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Spice Simulations of the Effects of Heavy Ions on the LAT Tracker

Gary Godfrey recently brought a concern to me that the tracker clusters might be too wide in the case of heavy ions to be useful for calorimeter calibration. Since the tracker has never been tested in a heavy ion beam, I set out to try to simulate the effects in Spice. The concern can be summarized as follows. The large ionization deposited on a silicon strip by a relativistic heavy ion, especially fully-ionized iron, can nearly completely saturate the tracker preamplifier. That has several negative effects:

- The comparator output will stay high, and therefore hold the layer trigger inactive, for about 150 microseconds. (However, the layer can still be read out during this time if a trigger comes from another source.)
- The affected preamplifier channel will stay saturated and essentially dead for a few milliseconds.
- Neighboring channels will also be affected. This is the effect under study in this note. When a preamplifier saturates, its input impedance increases drastically, compared with the normal ~5 kohms input impedance of the linear operating range. That results

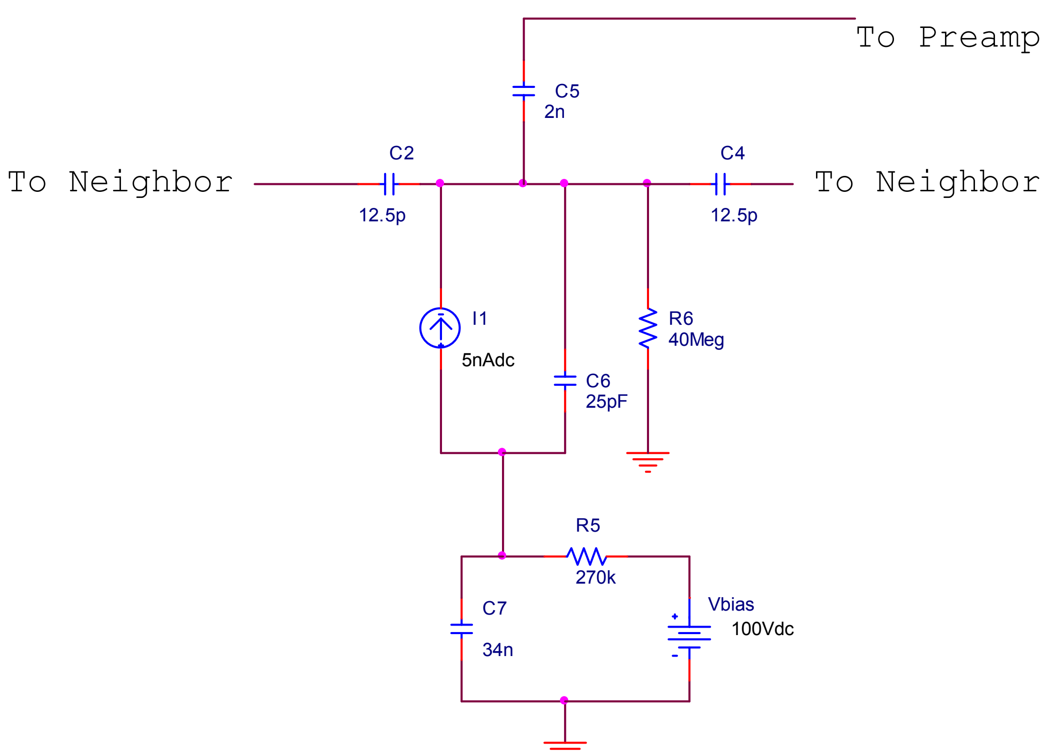

Figure 1. Schematic of the detector model showing one strip plus both interstrip capacitances. There are 23 strips in the model, but only a single bias supply plus filter.

