CMS Preshower Excess Leakage Currents

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on behalf of the ES group
Special thanks to Anna Peisert, Dave Barney, and Gang Qin

Outline

1. Some history of the problem
2. Producer dependence
3. Why it is believed to be surface current
4. X-Ray studies
5. Behavior in 2011
6. Hardware changes and prospects for 2012
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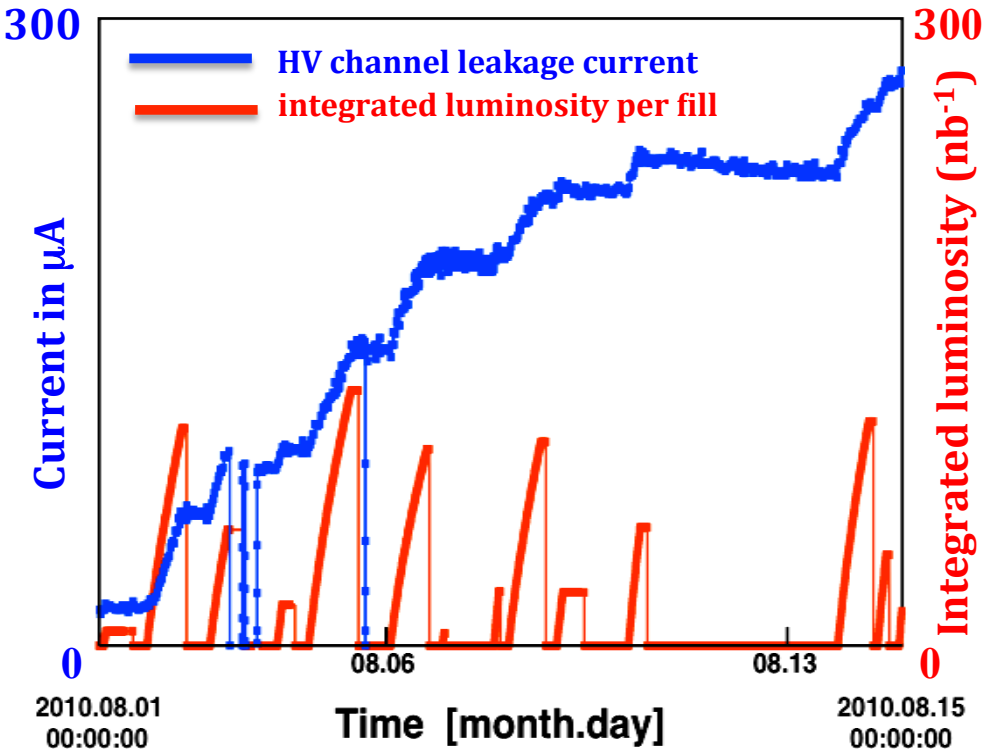
Excess Leakage Current Problem History

- Starting in Aug. 2010, had HV channels with current reaching max safe limit (2mA). A HV channel powers 6 to 35 sensors in parallel. The sensors that were responsible were unplugged. However, many sensors not responsible also had to be unplugged because most sensors are powered in pairs.
- Current increase correlated with luminosity. However, it started to become a problem 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 4 were unplugged in April 2011. Thus, no more needed to be unplugged for the period of highest instantaneous lumi and for the last 2/3 of the integrated lumi collected.



Excess Leakage Current Problem History

- Not random: Clear producer dependence.
- No clear correlation with location within the detector (phi, or z) except that more occur at low radius (were there is more fluence).
- No clear correlation with depletion voltage.
- 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).
- Problem was severe for first pb^{-1} of integrated lumi. Much less of a problem after that.

Producer dependence

Based on high leakage current sensors that were unplugged:

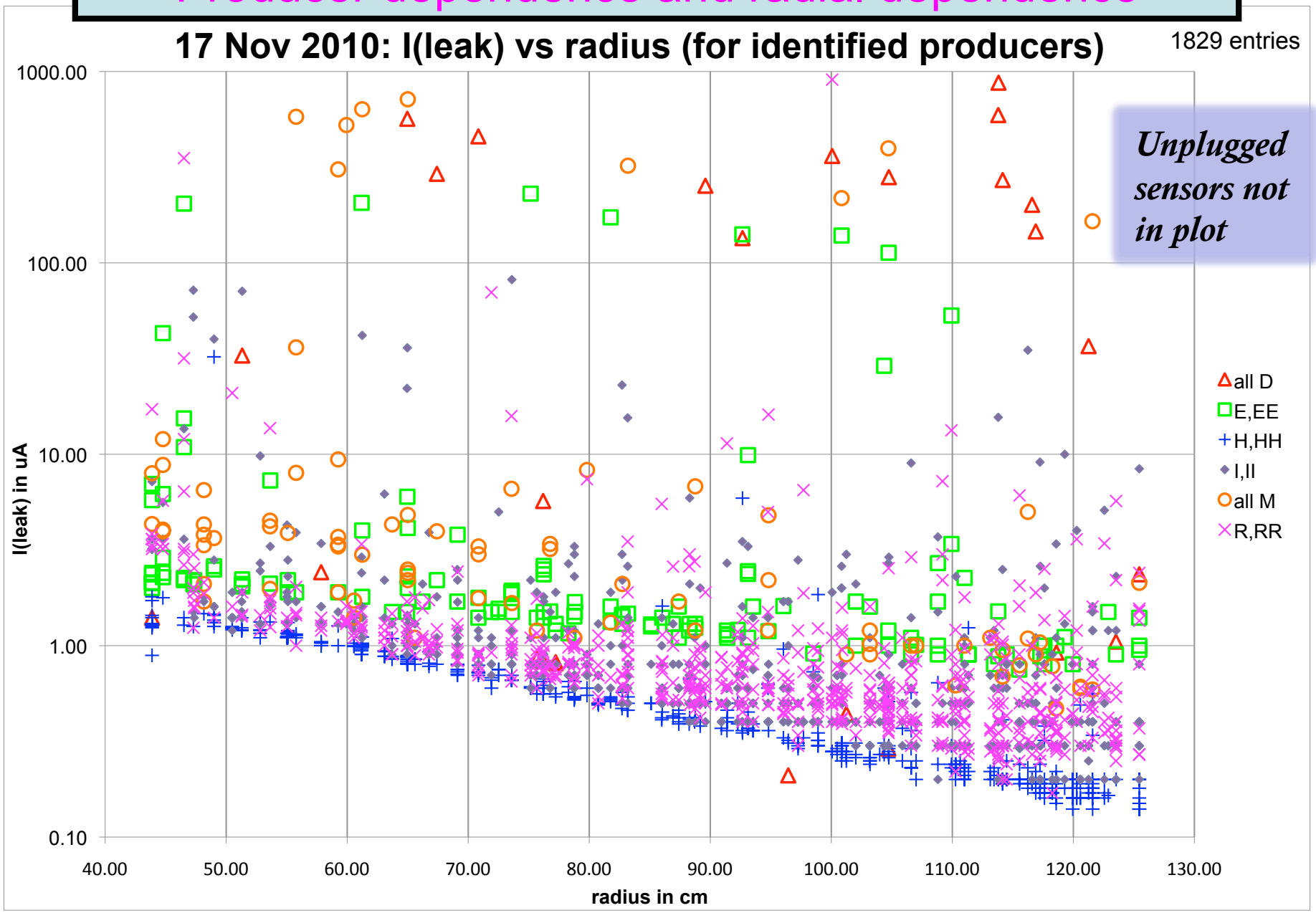
Count by producers of sensor pairs or singlets that were unplugged

