CHEC Camera: Monte-Carlo Trigger Studies
1) MAPM-based Camera

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This document provides a summary of the MC studies performed to provide a preliminary optimisation of the CHEC camera design and to inform the instrument requirements.

Method:

CORSIKA shower simulations are used to generate lists of photoelectrons (pe), which are converted to a Root-based image format assuming perfect optics. An electronics and readout simulation (LTools) is then applied. The results are therefore valid only for a telescope system in which the optical PSF is significantly smaller than the pixel size. A camera of 32x 64 pixel MAPM modules is assumed in all cases (see e.g. Figure 2, top). The simulated signal and noise pulse height distributions are based on a study by Homeschandra and Hinton in 2010. Figure 2 (middle) shows these pulse height distributions. The bottom panel shows 4 different pulse shapes used for testing, with a more or less pronounced tail.

Pixel-level thresholds are derived by requiring an accidental camera trigger rate of 200 Hz at double the nominal NSB level (with performance at the nominal extragalactic NSB level of 12 MHz/pixel shown in figures 2-5). This corresponds approximately to the "aggressive" trigger definition of the MC group – but the safe definition (accidental/NSB trigger rate < cosmic ray rate is only slightly lower). A digital pulse based on a pixel (or combination of neighbouring pixels) exceeding this threshold is assumed to be sent to the camera-level trigger where a neighbour requirement is applied.

Figure 1 shows a typical simulated shower image, the effect of NSB and the image used for triggering for the case of a 4-pixel merge at the trigger level.

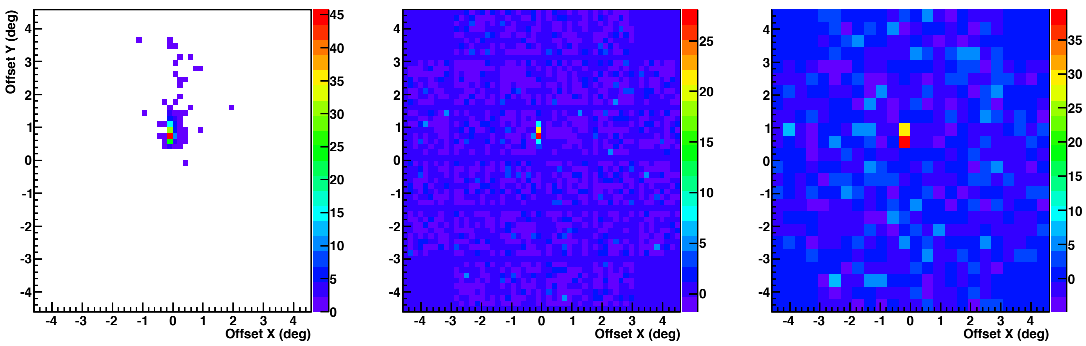


Figure 1: simulated shower image (left), after adding NSB photons and noise (middle) and the resulting trigger image, after applying a 4-pixel merge, as implemented for Target.