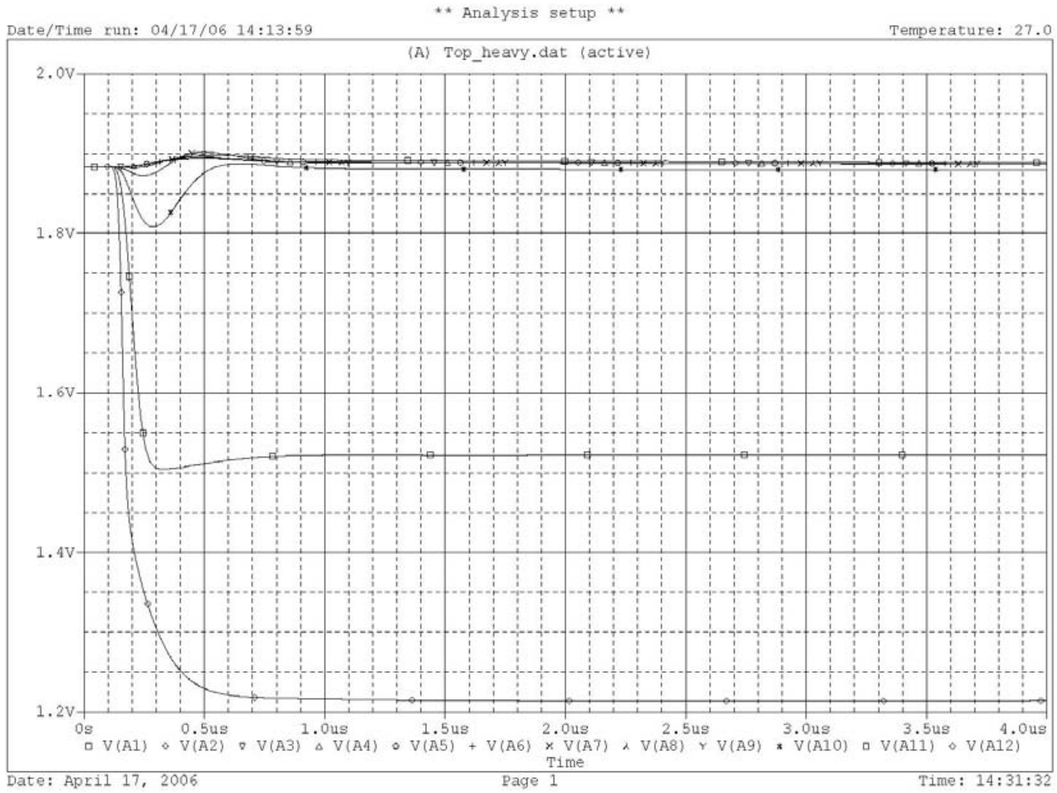

Figure 2. Preamplifier outputs for the case in which an oxygen ion passes through channel 12.

in a very large increase in coupling of the deposited charge to the neighboring channels, via the large interstrip capacitance of the SSDs. In fact, the coupling of the charge goes from being negligible to being something like 25% to each neighbor (with the remainder coupling to the backplane of the SSD).

Thanks to the relatively large coupling of SSD strips to the backplane on these wide-pitch detectors, the charge induced on successive neighbors should fall by a factor of 2 or more at each step across the strips. Therefore, I do not expect the clusters to grow extremely large. In particular, I do not expect a heavy ion to cause all channels in a layer to fire.

Figure 1 shows a schematic of the detector model, with just one strip shown out of the 23 included in the model. Not shown is a current source in only the 12th strip that supplies a 50 ns long pulse of current to simulate the heavy-ion charge deposition. The 5 nA leakage current indicated is typical for new SSDs. A relativistic iron ion at normal incidence should deposit a charge corresponding to $26^2 = 676$ MIPs, or 3.4 pC. The time constant of the bias charging of the strip is about $50\text{pF} \times 40\text{M}\Omega = 2\text{ms}$, and 3.4 pC divided by that time is only 1.7 nA, less than the leakage current already flowing. Furthermore, the charge stored by the bias on the capacitance of a single SSD is about $13\text{pF} \times 100\text{V} = 1.3\text{nC}$, about 400 times the iron-ion charge deposit. Therefore, I do not expect the charge deposit to make a significant perturbation of the SSD depletion and its capacitance, so the static model in Figure 1 makes sense.