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 (I)	0	0	0	1162	0.0%
Russia (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%

It is clear that not all producers are equal. Nearly all problematic sensors (in percentage) come from 2 producers.

A full measurement of all 2216 pairs/singlets was performed (by hand) on 17 Nov 2010. The leakage current dependence on producer can best be seen in a plot of Current vs. Radial position of pair with producers identified…

Producer dependence and radial dependence



What the previous plot shows:

– Hamamatsu (H) sensors have very uniform and lowest currents.

– Russian (R) and to a greater extent Indian (I) sensors have some excess current but few have very large values (>100 μA).

– Some ERSO (E) sensors have large currents but most are OK.

– Even though many MTC (M) sensors were unplugged, many of those still working have large currents.

– Most Demokritos (D) sensors have high currents.

– Calculated bulk damage follows closely the line formed by the H sensors. The implication is that H sensors have very little excess current. All other producers have varying degrees of excess current.

In spite of large currents, there was a negligible impact on physics from this problem, other than the loss of active sensors for those needing to be unplugged.

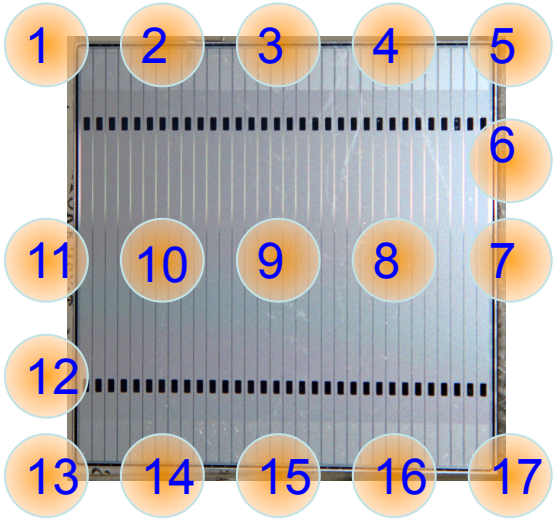
Why we think the excess is surface current:

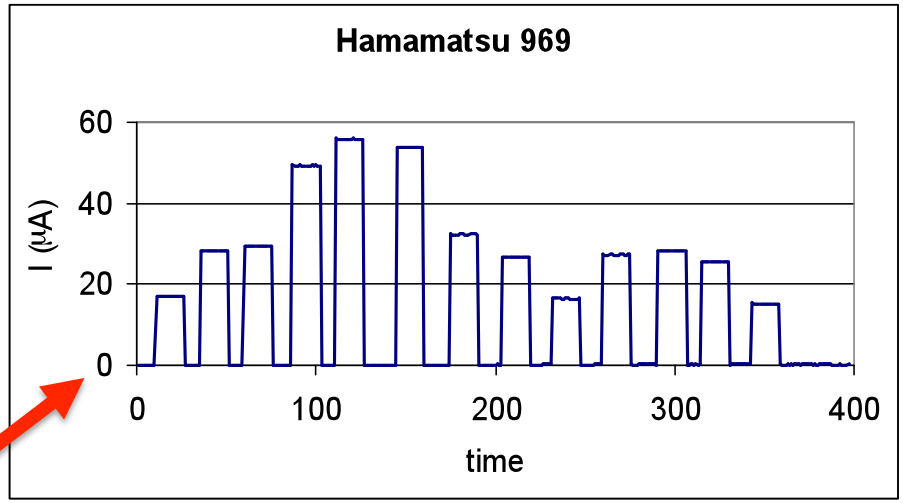
- Bulk damage should give at most 2μA by end 2010. This cannot explain why more than 60 pairs had >10μA.
- Temperature dependence does not follow well known bulk current exponential law.
- Studies of those sensors with highest currents showed some correlation with higher noise in some strips of those sensors. Usually endmost strip(s) were noisy.
- Many MTC (M) sensors had long term leakage current problems and humidity related problems. This is a strong indicator of surface currents occurring at the edge of the sensor.
- Each producer had different sensor edge geometry and configuration (number and width of guard rings). Surface currents most likely to go from strip to guard ring to edge of sensor to backplane.
- Current not consistent with bulk radiation or physical damage. What else could it be? Several past experiments have observed similar radiation induced excess currents (OPAL, CDF) that were believed to be surface effects.

