Calibration

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Excerpt from HyperK Letter of Intent

"… since in the current baseline design of Hyper-K the two tanks are separated into 10 individual compartments, it would require – roughly speaking – 10 times more time and manpower to perform the same calibration work. In addition, **due to its egg-shaped cross section, the dome above the Hyper-K tank will be quite a bit narrower compared to the maximum tank width. This may make calibrations near the wall of PMTs challenging, as will the bowed walls of the detector.**

Therefore, calibration methods should be carefully discussed during the detector design, and the detector should have dedicated, automated systems for placing various calibration sources at desired positions within the tank. **Due to the greater size and more complex geometry of Hyper-K, the positioning of calibration sources may need to be controlled by more advanced methods** than the vertical wire drop lines used in Super-K. Convenient methods like fixed rails, wire guides, or even submarine robots installed during detector construction should be considered …"

Calibration requirements

- Amplitude calibration
  - Continuously inject calibration pulses into the detection medium
  - Illuminate with a range of known optical wavelengths
  - Measure the number of photons per pulse on a pulse-by-pulse basis
- Timing calibration
  - Short optical pulse width (matching the PMT time jitter)
  - Calibrated and stable relative to a detector wide time reference
- Simulating the Cerenkov ring
  - Rings of light introduced into the detector volumes
  - Known intensity, emission time, wavelength spectrum

Proposed systems (UK)

- Pulsed light sources
  - Short duration light pulses from LEDs
  - Light coupled into optical fibres
  - Fibre ends inject light directly into the detector
  - Illuminate multiple PMTs on other side of a tank
  - Continuous low pulse rate operation during data taking
  - No risk to the detector (mechanical, radioactivity)
  - Electronics (which may require intervention) is easily accessible

- Pseudo-muon light source
  - Create a Cerenkov light cone at a fixed angle
  - Mimic expected Cerenkov spectrum
  - No use of radioactive source to generate Cherenkov light.

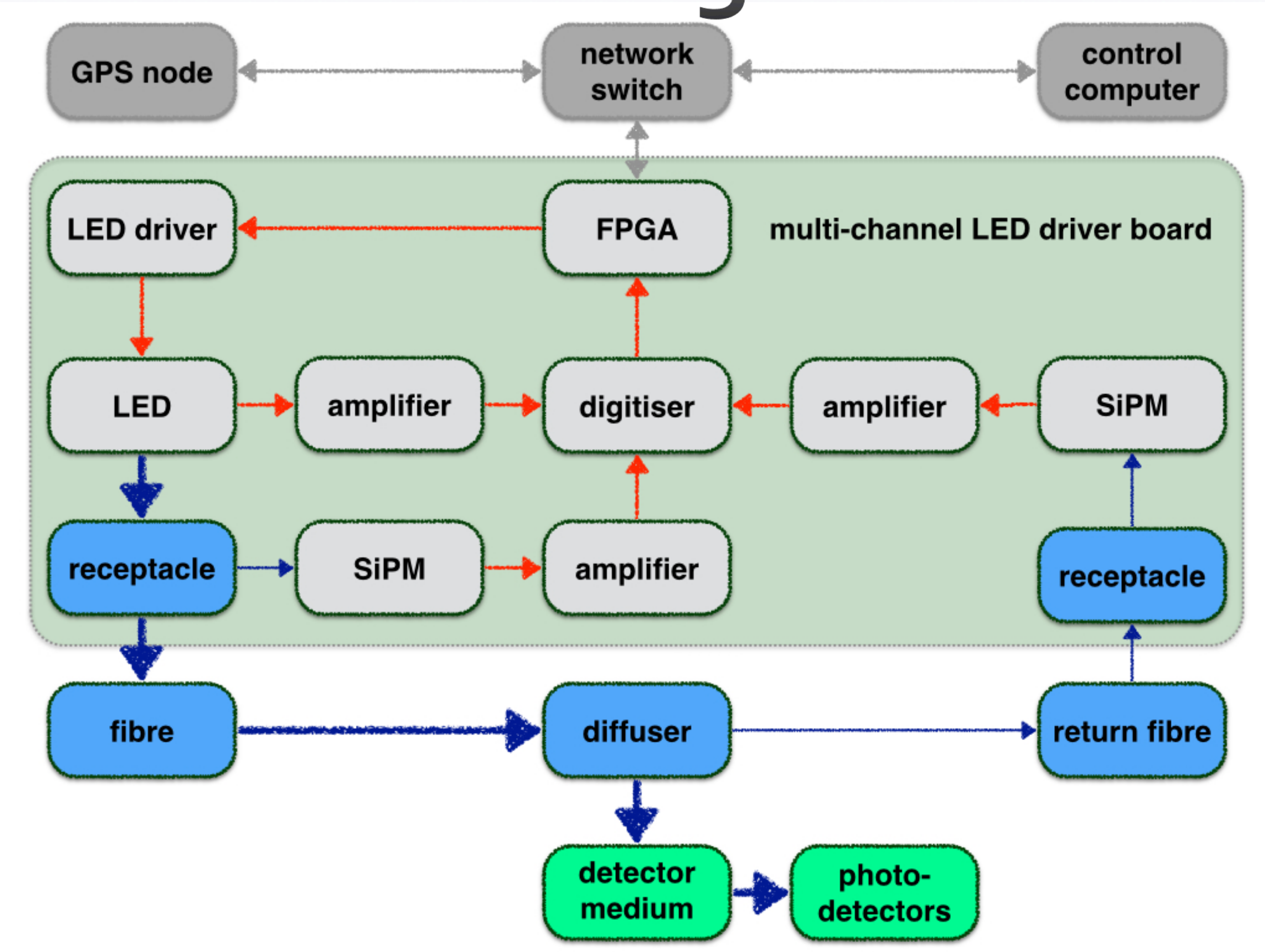
Pulsed light sources: Why LEDs?