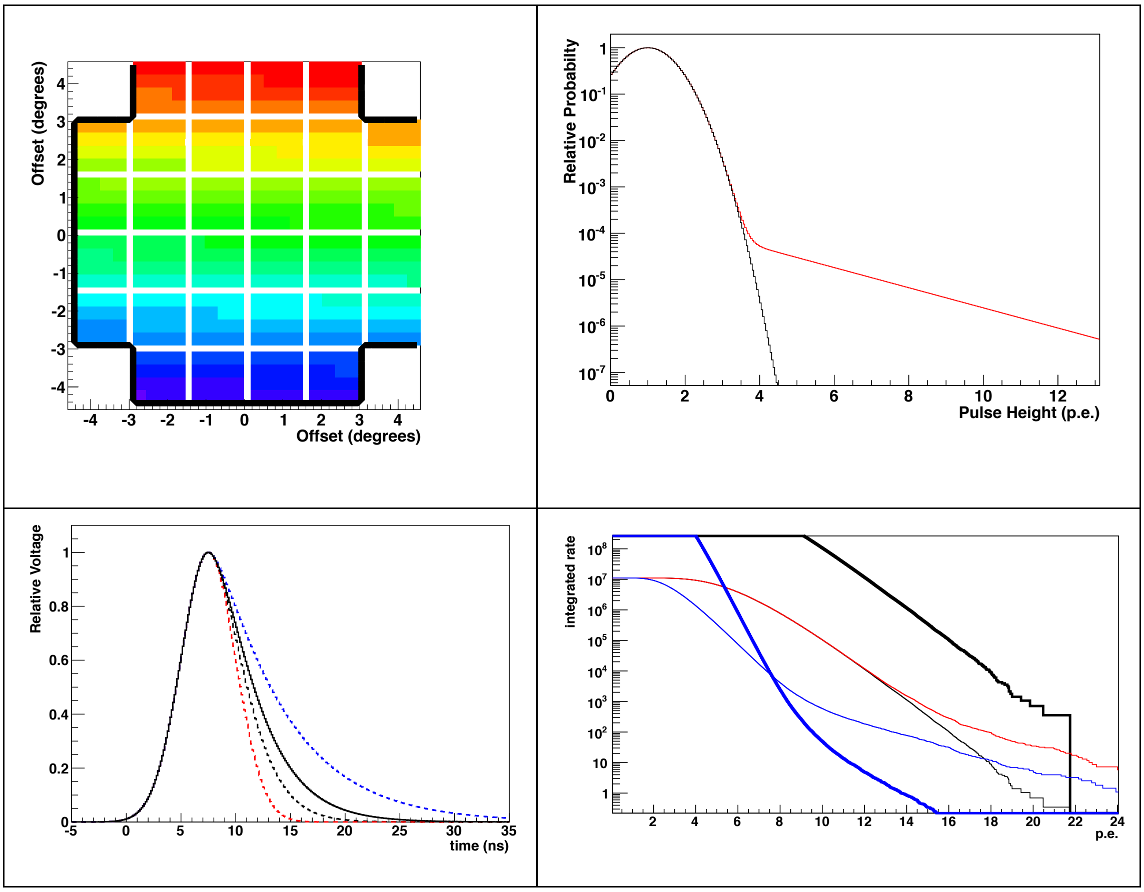


Figure 2: Top left: Camera layout with gaps in between modules. Colours indicate the mapping of individual pixels to the triggered pixel in the case of a 4-pixel merge. Top right: Pulse height spectrum assumed for signal (black) and noise (red) including after-pulsing. Bottom left: Pulse shapes for a perfectly Gaussian pulse (red, dashed) and for pulses with an exponential tail (black/blue dashed). The pulse indicated by the straight black line was used to perform the gain variance, NSB and time jitter tests described below. For all other tests, the dashed black pulse was used. Bottom right: rate versus threshold curves at double nominal NSB for trigger (super-)pixels (thin lines), and for the camera as a whole (thick lines). The merge of four neighbouring pixels into a trigger super-pixel is shown in blue, a multiplicity of 2 is used for the camera trigger. The black and red curves show a 16-pixel merge and a multiplicity of 1. The black curves have clipping applied to the individual pixel inputs at a level of 9 pe. The red curve shows the super-pixel rate without clipping.

Results:

Figure 3 shows that for two plausible CHEC camera configurations the basic (level B) requirements for triggering can be met. The trigger efficiency reaches 50% at a threshold of 60-70 pe – well below the requirement of 100 pe. In addition the triggers perform well at large energies and impact distances as can be seen in figures 3 and 4.

Figure 5 shows the impact of change pulse width on trigger performance. Figure 6 shows the impact of gaps in the camera and of changing coincidence window for the camera-level trigger. Gaps of 1-pixel width between modules have a significant negative effect on performance (at the ~15% level), but the CTA level B performance requirements can still be readily met. The performance is rather insensitive to the coincidence window width for windows > a few ns. It is also clear from figure 3 that merging of 4 pixels pre-trigger has superior performance to the no-merging scenario. Figure 6 also shows that a simple trigger with no neighbour requirement, based on a 16-pixel analogue sum, has a performance approaching that of a 4-merge/mult-2 trigger and should be further evaluated.