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 in lab: X-Ray studies

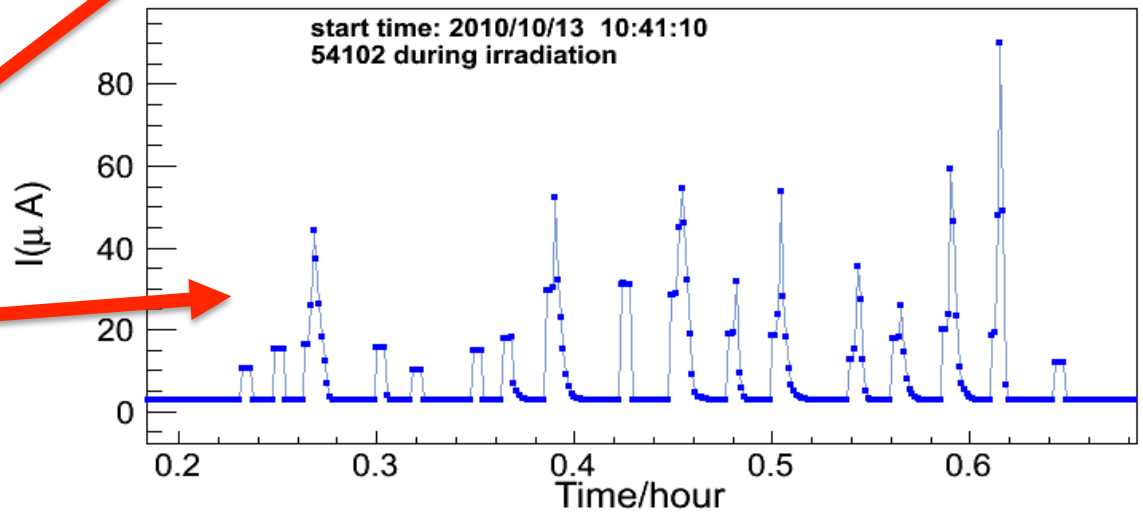
X-Ray machine in PH/ESE (bldg 14) used to provide high dose surface irradiation.
Typical energy 20KeV (should stop in first few microns of sensor).





H sensor, 60 Gy per point

M sensor, 10 Gy per point

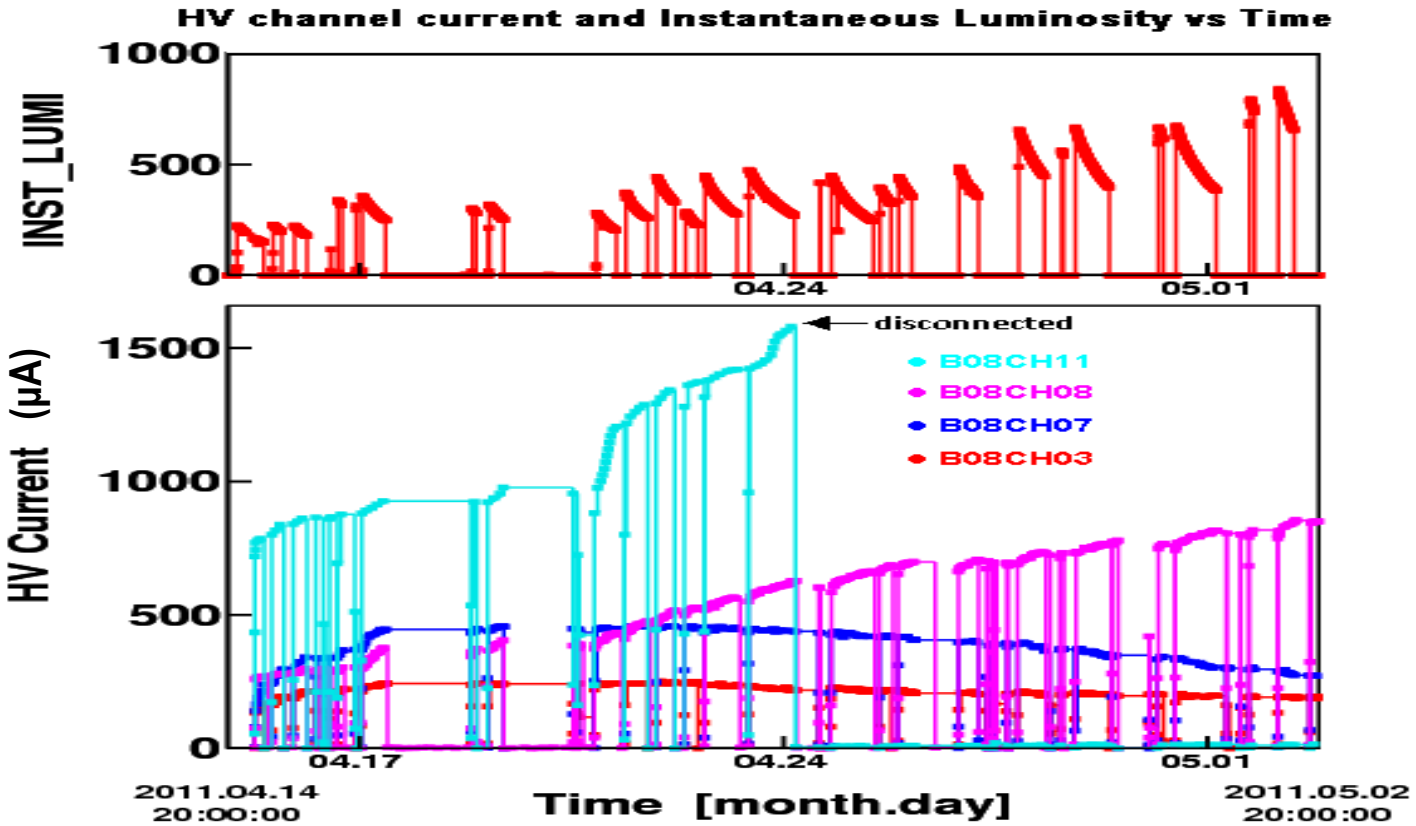


Excess Leakage Currents: X-Ray studies

- So far excess currents from X-rays observed for MTC (6/6), ERSO and Indian sensors. Not for Russian or HPK even up to 60 Gy/point. No Demokritos available for testing.
  - Results not reproducible systematically.
  - No position correlations found so far.
  - Amount of radiation required (for MTC) is much more than we should be receiving in LHC (highest expected dose ≈ 5 Gy for all 2010)
- Interesting positive results with higher humidity to remove 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.

