors (4 to 18 HV lines) in parallel.

The currents and voltages of the 192 HV channels are continuously monitored and recorded.

The 2216 lines had to be measured by hand outside of physics running (1-2 day job).



Data from the 2216 HV lines as of 14 Dec. 2011

Leakage Current Simulation

FLUKA simulation:

Events generated with DPMJET3 at √s = 7 TeV

Flux of particles scaled to flux of 1 MeV equiv. neutrons

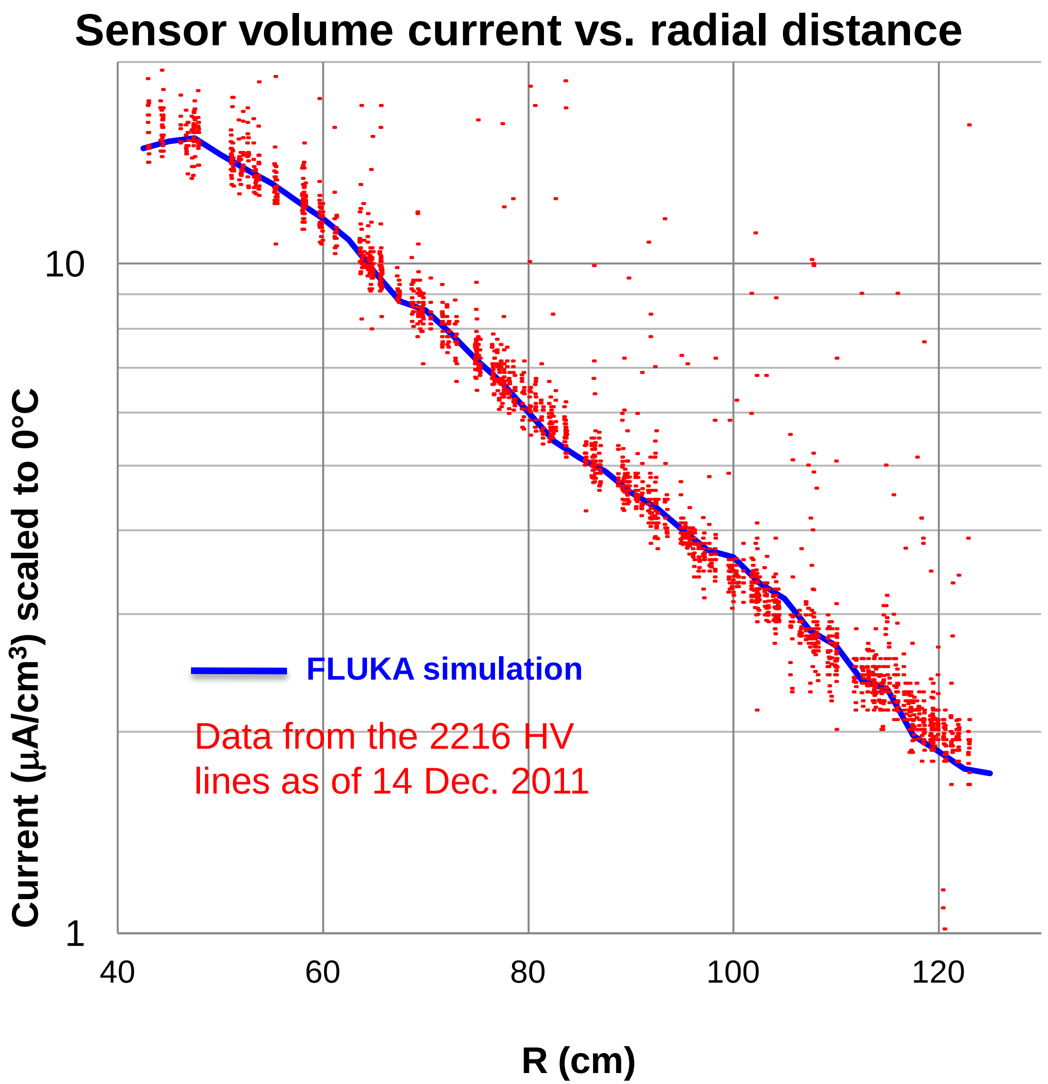
Hamburg model used to include annealing as function of time and temperature

Integrated luminosity from 2010 and 2011 = 5.86 fb^{-1}

Results:

Very good agreement as a function of radial distance (psuedo-rapidity)

Very good agreement in absolute scale



Leakage Currents (meas and simu) vs time

Look at evolution of leakage current over complete 2011 LHC pp run:

Here we use HV channel current (the only current recorded continuously).