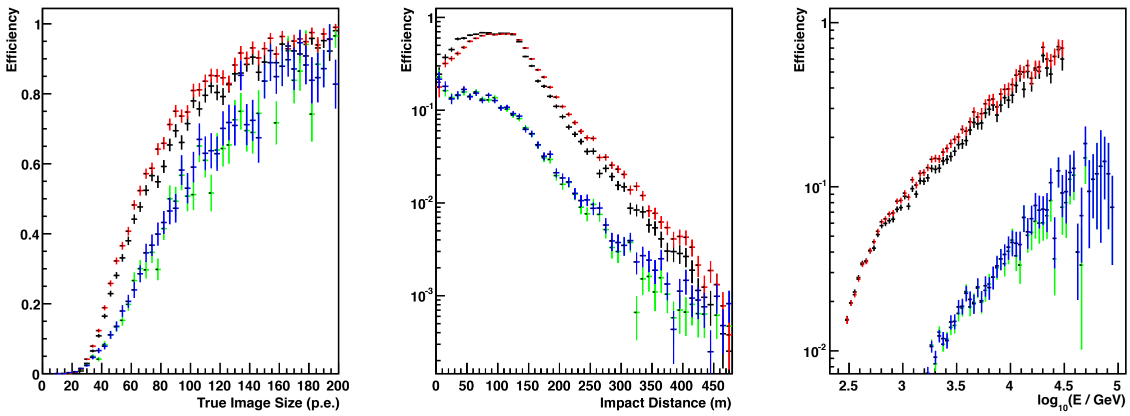


Figure 3: Trigger efficiency for gammas (red & black) and protons (blue & green) for a configuration with 16-pixels merged and multiplicity 1 (black/green) and 4-pixels merged and multiplicity 2 (red/blue) versus (from left to right): true image amplitude, impact distance and primary energy. A coincidence window of 9 ns and a pulse FWHM of 6.5 ns are used in all cases.

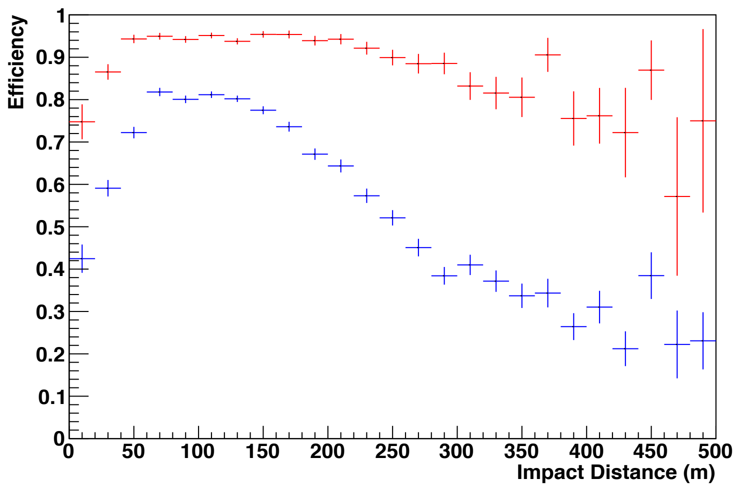


Figure 4: Trigger efficiency versus impact distance for true image sizes > 50 p.e. (blue) and 100 p.e. (red)