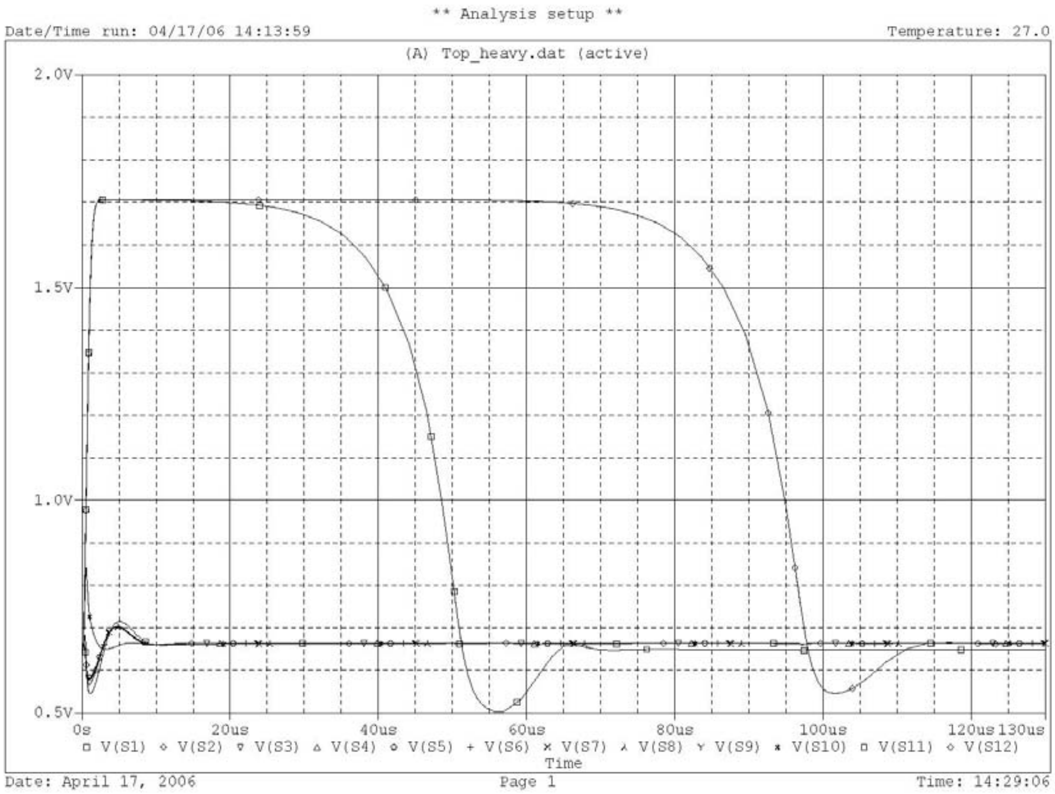

Figure 3. The shaper response to an oxygen ion passing through channel 12.

Figure 2 shows the preamp response to ionization from oxygen. The charge deposition of 64 MIPs is in channel 12, which therefore has the maximum response. Channels 1 through 11 are also plotted. Channels 13 through 23 are equivalent, from the symmetry, and are not plotted. The response of channel 12 is not completely saturated, but it is far into the nonlinear regime of the preamp, such that its input impedance is greatly impacted. Therefore, we see a large signal picked up in the neighboring channel, but the response of the next neighbor, channel 10, is small and quickly dies, such that the integral produced by the shaper is small. Figure 3 and Figure 4 show the shaper response, and Figure 4 also shows the comparator output. In summary, the prediction is that oxygen at normal incidence will produce a cluster of three hit strips. The comparators of the two strips around the cluster will pulse, but according to the simulation they go away before the trigger acknowledge arrives. Furthermore, the layer-OR in the hit layer will be high for about 100 μs, preventing retriggering during that period. Finally, Figure 5 plots the preamp output again, on a long time scale, showing that the strip hit by the ion will be inactive for a couple of milliseconds, and the neighbors will be inactive for about a quarter of a millisecond.

Figure 6 shows the preamp response to an iron ion at normal incidence (667 MIPs). Figure 7 shows the corresponding shaper response, and Figure 8 shows the comparator output. The hit strip plus 3 strips on each side respond with a right-sign signal. All other

