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Flat-fielding of H.E.S.S. Phase 1

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Abstract. This paper describes the calibration system which has been designed for the flat-fielding of the cameras of the Phase 1 H.E.S.S. telescopes. It employs a nitrogen laser with a pulse length of 4 ns which is used to energise a scintillator. This signal from the scintillator is then passed 50 m through multimode graded index optical fibre to the dish centre from where it illuminates uniformly the camera.

Two system designs are considered. Each design would have a dish centre unit which provides a uniform light pulse for the camera calibration. The first design places the laser in the electronics hut at the telescope base, having four lasers for Phase 1, the second design has one laser in the system's main control room with a beam-splitter and long fibre cables to guide the light to the DCUs of the Phase 1 telescopes.

1 Introduction

Calibration systems using a pulsed laser and an energised scintillator have been used on many gamma-ray telescopes, e.g. the HEGRA telescopes or the Mark VI telescope of the University of Durham. Guiding of either the scintillator light or the UV-laser light through an optical fibre has been used to simplify the maintenance of the laser compared to having a laser box in the dish centre of a gamma-ray telescope to illuminate the camera directly (after energising the scintillator).

The new issue with calibrating the H.E.S.S. cameras is the size of the telescope and therefore the larger distance to be passed by either the UV-light or the scintillator light flash. Due to high attenuation in the fibre in the required wavelength regions, one has to deal with both timing and intensity issues.

To adjust the High-Voltages (HV) of each photomultiplier-tube (PMT) of the camera to the same electronic gain ('flat-fielding') we use the shortest possible flash (<4ns) of a N_2-Laser which has to be processed by a piece of an organic scintillator to get a spectrum similar (compare Figures 1 and 2) to the Čerenkov-light spectrum coming from the atmosphere. This light flash then has to illuminate the camera as uniformly as possible to provide good flat-fielding. To achieve this for the cameras of the Phase 1 H.E.S.S. telescopes we consider two main design layouts, which will be described in detail later on in this paper.

2 Experimental Setup

Flashes of Čerenkov-light have a duration of 3–5 ns, therefore the electronics of the camera has to deal with bandwiths of several hundred Megahertz. So the best way to calibrate the PMT-camera is to use the shortest possible light pulse.

As a light source we use a high power N_2-Laser model VSL-337ND-S from Laser Science, Inc. with a wavelength of 337.1 nm and a pulselength of <4 ns. Although there are lasers on the market with a shorter pulselength, this laser is the best compromise in terms of size, maintenance requirements and cost.

We illuminate a piece of scintillator directly with the UV laser beam. This wavelength-shifting scintillator is the 'Premium Plastic Scintillator' BC-418 from Bicron Organics (Bicron Website, 01/06/01) with the following specifications:

- Refractive Index: 1.58
- Rise Time: 0.5 ns
- Decay Time: 1.4 ns
- Pulse Width (FWHM): 1.2 ns
- Wavelength of max. Emission: 391 nm

Therefore we expect a minimum pulsewidth of about 5ns directly after the scintillator.

To couple the light into the fibre, we drill a small hole into the piece of scintillator and place the end of the fibre near the maximum of the scintillator flash. We use an optical gel

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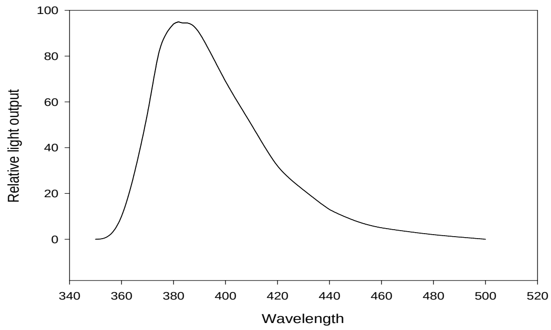

Fig. 1. Spectrum of the light output of the scintillator BC–418 from Bicron Organics