Only HV channels connected to sensors with no known anomalous surface current problems are used.

Calculated current based on FLUKA fluence as function of luminosity and corrected for annealing and temperature effects.

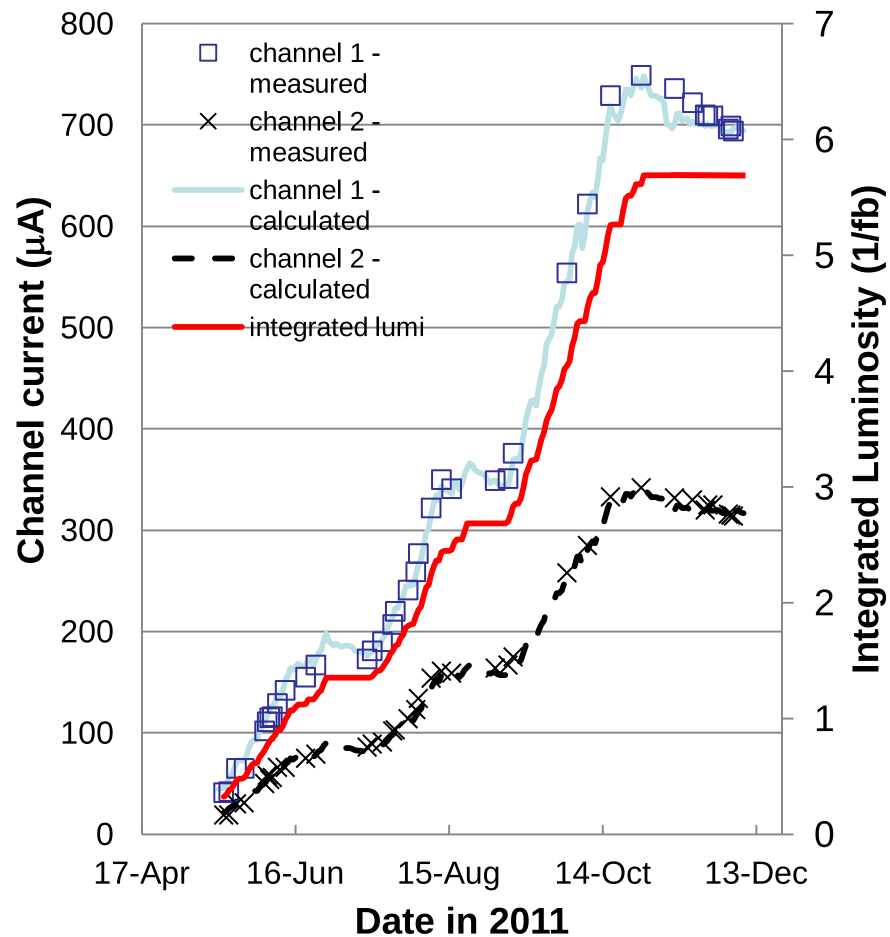
Two such HV channels are shown in plot

Results:

Beneficial annealing clearly observed.

Simulation of annealing and temperature is very good ➔ can predict future behaviour

Time dependence of current: measured vs calculated



Bulk Leakage Current Conclusions

Based on the calculated fluence as a function of luminosity from the FLUKA simulation, the highest fluence in the Preshower silicon is 4.93×10^{11} n/cm^2/fb^{-1} at R=47.5 cm (significantly more than in 1997 design report : 3.2×10^{11} n/cm^2/fb^{-1} @ $\sqrt{s}$ = 14 TeV).

In addition, the scaling factor to go to $\sqrt{s}$ = 8 TeV and to 13 or 14 TeV can be accurately estimated from the simulation. Therefore we think we can predict with reasonable accuracy the future leakage current for a given centre of mass energy and integrated luminosity scenario.