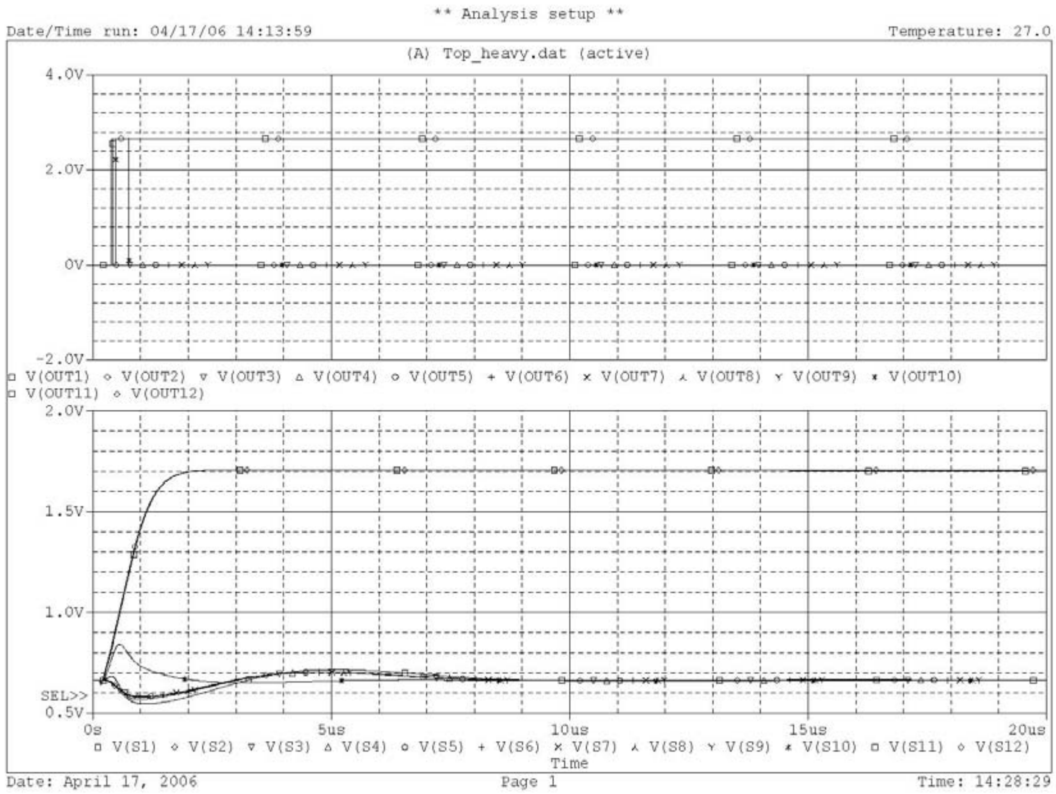

Figure 4. The comparator response (upper plot) and shaper response (lower plot) to an oxygen ion passing through channel 12.

amplifier channels are driven to the wrong sign, causing the shapers to swing negative initially and then overshoot the baseline into the positive direction with enough amplitude the fire the comparators. Interestingly, the two edge channels, 1 and 23, overshoot the most. That is an edge effect that is there no matter how many channels I simulate (although I have not tried to simulate more than 23). The edge channels always have the highest wrong-sign response. I don't understand in any detail the mechanics of the wrong-sign responses and how the wave of charge flowing down the detector chain piles up at the edges. I did check that the cross-coupling is not present if the detector capacitors are set to a very small value, so essentially none of the coupling takes place within the bias and power-supply networks of the amplifiers. Anyway, Figure 8 shows that the comparator outputs for the wrong-sign responses go high only after about 4μs delay. That should prevent them from getting latched by the Tracker readout system, as the trigger acknowledge signal should have a delay of only 2 to 3 μs.

In summary, the Spice simulations predict that an oxygen ion at normal incidence will produce a cluster of 3 strips, while an iron ion at normal incidence will produce a cluster of 7 strips. In both cases the cluster width is still small compared with a calorimeter log, so the track extrapolation to the calorimeter should be fine. However, the simulation is idealistic. Testing a tracker in a heavy ion beam would be the only way to gain high confidence in knowing the Tracker response to a heavy ion prior to launch.

As has long been known, heavy ions have a complex impact on the trigger dead time. If a heavy ion passes all the way through a single tower it will make the trigger from that tower dead for one or two hundred microseconds. However, all other tower triggers will remain alive, and the impacted tower will remain alive with respect to recording tracks that are triggered by other towers or by the Calorimeter, except for the cluster of strips right around the track of the heavy ion, which will remain dead for one or two milliseconds. A high-accuracy analysis of the trigger dead time would have to include a model of this partial dead time.

Figure 5. The preamp output for an oxygen ion incident on strip 12, shown over a long enough time period to see the decay back to the baseline.