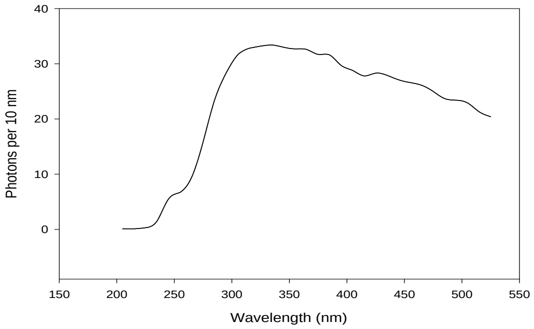

Fig. 2. Cherenkov Spectrum for 1 TeV γ-rays at Gamsberg, Namibia (H.E.S.S. site), derived from MOCCA simulations

with the same refractive index as the scintillator to improve the light input into the fibre.

At the end of the fibre we use a diffuser to illuminate the PMTs of the camera uniformly. Between the diffuser and the PMT we place a filter holder containing neutral density filters to reduce the intensity and colour filters to calibrate the PMTs at different wavelengths. At the telescope the diffuser will be the last element to ensure a uniform illumination of the camera.

The PMT used in our tests is a Photonis XP2960 with a high voltage supply card, as they will be used in H.E.S.S., set to a voltage of 1.1 kV.

2.1 Choice of optical fibre

In transporting a relatively short light pulse, two issues must be addressed:

- The attenuation in the fibre in our required wavelengths (see fig.2) is much higher than in the standard application of communications where mostly infared light is used.
- Due to dispersion the pulse broadening is quite significant after any distance ≥ 20 m.

After testing several fibre samples from different companies we realised that many fibres have either too high an attenuation or a too high pulse broadening. Taking into account the problem of coupling enough light into the fibre, one has to realise that light throughput and pulse width of the light pulse are competing. A bigger numerical aperture or simply a bigger diameter makes it easier to couple more light into the fibre, but as the dispersion is mainly modal in character, one experiences also a broader pulse in this case.

The pulse width after 50 m of a 1mm plastic fibre from Radiosphere for example is (9.6 ± 0.7)ns, but the light throughput is very good due to the big input diameter. In comparison to that, a 100 m piece of a 50 μm Brandrex fibre had a pulse length of (7.9 ± 0.7)ns but the light output was a factor of 50 smaller (compared to 100 m of the former fibre!), probably due to insufficient coupling to the small fibre diameter.

One way to improve the timing is to use a multimode graded index (MGI) fibre instead of a multimode step index fibre. For the required total reflection inside an optical fibre one needs a change of the refracted index between the core and the cladding material. Step-index fibres have a core with a uniform index of refraction right up to the cladding interface, where the index changes in a step-like fashion. The core of graded-index fibre has an index of refraction that radially decreases continously from the center to the cladding interface. As a result, the light travels faster at the edge of the core than in the centre (Photonics Handbook, 2000).

So the best fibre for our application is a 100 μm multimode graded index fibre, which has a reasonable light throughput and a good pulsewidth of (6.3 ± 0.7)ns after 50 m. This good timing is caused by the graded index of the fibre that prevents the modal dispersion which is the main cause of the pulse broadening in step index fibres. Tests for chromatic dispersion indicate that this is not important.

3 ‘Simple’ Design Layout

The quickest way — in terms of further required research (therefore ‘Simple’) — to establish a working calibration system is to set up a laser in the electronics hut at the base of each telescope and guide the light through $\approx$ 50m of fibre to the centre of the dish.

The fibre of choice here is the MGI-fibre, chosen for its good attenuation and timing properties. The resulting pulse after travelling through 50 m of the MGI-fibre has a length of (6.4 ± 0.7)ns with a rise time of (3.3 ± 0.5)ns.

To differentiate between modules located at different places of the system, we distinguish the main control room unit (CRU), the unit in the electronics hut located at the base of each telescope (telescope base unit=TBU) and the module consistent of optical devices installed in the centre of the dish (dish centre unit=DCU), which are described in detail in the following sections.