- Pros
  - LEDs are cheap (few $/£/€ each), low cost driver electronics
  - Exist in the wavelength range of interest to us
  - Spectral emission in a narrow wavelength range (e.g. 10-15 nm)
  - Can be pulsed at few nanoseconds pulse width
  - Number of photons per pulse at fibre end from 1e3 to 1e5.
  - Significant UK expertise in using LEDs for calibration systems (ANTARES, KM3NeT, SNO+)
  - In principle relatively easy to couple to optical fibres to deliver light to a remote location

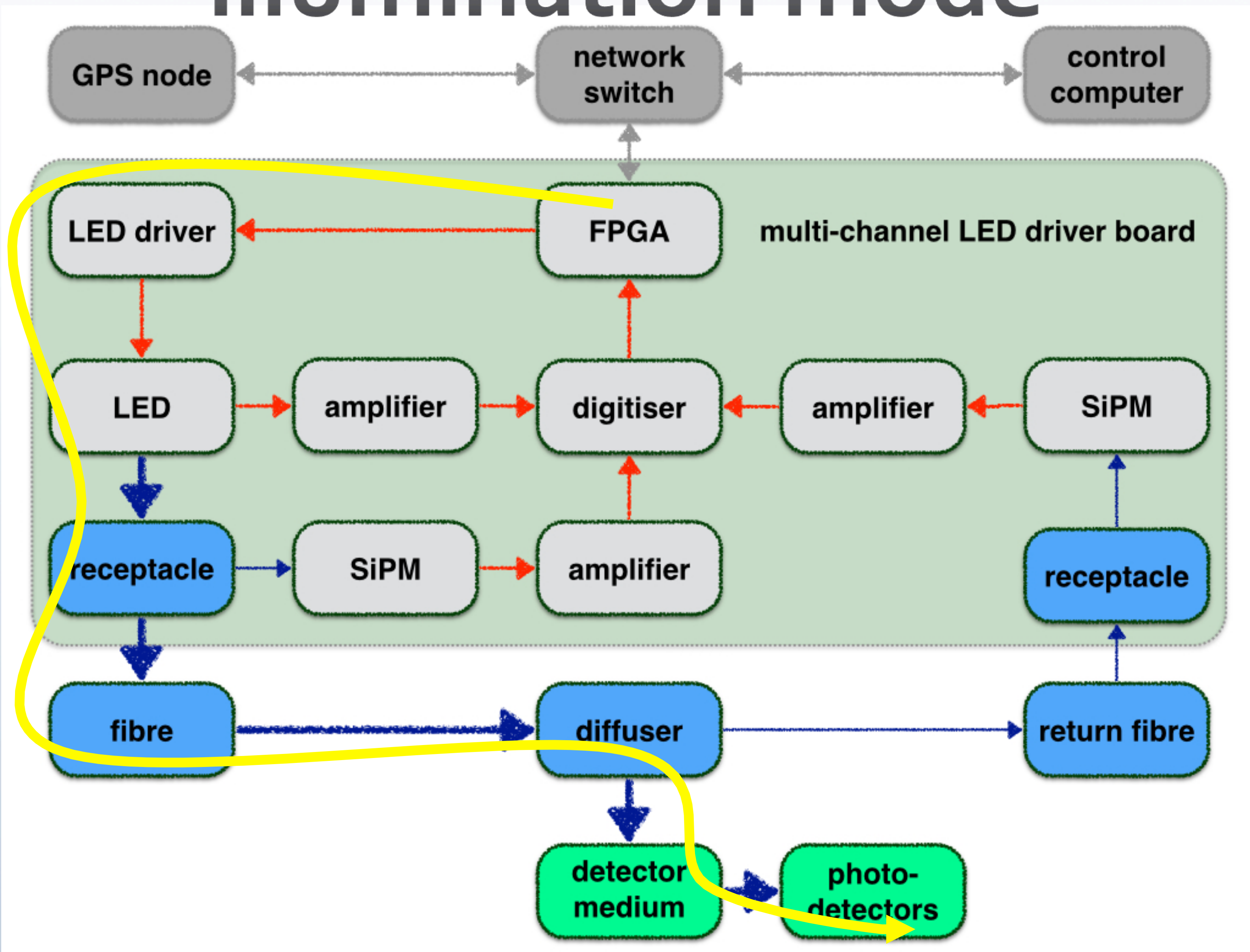
Pulsed light sources: Why LEDs?