Behavior in 2011 run

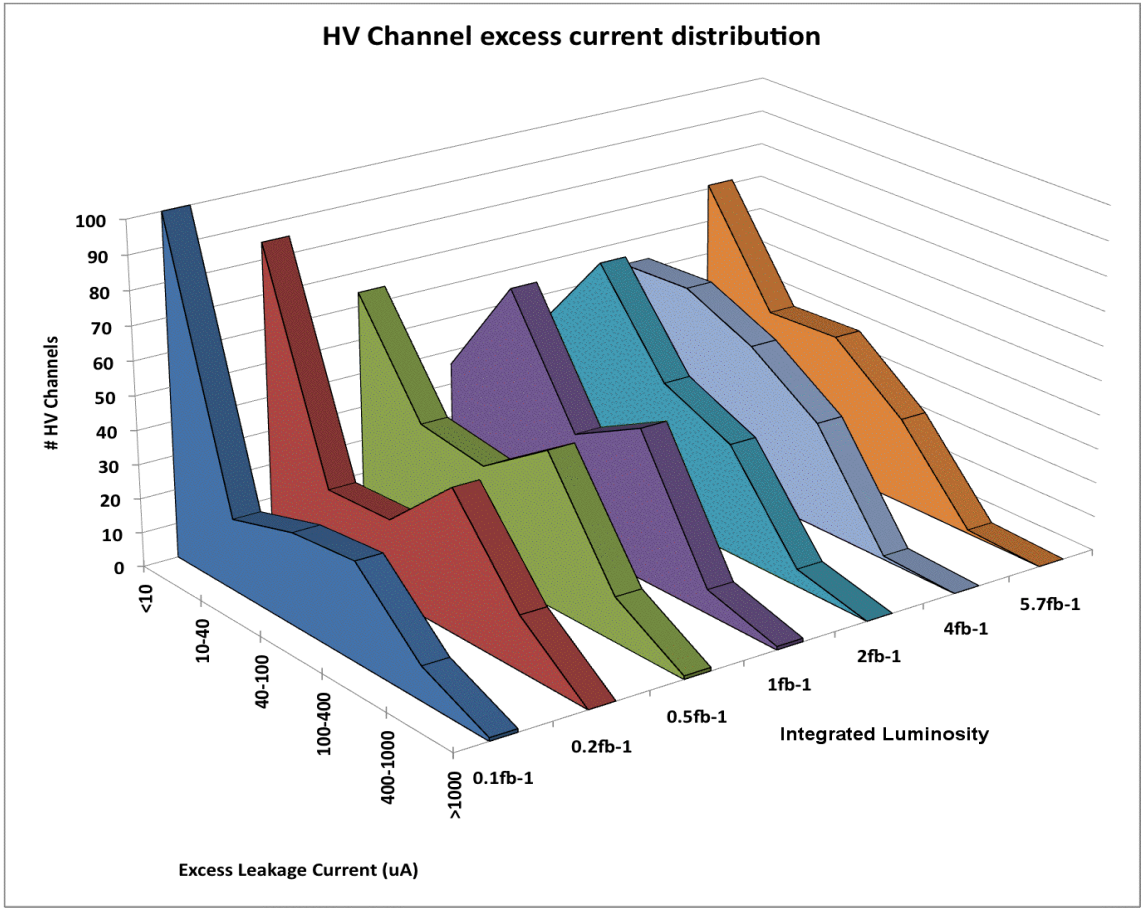
Although we made occasional measurements of all pairs/singlets in 2011, much info was obtained from CAEN supply current measurements in PVSS.



From May 2011 onward, most HV channels showed slowly increasing, flat, or slowly decreasing leakage currents. It appears that there is a saturation effect.