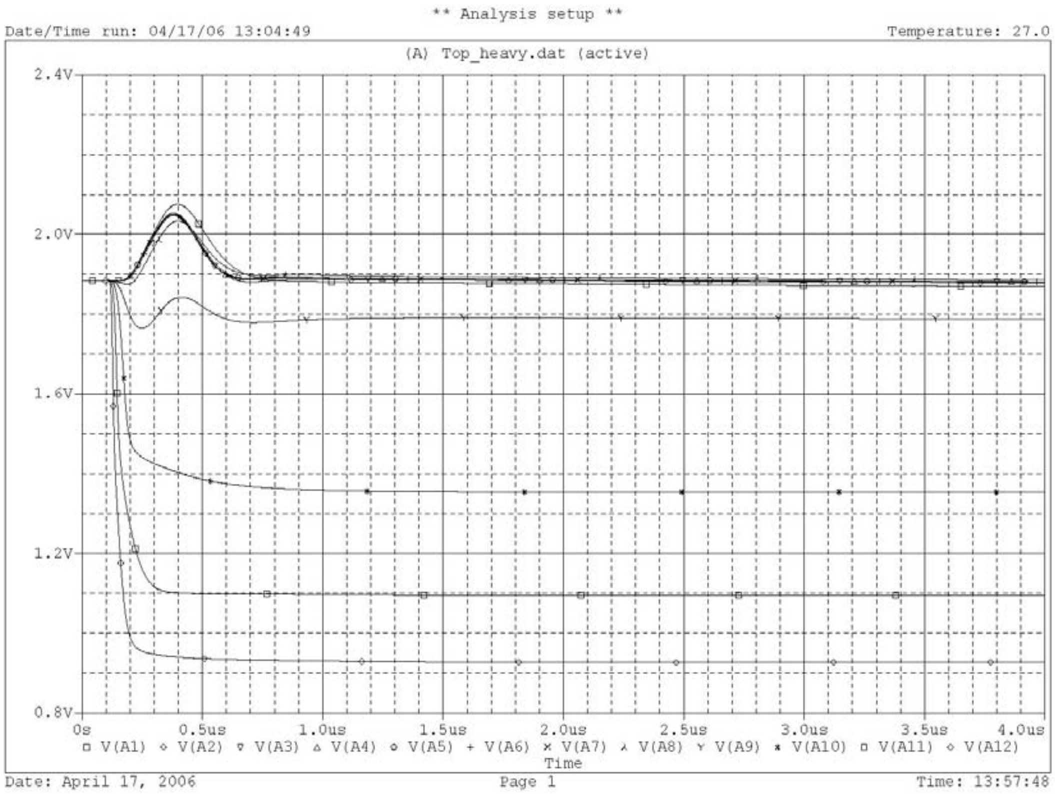

Figure 6. The amplifier outputs for an iron ion at normal incidence on strip 12.

