LED Calibration Status

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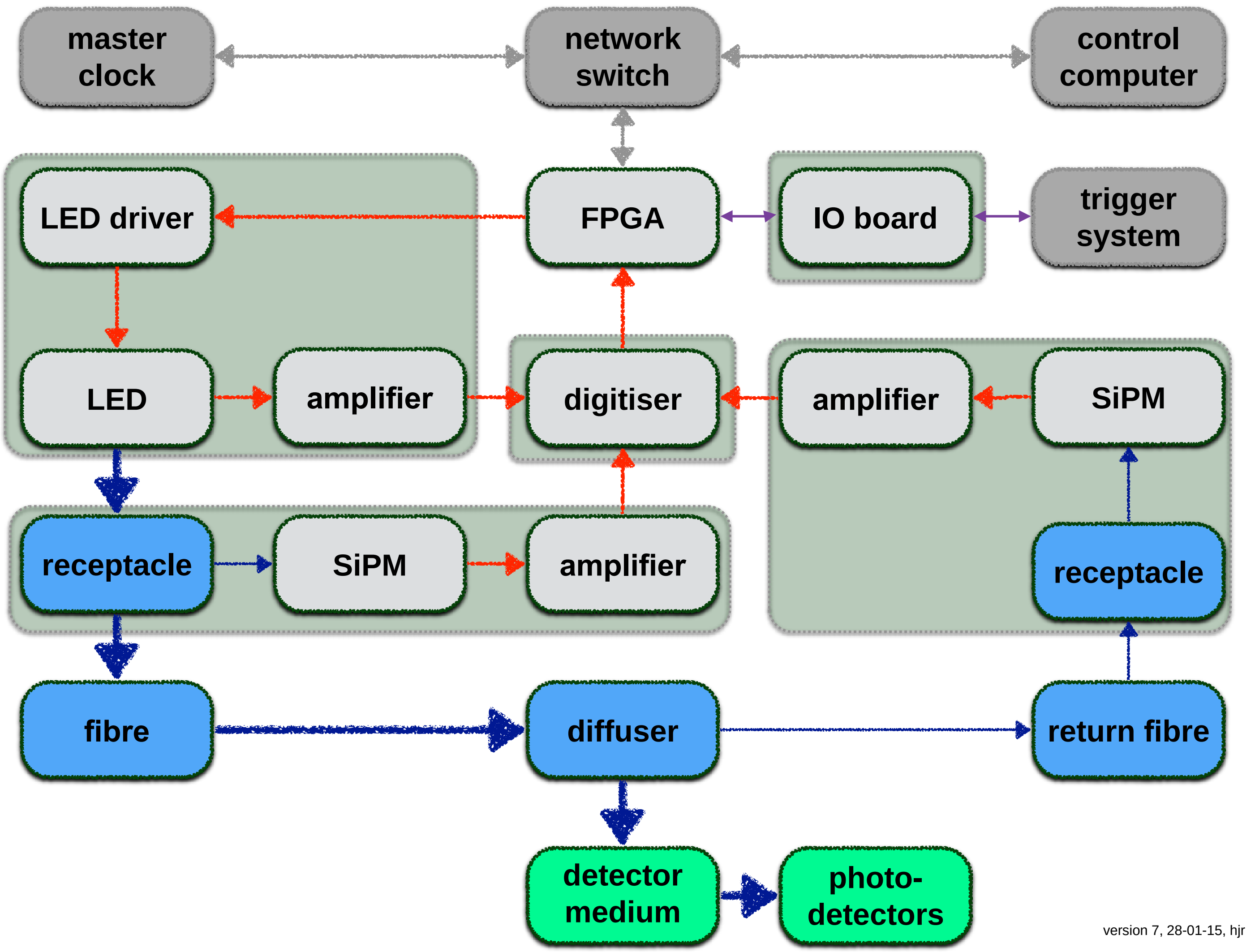
Current Status

- UK funding approved for the next 3 years.
- Calibration package
  - LED driver and testing
  - Fibre coupling and housing
  - Monitoring system
  - Pseudo-muon source
  - PDRA, Engineering support
  - Software development