The average of 9 sensors located near R=47.5 cm gives 109 µA on 14 Dec. 2011 (5.86 fb^{-1}) and at 19°C. At current operating temperature (11°C) this is about 50 µA.

Can estimate for 20 fb^{-1} in 2012 at $\sqrt{s}$ = 8 TeV: an additional 200 µA per sensor. The safe limit is around 1mA per sensor, so this is OK. However, for the higher luminosity and higher energy expected after 2014, the operating temperature will have to be reduced (nominal is -10°C).

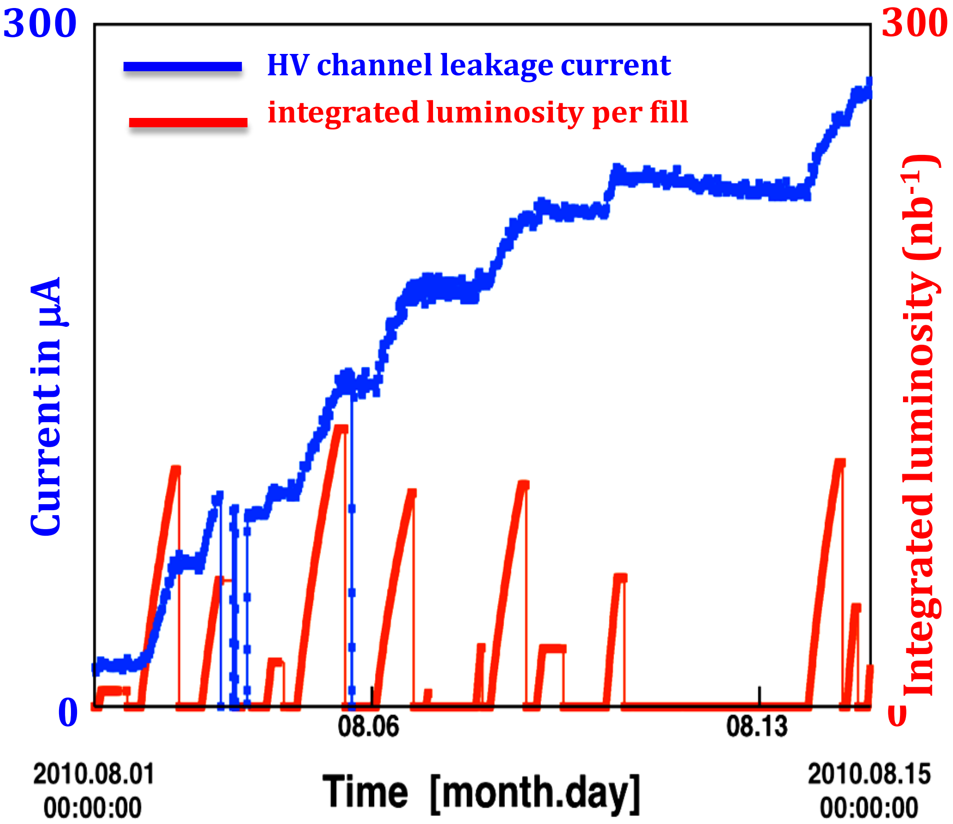
Anomalous Excess Leakage Current History

Starting in Aug. 2010, had HV channels with current reaching max safe limit (2mA). Since a HV channel powers 6 to 35 sensors, the sensors that were responsible had to be identified and then unplugged. However, many sensors not responsible also had to be unplugged because most sensors are powered in pairs.

Current increase correlated with luminosity.

Became problematic with very little lumi (10^{31} cm^{-2}s^{-1}, 3.5 pb^{-1}). Bulk damage from this lumi should be <<1μA.

A total of 81 sensors (2% of all Preshower sensors) were unplugged, mostly in Aug-Sep 2010, the last in April 2011.



Anomalous Excess Leakage Current Observations

- ✦No clear correlation with location within the detector (phi, or z) except that more occur at low radius (where there is more fluence).
- ✦ No clear correlation with depletion voltage of sensor.
- ✦ Current increases somewhat linearly with bias voltage (➔resistive?)
- ✦ At start, current increases somewhat linearly with integr. lumi
- ✦ Current decreases with greatly varying speeds when bias voltage ON but no luminosity present (time constant of minutes to weeks).
- ✦ Current decreases slightly faster when bias voltage is OFF (and no lumi present).
- ✦ Current reduced by about 30% with decrease in temperature of 10°C (if this was bulk current it should have decreased by more than a factor of 2).
- ✦ But not random: Clear producer dependence.