- Cons
  - LEDs aren't designed to be pulsed - no guarantee that a particular LED will deliver ns pulses
  - Variations within a batch of nominally identical LEDs
  - Higher drive currents required to illuminate compared to laser diodes
  - Coupling of fibre to LEDs leads to large optical power losses, need to improve on current method for small core diameters

Pulsed light sources: flow diagram



Pulsed light sources: illumination mode

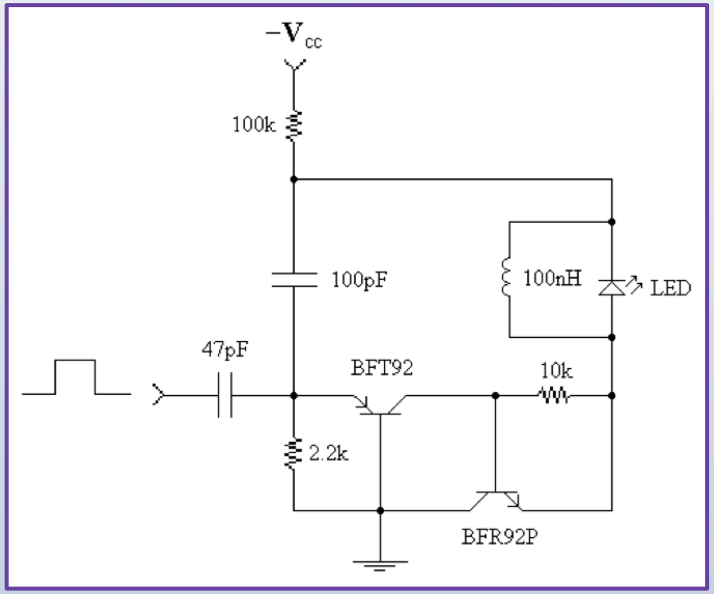


Pulsed light sources: illumination mode

- Features
  - Front end uses programmable FPGA which controls multiple LED driver (pulser) circuits on one board
  - LEDs will be coupled to graded-index multi-mode optical fibre, low dispersion (100ps per 100m) and low attenuation
  - Fibre to be coupled to a suitable diffuser at the detector end
- Aims
  - Inject of order 10^3-10^4 photons per flash
  - Minimum optical pulse width (few nanoseconds)
  - Minimize losses between LED and diffuser

LED pulser designs

- We plan to evaluate a number of LED pulser board designs:
  - Simple Kapustinsky et al., design using two transistor switch modified to add a reverse current inductor to sweep out charge. Successfully used in ANTARES where multiple LED drivers were were slaved onto 1 PCB for LED beacon operation



LED driver designs

- Dual MOSFETs push-pull design as featured in the SNO+ light calibration system
- Improvement : 4 MOSFETs in a H-bridge arrangement with on chip driver circuits
- Alternative: Quad OpAmps, (may struggle to deliver sufficient current)

SNO+ preliminary, paper in preparation

- **Why FPGAs?**
  - Modern FPGA permits accurate digital control over the electrical excitation pulse being delivered to the LED
  - Can control pulse width in 100 ps steps in principle
  - Can synchronize pulse times to 1 ns over kilometre distances