Behavior in 2011 run

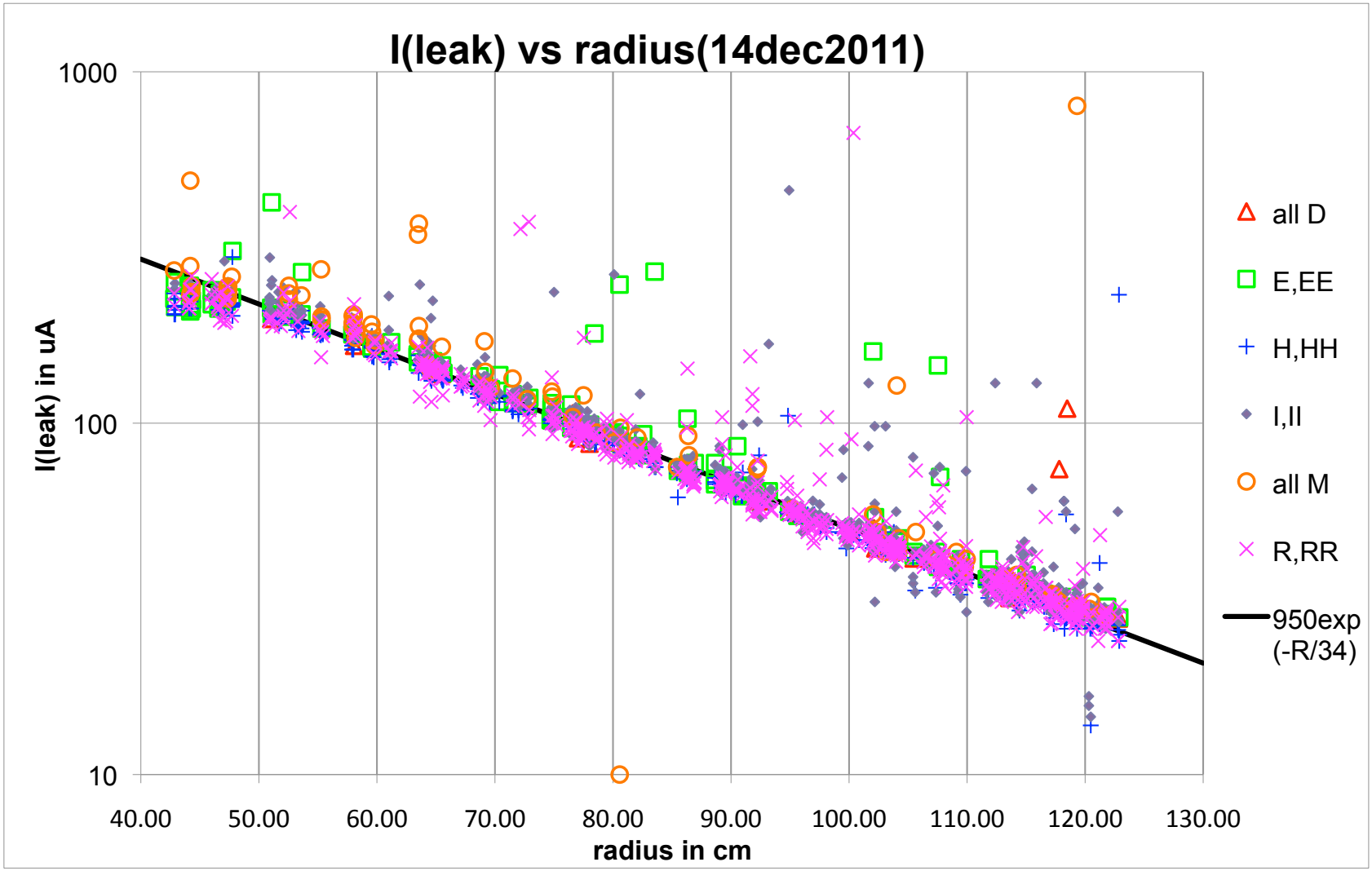
Saturation effect is more clear looking at the distribution of the amount of excess leakage current for HV channels as a function of integrated lumi.



After 1 fb^{-1}, fewer and fewer high excess current channels are observed.

Behavior at end of 2011 run

Current vs. Radius at end of 2011 pp running



Hardware changes

Have obtained more HV channels, 192 ➔ 384 (16 more CAEN modules).

A new HV distribution patch panel has being designed, fabricated and is being installed now.

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/singlet 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/singlets when needed.

4. Have reconnected the unplugged pairs/singlets 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 modules from now on.

Prospects for 2012 running

What can we expect for 2012 and up to 20 fb^{-1} of integrated lumi?

1.Expect that there will be a significant number of sensors with excess currents but the amount of excess will be modest (< 100 μA). We could expect a few new cases of sensors that reach a dangerous level of current and need to be unplugged.

2.It seems possible that the surface current problem will be minor or non-existent when we reach the point of type inversion of the silicon (should start to occur at around 20 fb^{-1}) because of reduced fields on the top edge surface.

3.The new HV distribution scheme should allow for higher tolerance of modest excess currents.

4.We hope to recover some, if not all, previously unplugged sensors.

We are fairly confident that the surface current effect will have a minor effect on the 2012 Preshower operation. We are hopeful that the useful active percentage of sensors will be greater in 2012 than in 2010-2011.