Producer dependence of unplugged sensors

Count by producer of sensor pairs or singles that were unplugged

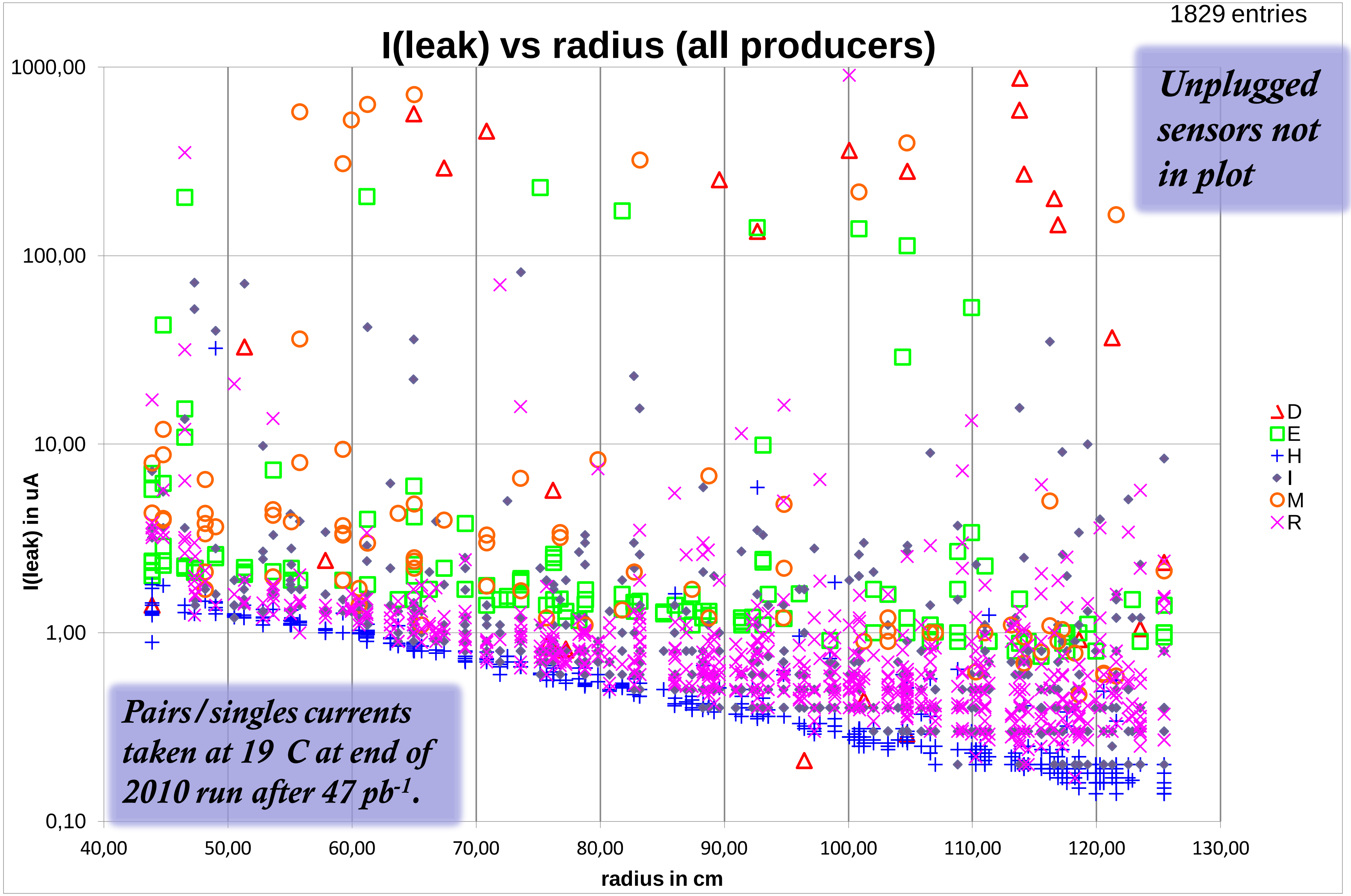
producer	Bad known for certain	probable bad from mixed pairs	Total likely bad	Total from producer	% likely bad
Demokritos (D)	1	1	2	27	7.4%
Hamamatsu (H)	0	0	0	989	0.0%
India-BEL (I)	0	0	0	1162	0.0%
Russia-ELMA (R)	1	1	2	1529	0.1%
Taiwan-ERSO (E)	0	4	4	481	0.8%
Taiwan-MTC (M)	20	18	38	100	38.0%