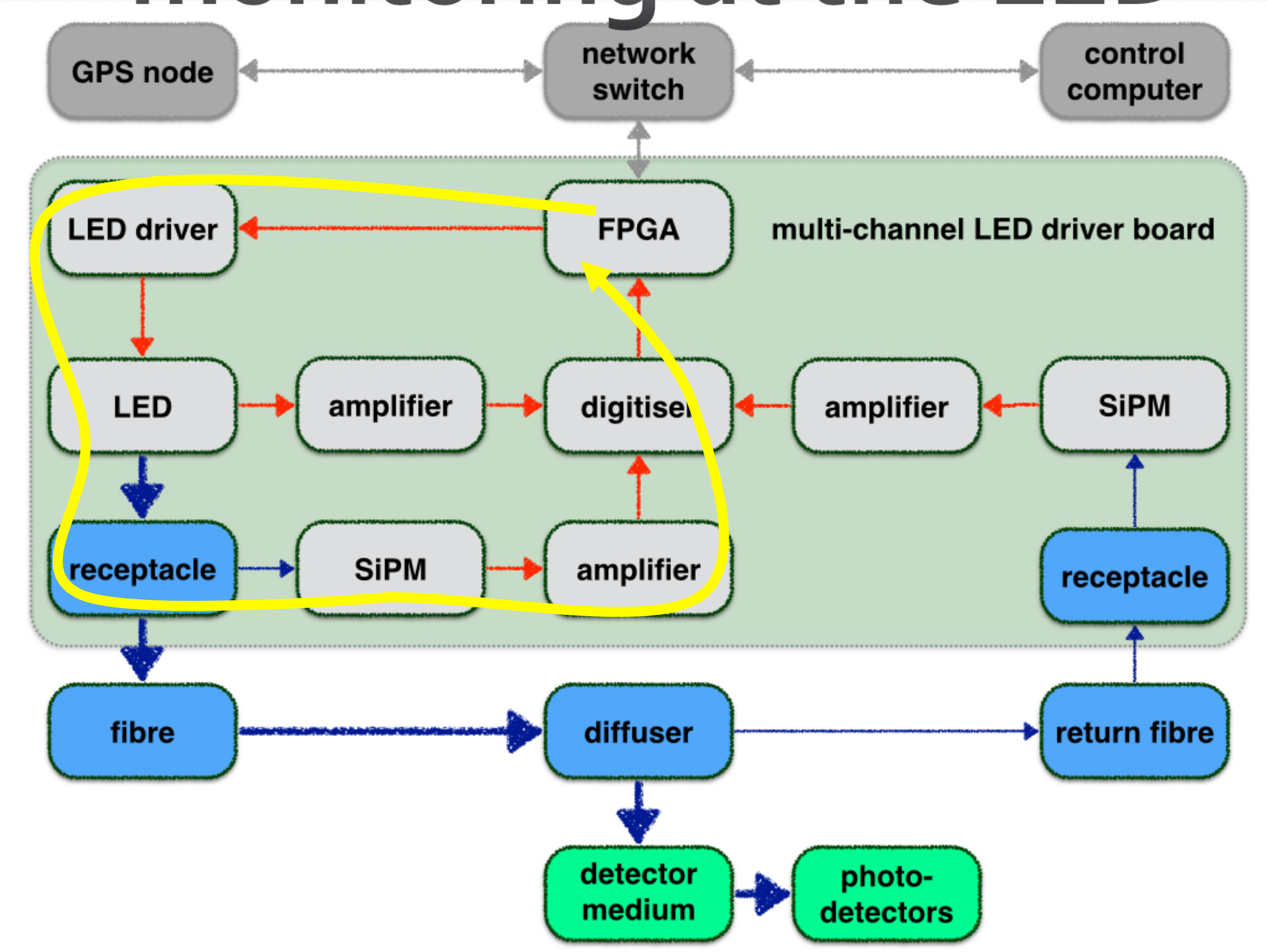
LED, fibre and couplings

- LED will be directly coupled to fibre via a drilled hole in the LED plastic lens
- Enables the fibre to be placed close to the diode emission region
- Graded-index multimode fibre small diameter (60 micrometer) presents a challenge for efficient coupling
- Graded-index fibre is needed to minimise time dispersion over the 100m from LED to detector. Low attenuation is a plus.
- Large core (1000 micrometer) step index fibre would lead to unacceptable 14 nanosecond optical pulse width over 100 m.