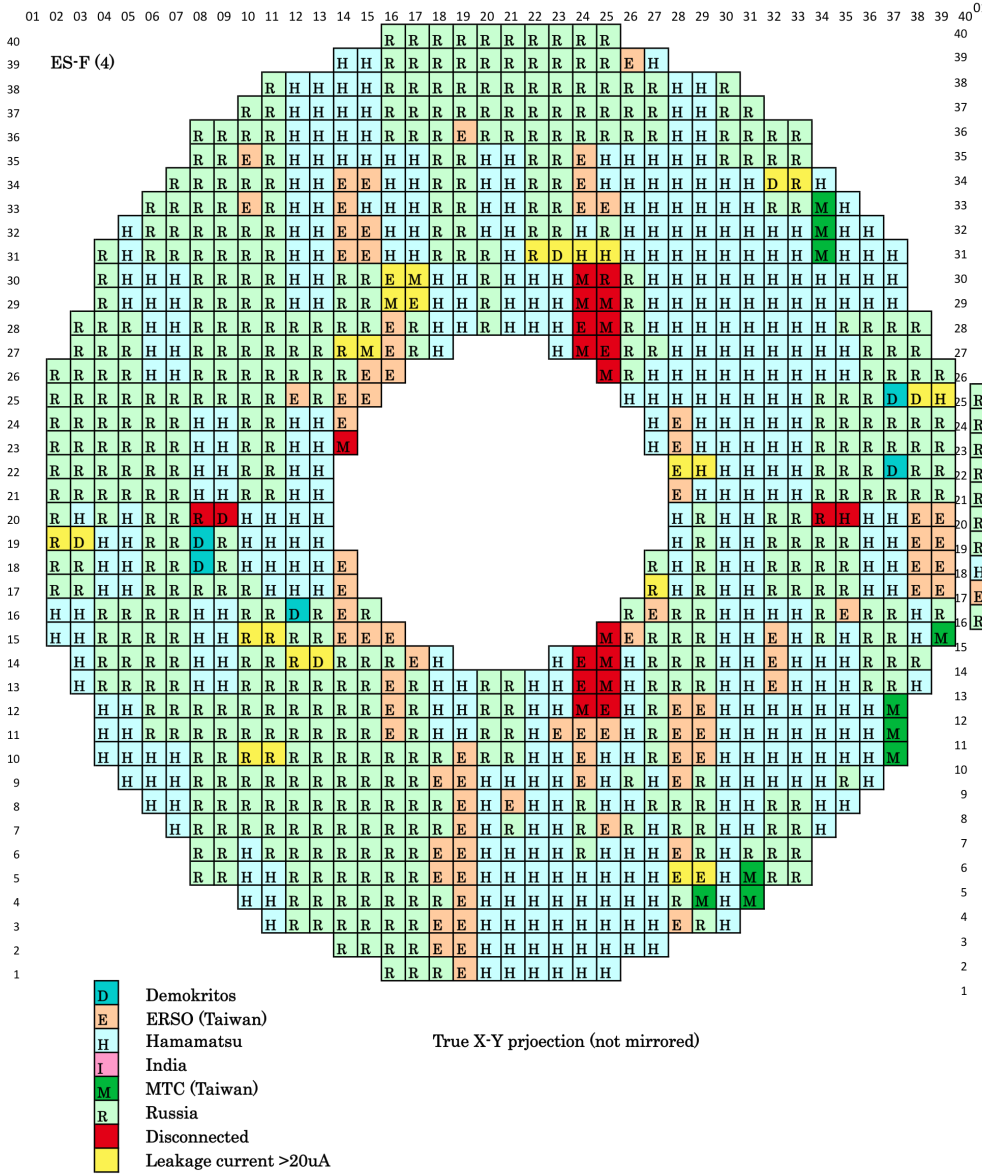
Summary

- **Excess currents problems observed at very start of serious lumi running (mid-2010). Was very large and unexpected and required unplugging about 2% of sensors.**
- **A clear "saturation" effect is observed such that no new problematic sensors after 0.2 fb^{-1}. Most excess currents have decreased.**
- **New HV distribution panels being being installed now, should allow quick identification of high current sensor pairs. Hope to recover some or all unplugged sensors.**
- **Circumstantial and X-Ray study evidence point to surface effect as cause but no clear understanding of mechanism. Problem is highly producer dependent and may point to design or process quality issues.**