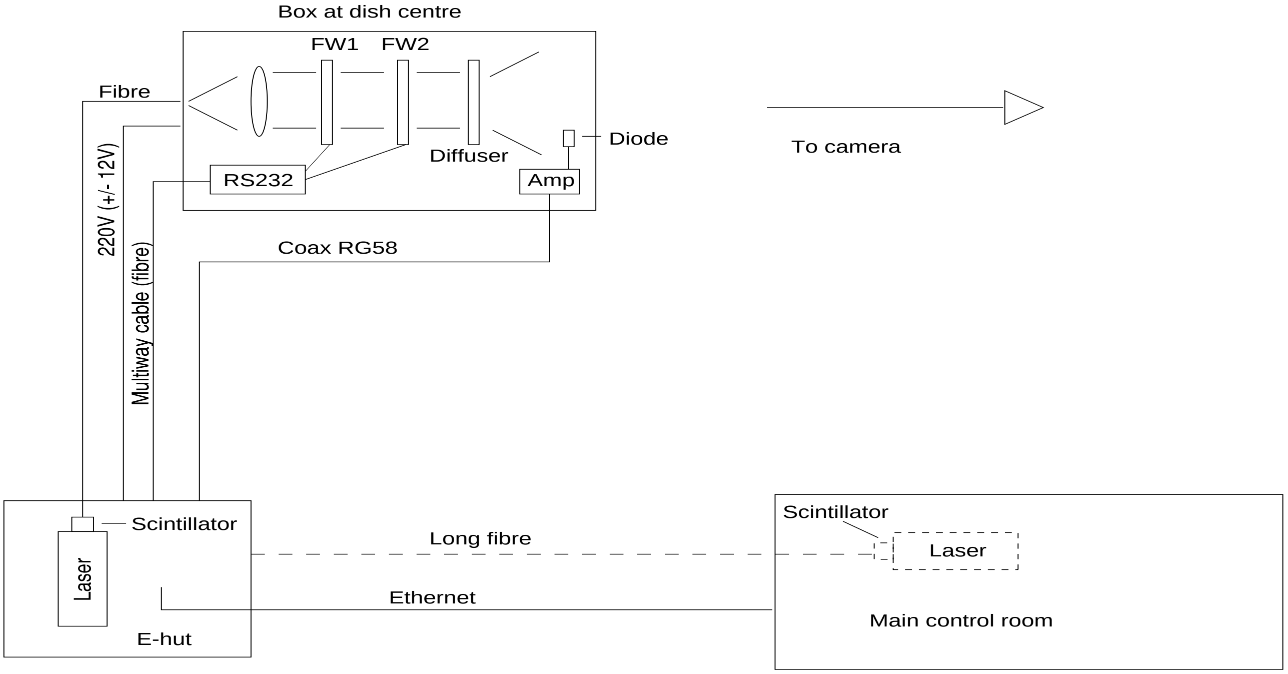

Fig. 3. Sketch of both possible design layouts, the laser at the main control room remains optional so far.

3.1 Telescope Base Unit (TBU)

Initially, the TBU will contain a stand-alone system, using the internal trigger of the laser to produce the required data for the flat-fielding. Later on the laser would be triggered via Ethernet by a subprocess of the camera data-acquisition-process of the control software of H.E.S.S. This subprocess might be divided into several processes to distinguish, for example, between a pure flat-fielding run or special needs like test-runs with chosen wavelengths or intensities. It will be possible to run the flat-fielding system during normal data-taking to monitor changes in PMT gain.

Although the laser already has an opto-isolated trigger input we propose to use an Ethernet-Optical converter to have a pure optical trigger line and convert this only inside the laser box to the required electrical TTL pulse to avoid noise. This noise can be created by electrical cable carrying the TTL trigger pulse to the laser, because the cables act like antennas especially if one uses the laser in the pulsed mode.

Any communication devices e.g. to control filter wheels (like Ethernet-RS232 converter) or to process (digitize) data from the monitoring diode would also be placed in the electronic hut and would be controlled via Ethernet by the mentioned subprocess from the main control room.