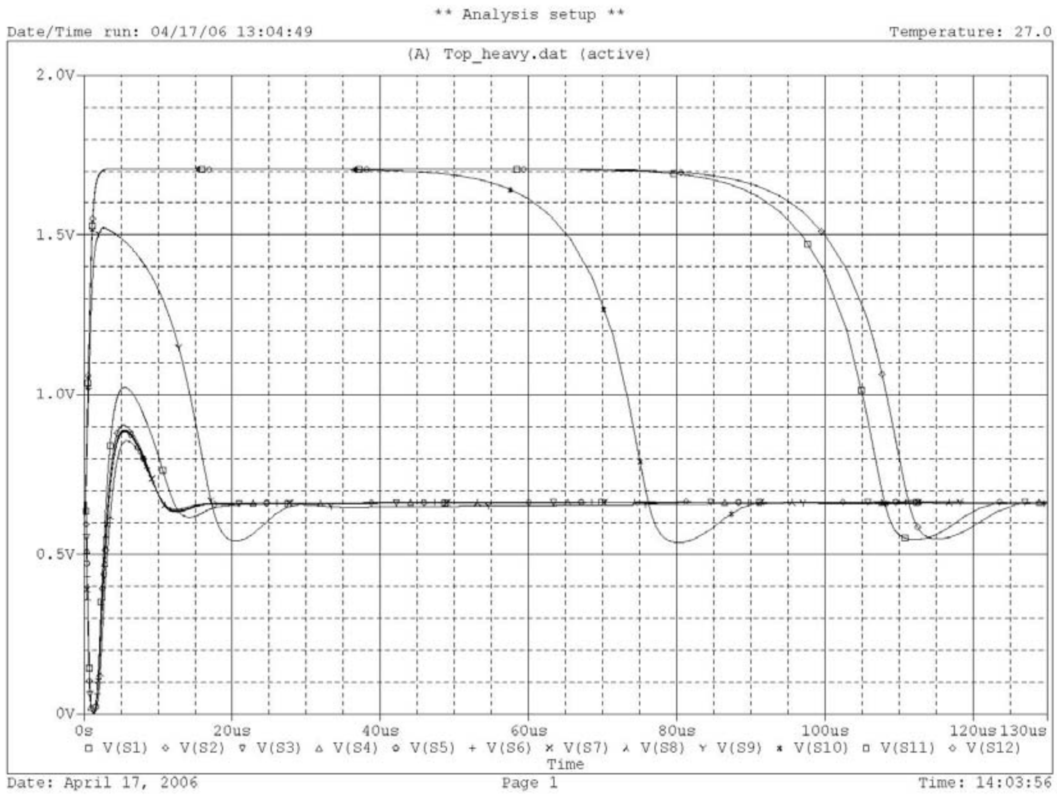

Figure 7. The shaping amplifier outputs for an iron ion at normal incidence on strip 12.

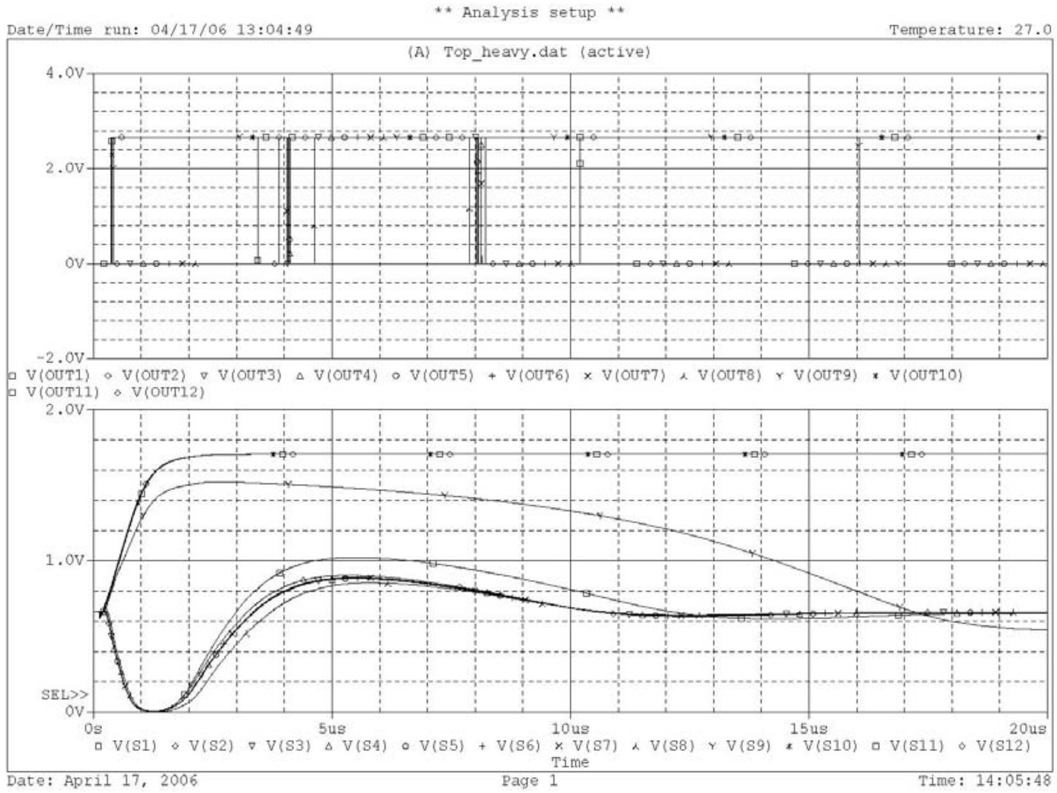

Figure 8. The shaping amplifier (lower) and comparator (upper) outputs for an iron ion at normal incidence on strip 12.