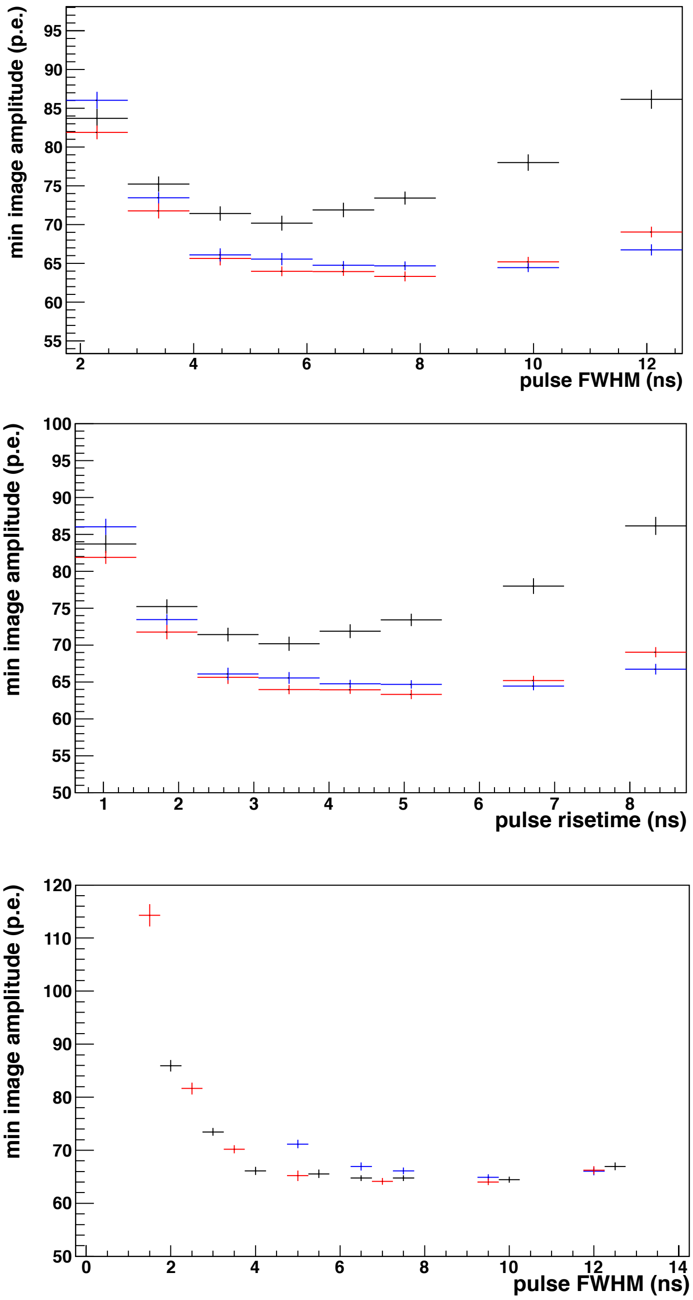


Figure 5: Image amplitude for 50% trigger efficiency as a function of pulse width (FWHM – top, 10-90% risetime – middle), for coincidence windows of 3 (black), 6 (red) and 9 (blue) ns and a 4-pixel merge for the trigger and multiplicity 2. The bottom plot shows the effect of changing the pulse shape as indicated in Figure 2, bottom left.

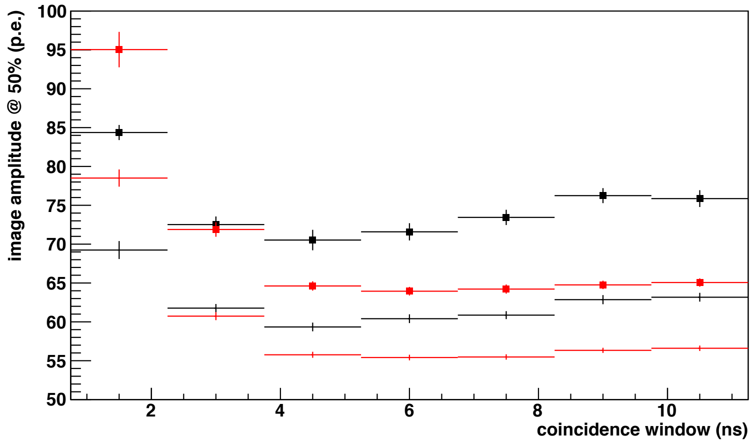
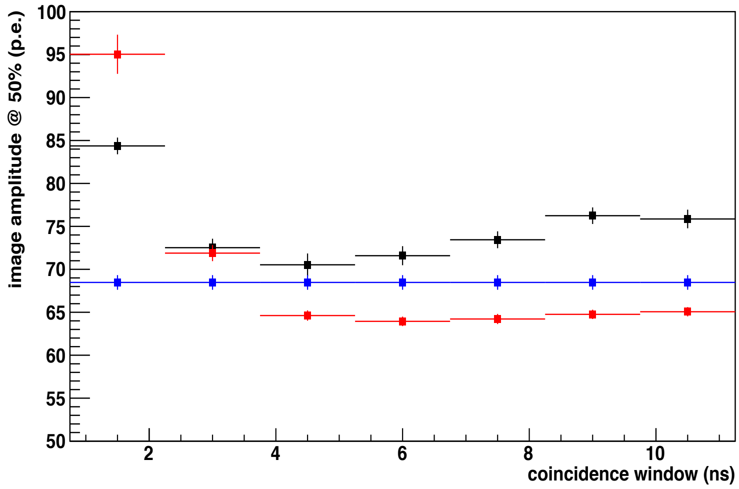


Figure 6: (top) Image amplitude for 50% triggering efficiency version coincidence window for cameras with (solid markers) and without (no markers) gaps. The red curves are for 4 pixels merged for the trigger and black to individual pixels. (bottom) As for top, but only for configurations with gaps and with a blue line, corresponding to a merge of 16-pixels and a multiplicity of 1, added.