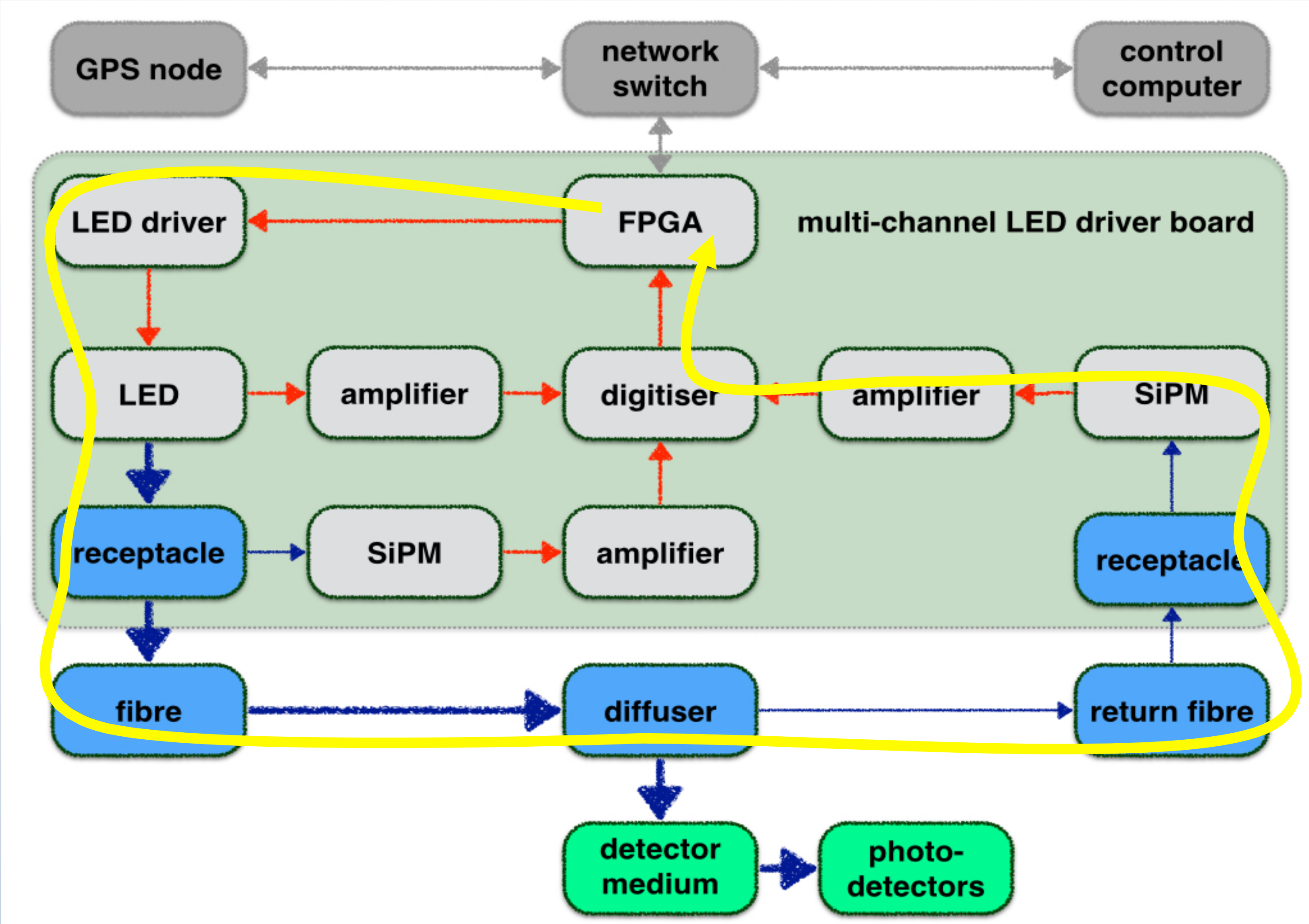
Pulsed light sources: monitoring modes

- Propose to monitor the light flashes at 2 different points in the chain:
- At the LED
  - Will have a small SiPMT coupled directly to the LED to measure the characteristics of each individual light pulse.
- At the diffuser
  - Directly coupled return fibre of the same type as delivers the light to monitor the average optical pulse shape and round trip time.
- Both systems will constantly monitor light pulse characteristics, e.g. amplitude, timing, pulse-to-pulse reproducibility, longevity, variation with environmental parameters,
- Known and stable pulse characteristics essential, e.g. to measure water properties including attenuation and scattering