Nearly all problematic sensors (in percentage) come from 2 producers (D,M). Three producers (H,I,R) have little or no serious problems, the final one (E) has problems at a low rate.

What about the rest of the (still plugged) sensors?

Note: In spite of having another ~100 sensors with large currents, there was a negligible impact on physics from this problem.

Producer dependence and radial dependence



Unplugged sensors not in plot

Pairs/singles currents taken at 19 C at end of 2010 run after 47 pb-1.

What are the anomalous excess currents?

How much producer dependence?

H sensors have very uniform and lowest currents. R and I sensors have some excess current but few have very large values (>100 μA). Some E sensors have large currents but most are OK.

Even though many M sensors were unplugged, many of those still working have large currents. Most D sensors have high currents.

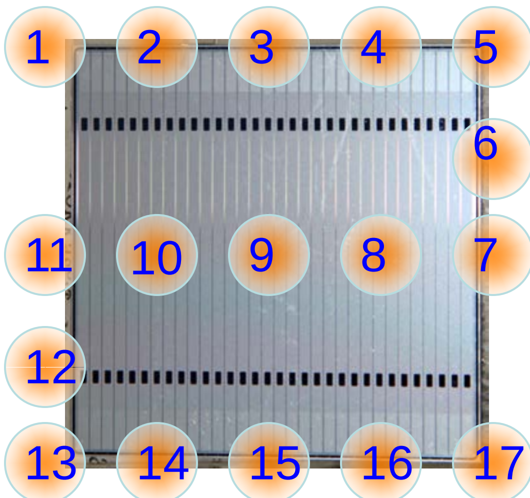
Why are these likely to be surface currents?

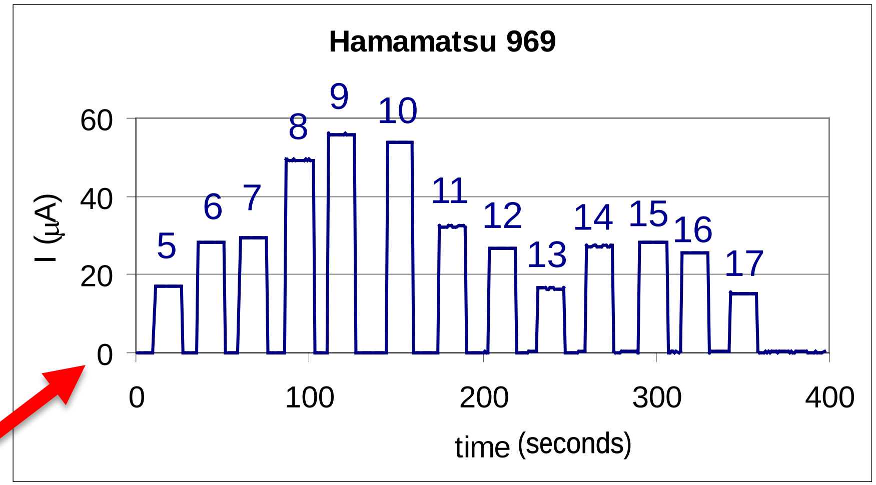
- Bulk damage gives <2μA at end 2010. But more than 60 pairs had >10μA.
- Temperature dependence does not follow bulk current exponential law.
- Studies of those sensors with highest currents showed some correlation with higher noise in some (usually endmost) strips of those sensors.
- Many M sensors had long term leakage current and humidity related problems ➔ strong indicator of surface currents at the edge of the sensor.
- Producers had different sensor edge geometry and configuration (number and width of guard rings).

Surface current hypothesis: trapped charge (holes) in oxide or at interface leading to (+) charge which attracts (-) near Si surface ➔ conductive path.