The following plots show the impact of clipping, gain variations, time jitter and electronic noise, assuming a nominal configuration (pulse shape as in Fig.2, 10 ns coincidence window, merge-4/mult-2, 1-pixel wide gaps as shown in figure 1 top, electronic noise of 0.4 p.e. rms and a trigger time jitter of 1 ns rms).

Adding electronic noise at the expected level of 0.4 p.e. to the simulations results in a ~10% increase in the image amplitude required for 50% trigger probability. Electronics noise levels significantly greater than 0.4 pe (per pixel rms) on the trigger path, are therefore very undesirable. Figure 7 illustrates the effect of signal clipping (pre-sum) on the performance. No gain in performance can be seen for the 3 different clipping levels tested for a merger of 4-pixels. However for a 16-pixel merge and multiplicity 1 clipping looks very promising, and may make this style of trigger very powerful.

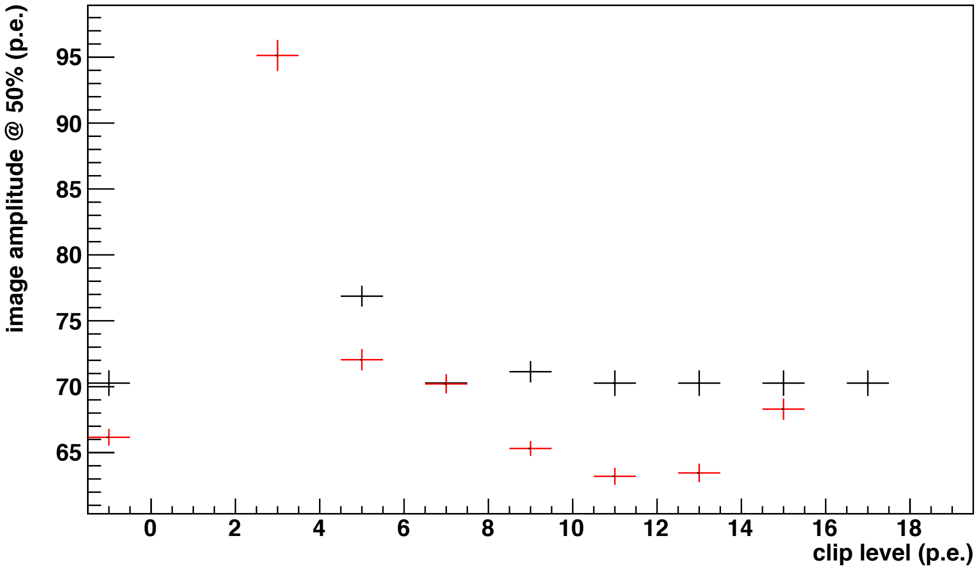


Figure 2: Trigger efficiency versus clipping level for merge-16/mult-1 (red) and merge-4/mult-2 (black). A value of -1 denotes no clipping. A 10 ns camera-level trigger window and 20% rms gain variations are assumed – see below.

Figure 8 shows the impact of trigger time jitter and gain variations on the performance. Gain variations of <20% rms have a modest (<10%) impact on performance. Time jitter on the inputs to the camera level trigger is acceptable up to ~2 ns rms when a ~10 ns wide gate is used. Smaller variations (~1 ns rms) are required to make proper use of narrower gates.