3.2 Dish Centre Unit (DCU)

The DCU will contain the following devices (see Figure 3):

- light output fibre optics
- two filter wheels, one with different colour filters and one with a neutral density filter to control the illuminating intensity. Both filters would be steered by a motor controlled by the chain *RS232 – Ethernet – pulser subprocess*.
- a diffuser to illuminate the camera as uniformly as possible
- a monitoring diode which will be placed in a way that it can see the outcoming light from the diffuser without producing a shadow on the camera
- an amplifier unit for the diode signal before it is sent down to the electronics hut at the base of the telescope using RG58 coax cable.

4 Single Laser Design Layout

Instead of having one laser at the base of each telescope, we considered a second design layout, where we would have one laser in the main control room and guide the laser flash via optical fibre to the four telescopes of Phase 1.

The advantages of this solution are:

- much easier comparison of the state of each camera without the need of taking into account potential differences between four lasers due to ageing or other circumstances,
- reduction of purchasing costs (one laser instead of four), maintenance costs and time,
- fewer shielding problems.

One disadvantage of this solution is that the pulse length will inevitably be lengthened compared to the solution where the laser is at the telescope base. This is mainly due to modal dispersion inside the fibre as described earlier.

We have performed some preliminary measurements with a long graded-index fibre (300m). The pulse has a very low amplitude due to our current simple coupling method, which is basically placing the end of the fibre into a hole on the scintillator's surface which itself is attached to the laser box and therefore illuminated by the UV laser beam. Detaching and attaching the fibre again to the scintillator yields an uncertainty factor in the resulting light output of about 2.

Considering these uncertainties, the pulse width appears to be about 12–13ns after 300m of fibre. Nothing reliable though can be said about the rise time yet, which is important for the trigger of the camera. These measurements will be established in June/July 2001, when we will test a professional coupling system on loan from BFI-Optilas.

One may distinguish two possible arrangements for the one-laser solution:

- At the CRU, by coupling the laser light directly into the fibre (after splitting it up into four similar beams for the complete Phase 1), and guiding the light to the dish centre to illuminate the piece of scintillator there, or

- illuminate the scintillator directly with the laser at the CRU; collect and couple the light into the fibre, and guide it to the dish centre,

whereas for the four-laser layout for reasons of simplicity the scintillator would be installed in the TBU to keep the DCU box as simple as possible.

The obvious difference is the wavelengths of the light which have to be guided through the fibre and the way of coupling the light. Because the scintillator light flash is spherical, it is much more difficult to collect much light and couple this into the fibre compared to collecting and coupling the parallel laser light.

However it is difficult to locate an appropiate fibre to guide the UV laser light directly through a large distance. Either the fibre's attenuation is very high in the UV-range or it has to be a very special UV-fibre at very high costs and — as in the case of two tested samples — just too delicate to place on the telescope without a high probability of breaking. UV-transmissive MGI-fibres exist, and are claimed to have extremely small modal dispersion. However, a customized run is needed for our requirements of length and protection of the fibre, because standard applications only use short unprotected samples of these UV-fibres.

At the moment we instead propose to use the MGI-fibre, which is very flexible and therefore easy to handle. The MGI-fibre has the best timing compared to all the other fibres tested, but unfortunately too high an attenuation in the UV. We will therefore require a low-less coupling system to guide the laser light into the fibre.

4.1 System units

The components of the CRU placed in the main control room for this design layout would be the laser box with a beam splitter and the light coupling units. As in the 'Simple' layout, the CRU should be triggered by a subprocess of the camera DAQ-process.

The TBU now consists mainly of the fibre connection interface to access different fibre cables running up the telescopes, the Ethernet-RS232 converters and the processing unit for the monitoring diode data, connected with the main control room via Ethernet. The DCU would be the same as used in the simple design layout.

5 Status and Conclusion

The simple design layout of having a laser at each base of the four telescopes of Phase 1 is feasible in a very short timescale and will probably be used as a quick solution for calibrating the first telescope.

The single laser layout of having only one laser at the main control room and guiding the light via fibre to the four telescopes provides a very 'easy-to-use' calibration system with the big advantages of having the same laser pulse every time at every telescope and requirement to maintain only one laser instead of four. However, there are inherent difficulties in the transmission of short signals through long distances using optical fibres.

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