Attempt to generate excess currents: X-Ray studies

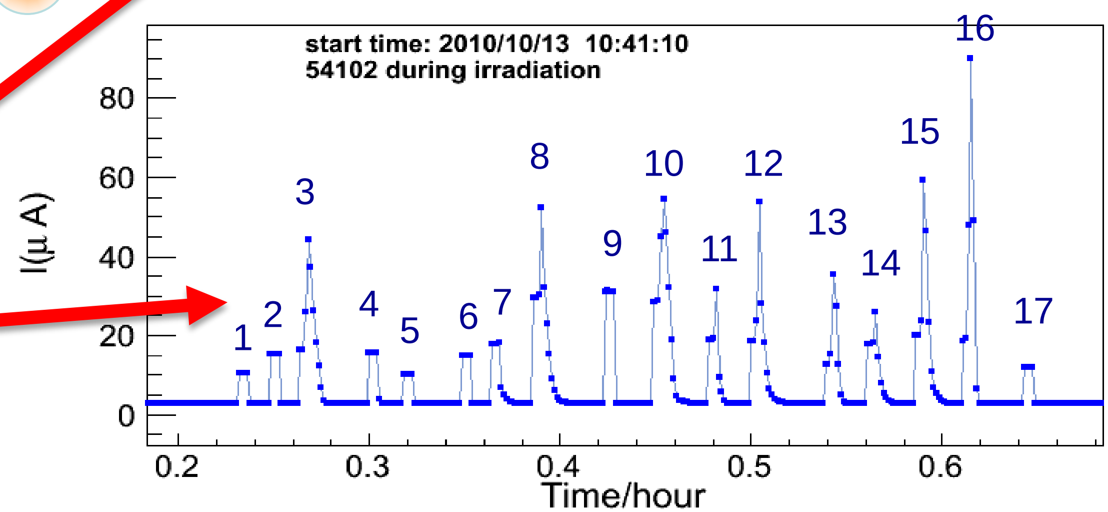
X-Ray machine at CERN was used to provide high dose surface irradiation. Typical energy 20 keV (should stop in first few microns of sensor). Scan surface in 17 points.





H sensor, 60 Gy per point

M sensor, 10 Gy per point



Excess Leakage Currents: X-Ray studies

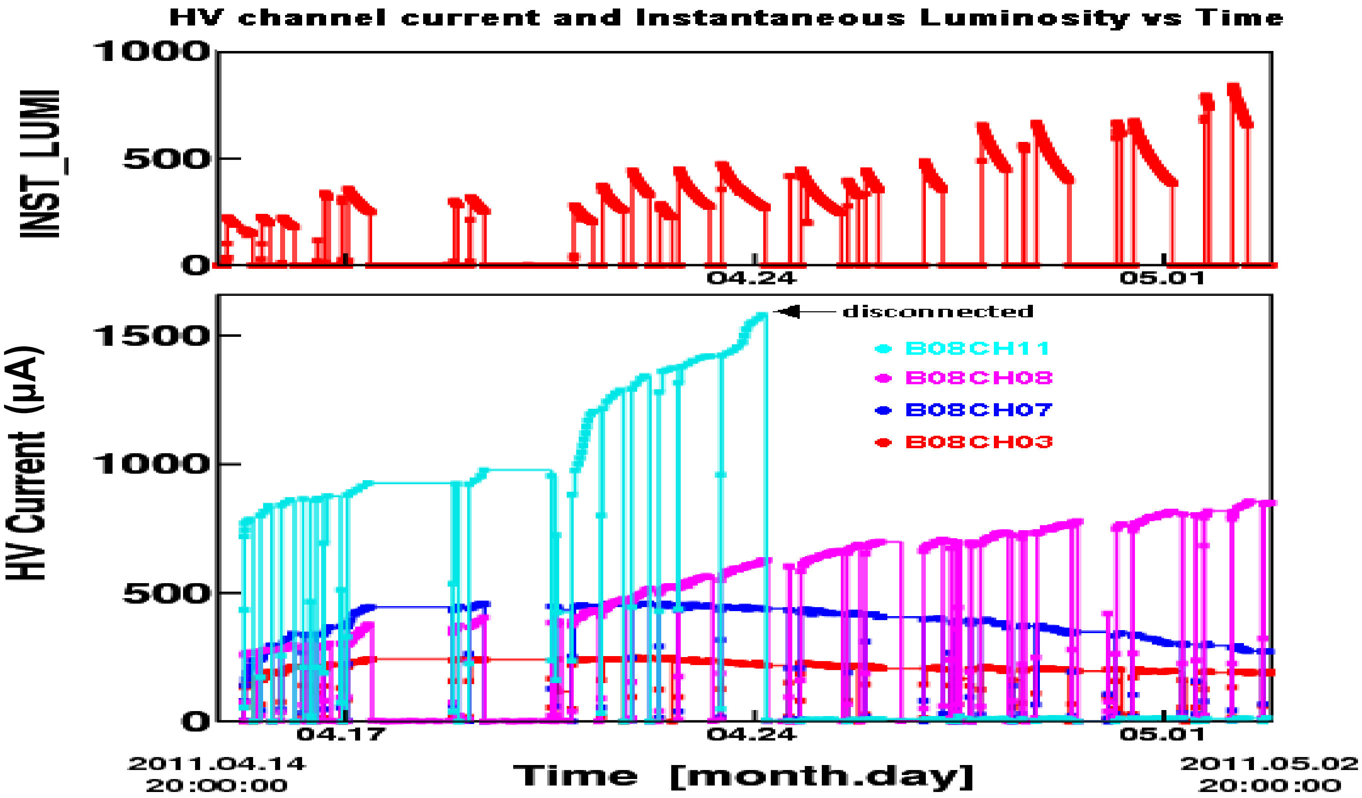
- Excess currents from X-rays observed for M (6/6), E and I sensors. Not for R or H even up to 60 Gy/point. No D available for testing.
  - Results not reproducible systematically.
  - No position correlations found so far.
  - Amount of radiation required (even for M) is much more than we were receiving in LHC (highest expected dose ≈ 5 Gy for all 2010)