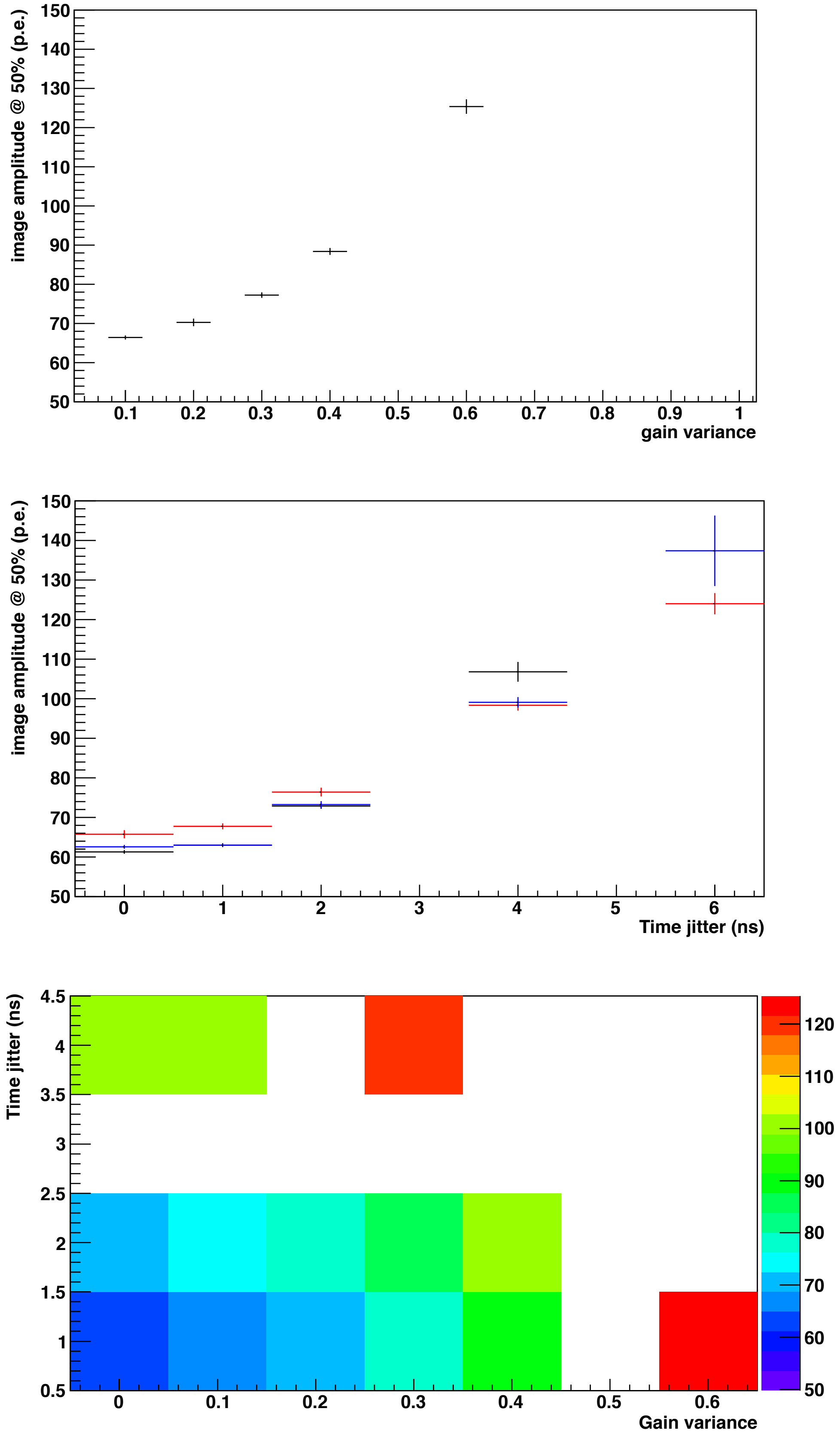


Figure 3: Trigger efficiency versus gain variations (top) and time jitter (middle) for the merge-4/mult-2 configuration (black) and the merge-16/mult-1 (red). The blue curve shows the impact of changing the coincidence window from 7ns to 10ns. The bottom plot shows the combined impact of these two effects for a coincidence window of 10ns.

Figure 9 shows the impact on camera trigger uniformity of the camera gaps and non-ideal triggering approach. The worst case for uniformity is the merge-16, multiplicity-1 trigger – an analogue-sum trigger with no overlap between patches. Even in this case the non-uniformity as at the 5-10% level for amplitudes >100 pe.