Pulsed light sources: monitoring at the LED



Pulsed light sources: monitoring at the diffuser

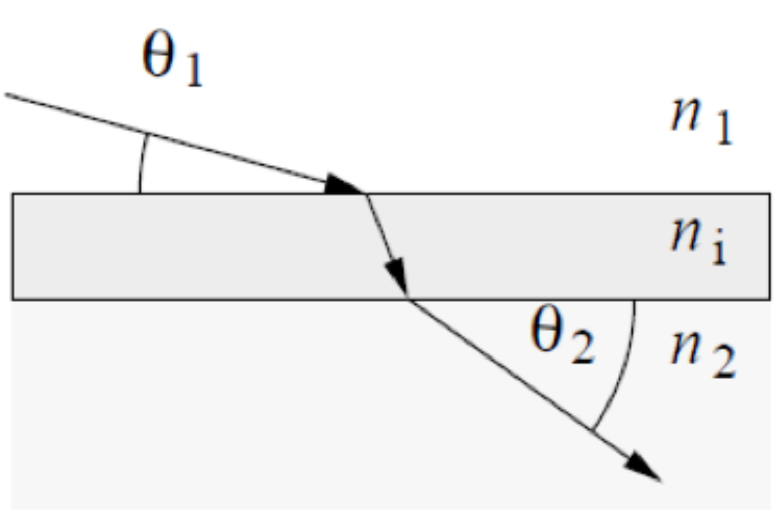


Pulsed light source: next steps

- Transfer different LED pulser board designs to the FPGA environment, in the first instance 3 designs on one board
- Evaluate key parameters, e.g. pulse width, pulse shape, reproducibility, amplitude range, for all 3 pulser designs
- Compare and characterise high intensity LEDs, measurements include spectral output, pulsed timing performance, in-batch reproducibility, etc.
- Design of the LED to fibre coupling mechanisms (LED and diffuser ends will be different)
- In water performance studies of the diffuser

Pseudo-muon source

- Objective is to inject a Cerenkov-like cone of light into the detector
- Can be achieved using a short, narrow transparent (acrylic) tube along with a light source which produces almost parallel light
- Different muon momenta can be achieved by using different lengths

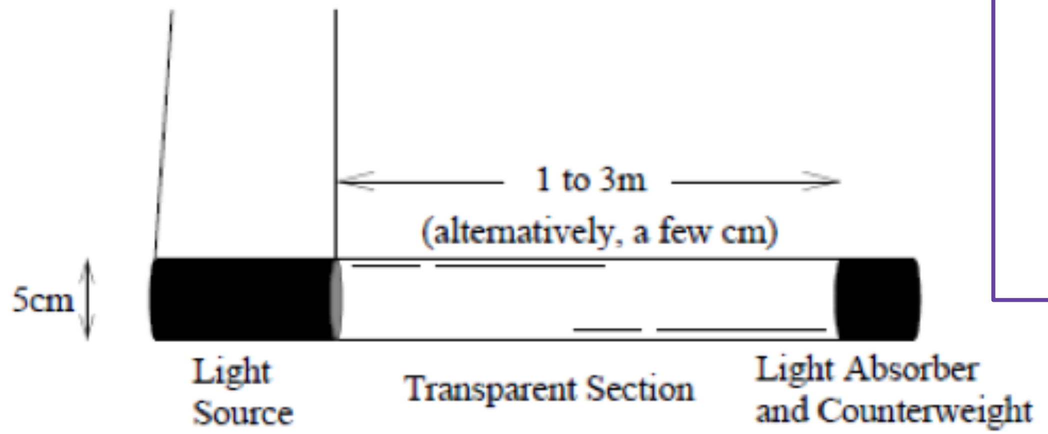


$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

independent of n_i

As $\theta_1 \rightarrow 90^{\circ}$ $\sin(\theta_2) \rightarrow 1/n_c$

Light emitted at Cherenkov angle.



Pseudo-muon source: next steps

- Optical simulation of the source to drive the design
- Identification of a suitable selection of LEDs that, when their output light is convoluted, will give a good approximation to a Cerenkov spectrum
- Tests of a prototype in a large water tank in the UK to evaluate angular profile and optical output
- Ultimately deploy in 1 kton prototype

Status

- UK activities in this area have started (via bridging funds)
- A full R&D proposal has been submitted and outcomes expected soon
- A clear set of calibration work packages, milestones and deliverables have been identified and responsibilities assigned
- Expect functioning devices and detailed performance data on a 3 year timescale
- Input from EU partners welcome