- Interesting positive results with higher humidity to <u>remove</u> excess current. Likely explanation is humidity leads to negative surface charge which increases hole mobility, eliminating trapped charges. Unfortunately, adding humidity to Preshower volume could cause condensation/frost problems.

- Conclusion: many similarities between X-Ray induced currents and excess currents in Preshower. Thus, strong evidence for surface leakage but mechanism not fully understood.

Excess current behavior in 2011 run

Although we made occasional measurements of all pairs/singles in 2011, much info was obtained from CAEN supply current measurements.



From May 2011 onward, most HV channels showed slowly increasing, flat, or slowly decreasing leakage currents. By end 2011, many saturated then started to decrease.

Hardware changes between 2011 and 2012

Have doubled the number of HV channels, 192 → 384.

A new HV distribution patch panel has been installed.

1. Redistribution of sensors to HV channels in order to avoid approaching the current limit due to bulk damage leakage currents.

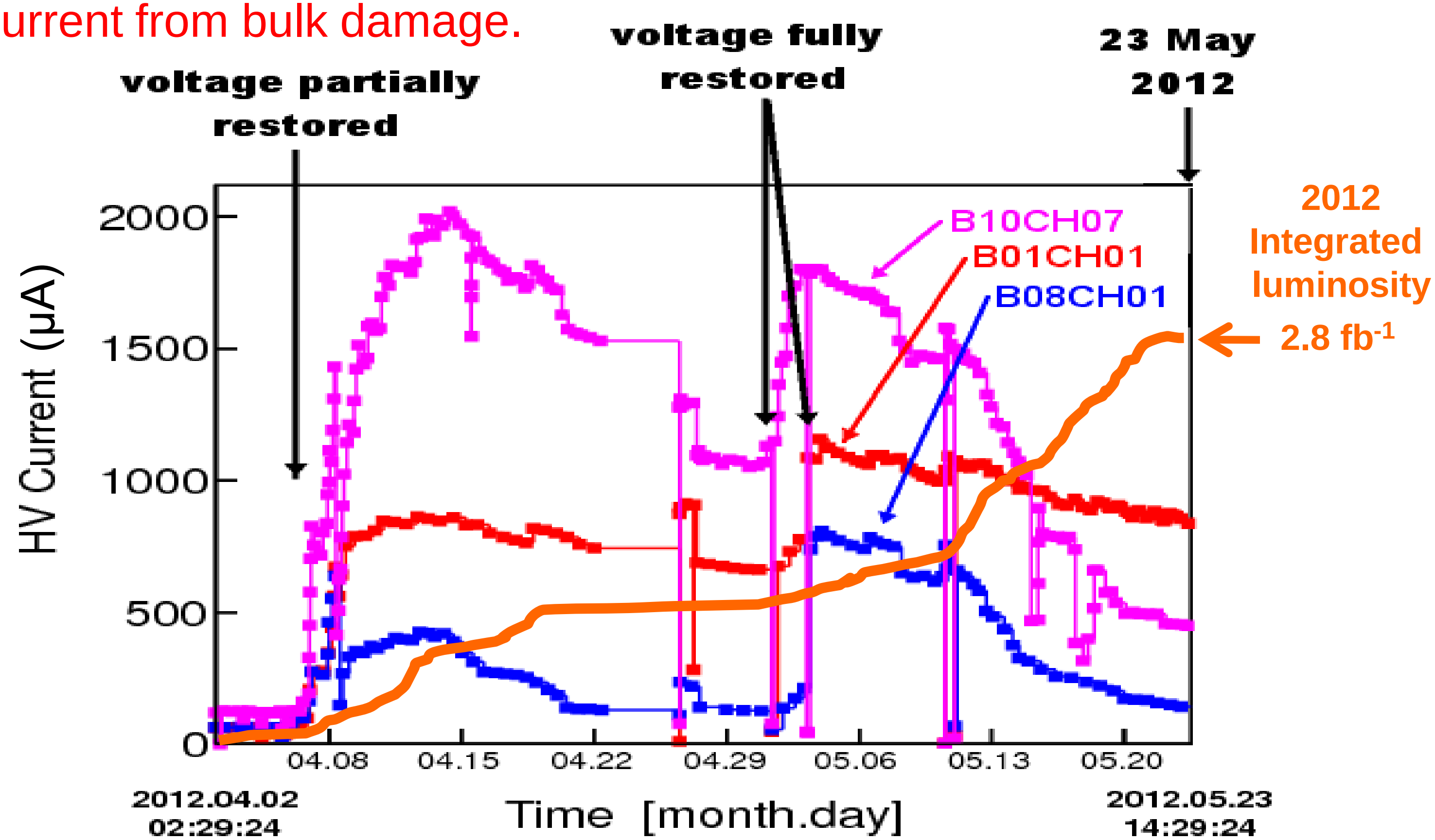
2. Can continuously and automatically measure the sensor pair/singles leakage currents which will allow to monitor bulk damage and to take action for dangerously high currents (e.g. from surface current problems).

3. Can still disconnect pairs/singles when needed.