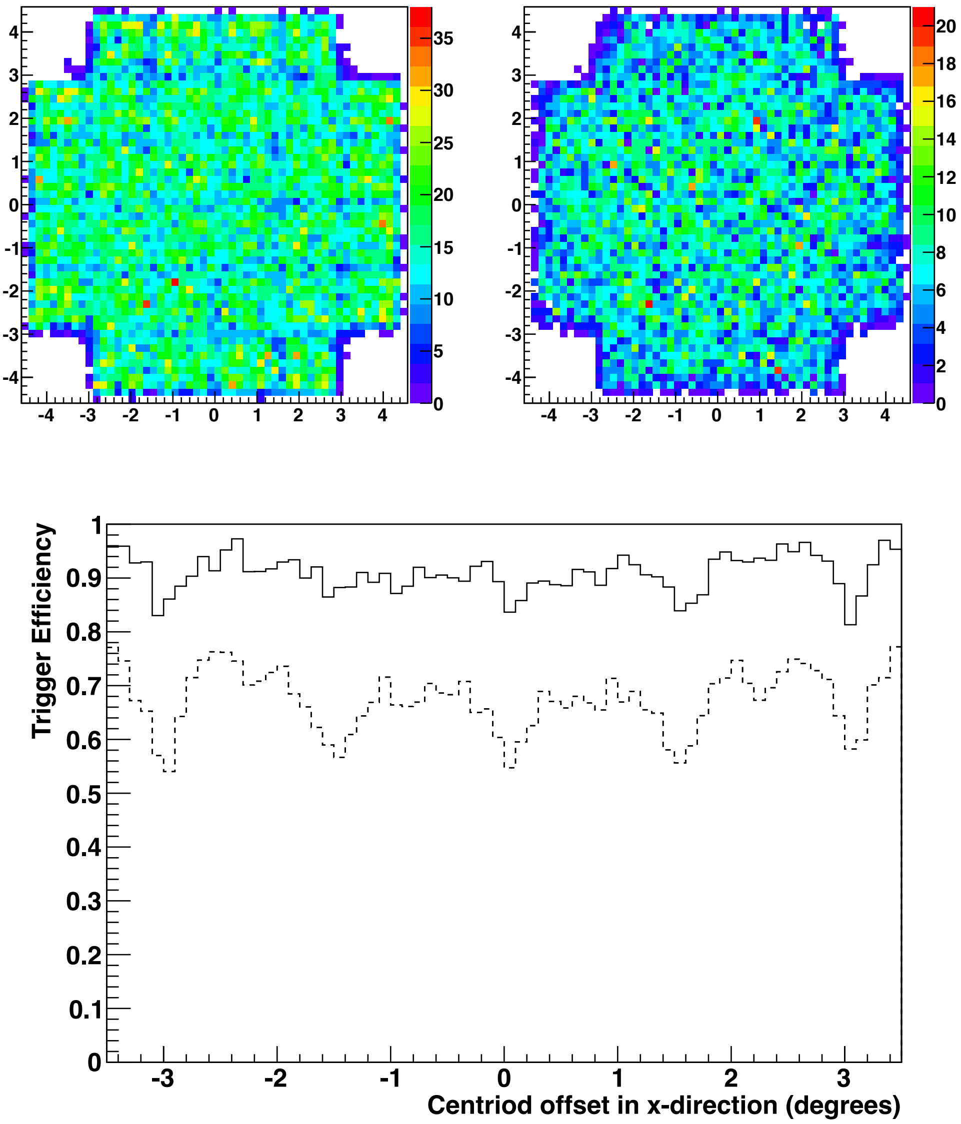


Figure 4: (top) distribution of the centroids of triggering images in a camera with 1-pixel gaps, for a 16-pixel merge and a multiplicity 1 camera trigger, for image amplitudes >50 pe (left) and > 100 pe (right). (bottom) trigger efficiency as a function of x-offset – for all values of y – for >50 pe (dashed) and >100 pe (solid) images.

Recommendations:

Pulse Shape (after pre-amplifier/at Target input):
10-90% risetime **3.5-6.0 ns**, and
FWHM **5.5-10.5 ns**

Trigger logic: analogue sum of 4 pixels, discriminated and sent to camera-trigger where a neighbour requirement and a minimum multiplicity of 2 is applied within a coincidence window (between digital signals on the backplane).

Camera Trigger Coincidence Window: 6-10 ns.

(a simple OR of all discriminated 16-pixel sums is attractive – particularly with clipping, but has inferior performance at larger impact distances – at least when no signal clipping is applied.)

Time jitter on digital inputs to camera trigger: <2ns for a 10 ns coincidence window, <1ns for a 6ns window.

Electronic Noise: <0.5 mV rms per pixel on the trigger path.

Pixel to pixel gain variations: <25% rms (4-pixel sum), <35% (16-pixel sum)

Gaps: <1 pixel=6mm gaps between MAPMs (including glass thickness).