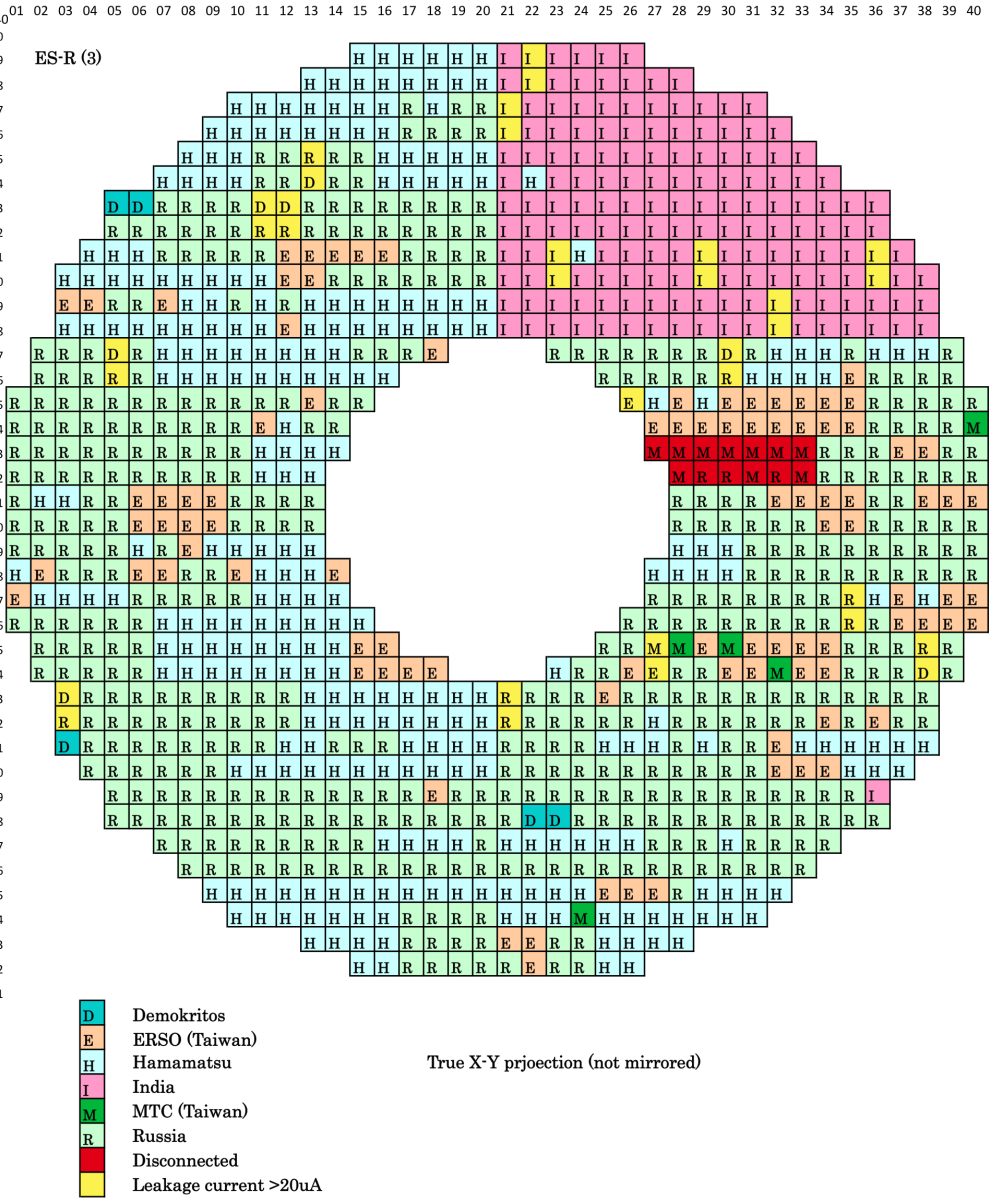
Extra slides

Producer dependence

ES minus Front

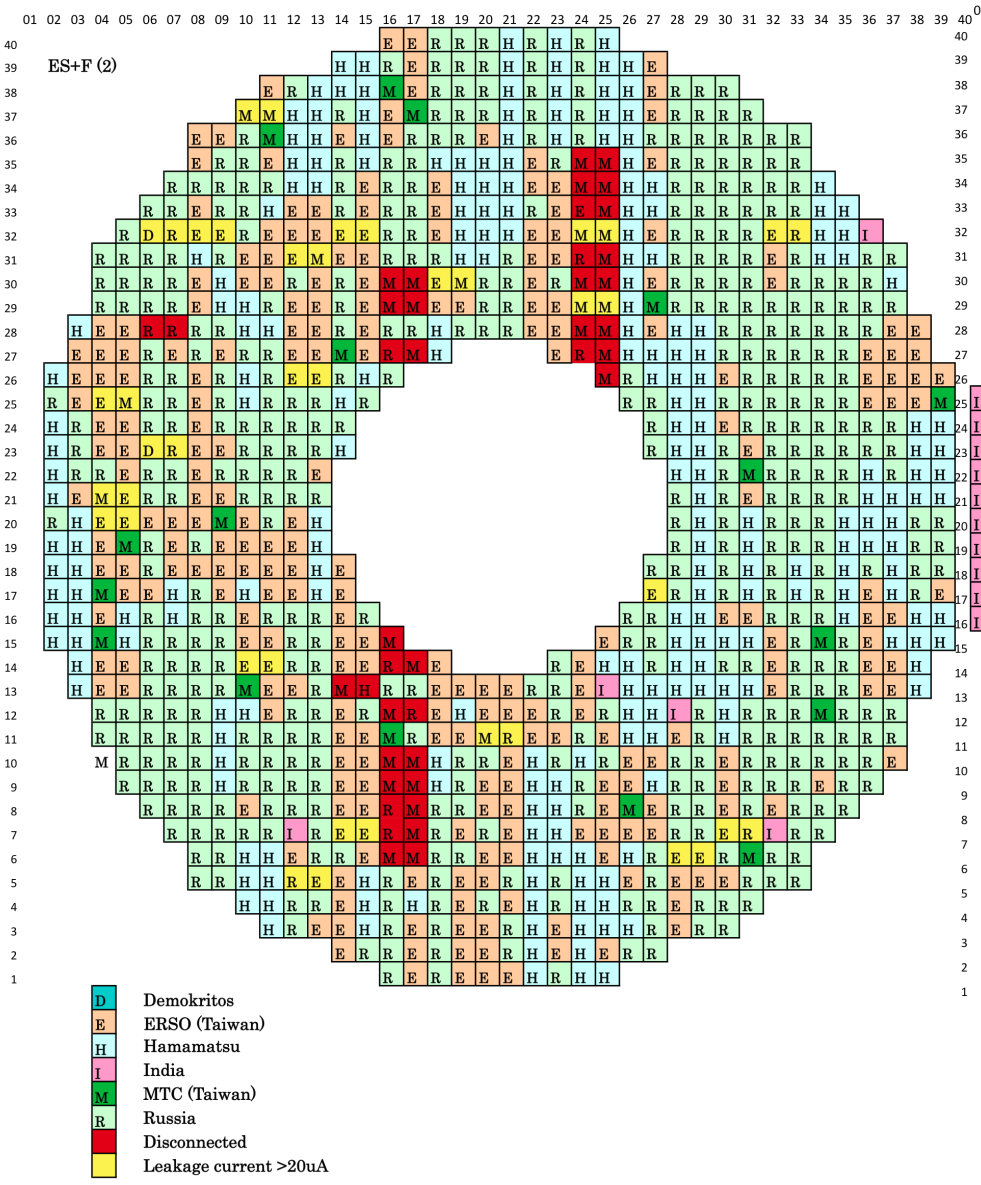


ES minus Rear

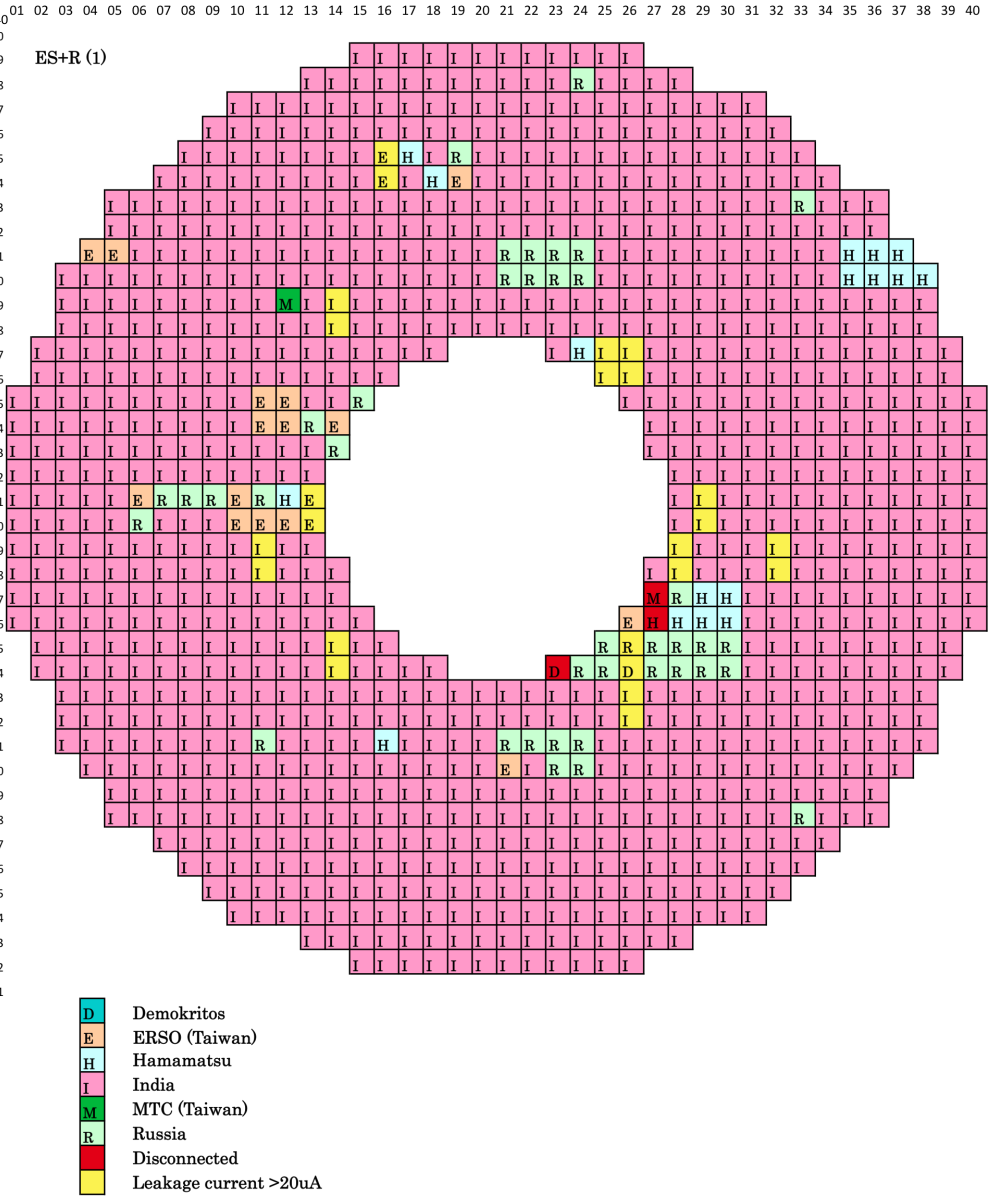


Producer dependence

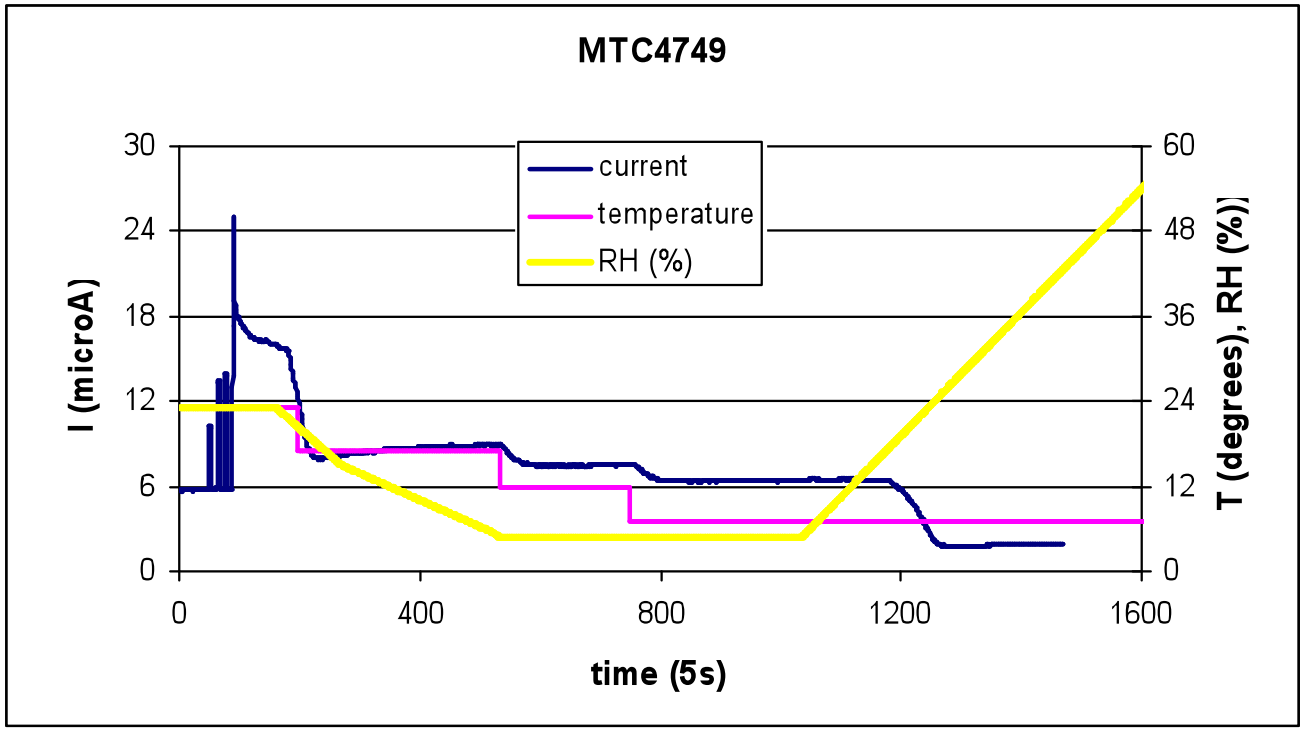
ES plus Front



ES plus Rear



Surface Leakage Currents: X-Ray studies



Taiwan-MTC sensor irradiated 5 Gy per point. On 4th point, current increases dramatically. Similar to effect in LHC?

We observed the effect of temperature and humidity on this excess current.

A clear temperature dependence but difficult to quantify relationship (not like bulk current which is exponential with T).

However, we find “high” (>20%) humidity seems to reduce the excess current. Even for very slow to recover sensors (Indian), a very high humidity seems to eliminate the excess current very quickly.

Surface Leakage Currents: X-Ray studies

Hamamatsu (HPK) sensors irradiated 60 Gy per point. No undesired effects observed.

But

The baseline current increases between the irradiations. Observed on two different HPK sensors.

Probably seen on sensors from other producers but difficult to measure as currents are not always stable.

This may be “permanent” surface damage as observed in other experiments (notably e+e-). Causes could be interface and/or oxide hole traps.

This is << bulk damage current.