4. Have reconnected the unplugged pairs/singles and put them on their own HV channel whenever possible. Hope that they will quickly go through the high current regime and then saturate and drop in current to a safe value so that they can be considered good working sensors from now on (this was tested to be true for one such pair at end of 2011).

Excess current behavior in 2012 run

On 8 April 2012 we turned on the HV to all previously unplugged sensors and checked their currents after about 10 pb^{-1}. Some went to high current and we had to lower their voltages. Most increased in current but not to a dangerous level. But most saturated and the currents decreased, albeit at different rates. Nearly all are back to their nominal voltage and many are back to their expected current from bulk damage.



Summary

- **Bulk damage currents measured with high statistics. Good agreement with FLUKA based simulation including annealing effects.**
- **No problem with sensor currents for 2012 but lower temperature required thereafter.**
- **Anomalous excess currents observed at start of 2010 pp run. Was very large and unexpected and required unplugging about 2% of sensors.**
- **Circumstantial and X-Ray study evidence point to surface effect as cause but no clear understanding of mechanism. Problem is producer dependent and may point to design or process quality issues.**
- **A clear "saturation" effect is observed such that no new problematic sensors after 0.2 fb^{-1}. Most excess currents have decreased. We also have recovered all unplugged sensors.**
- **Still to do: measure bulk leakage current temperature coefficient and measure change in depletion voltage (we should observe up to a 50V drop at inner radius).**