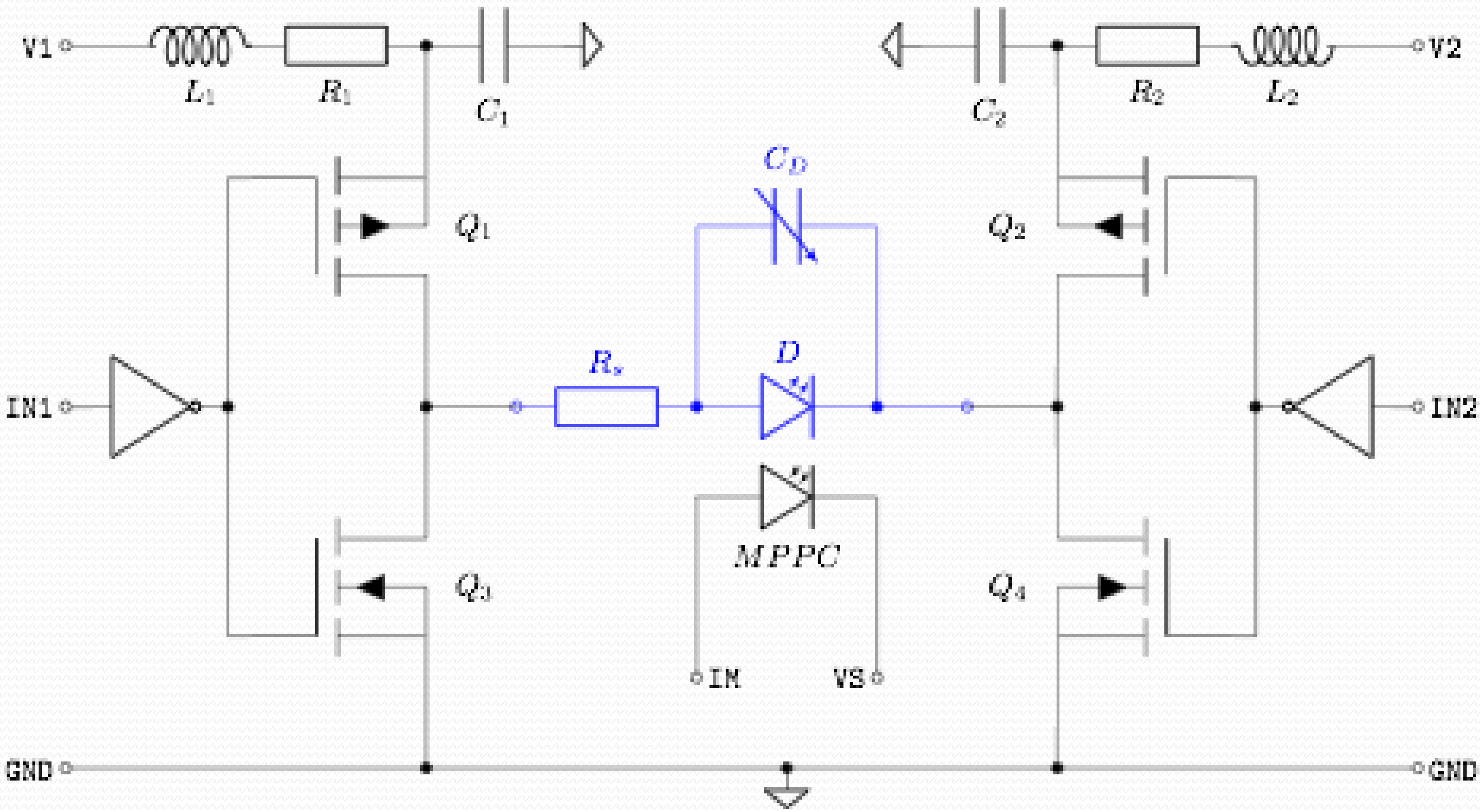
Optical calibration: Overview and prototype work

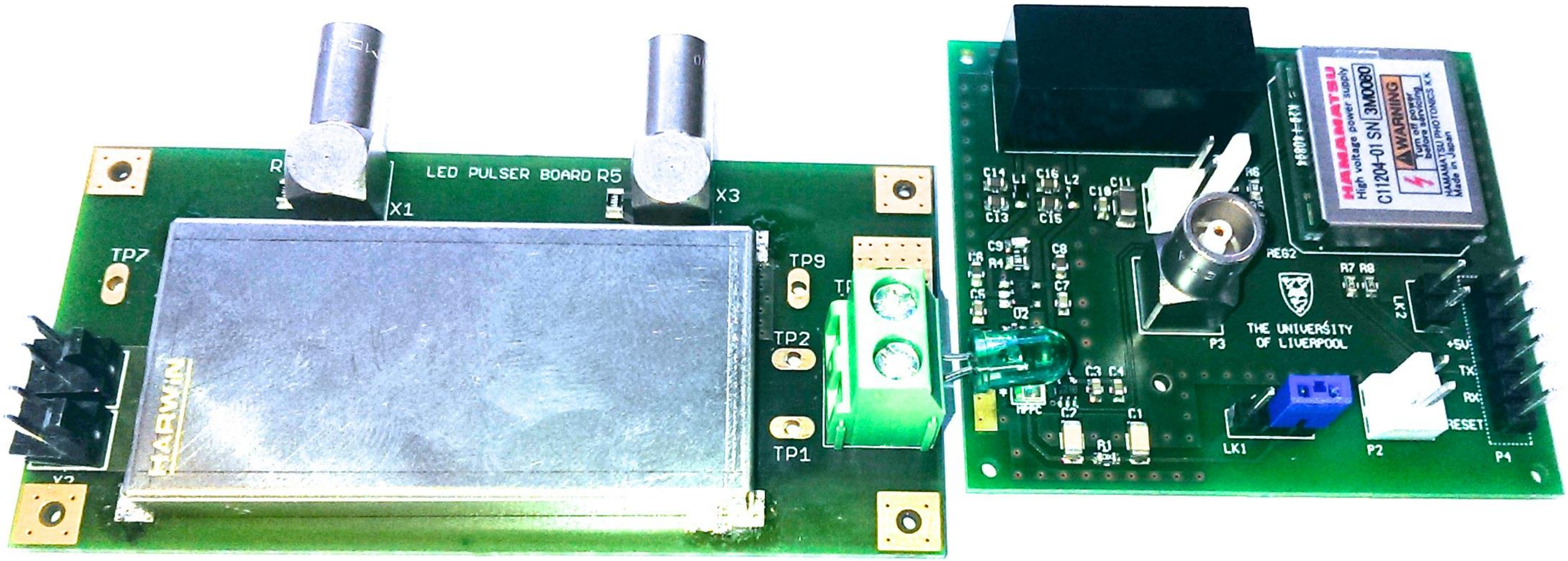


First Prototype

- The first prototype has been developed using bridging funds
- Simple driver circuit, only one design for now.
  - More ambitious design to follow.
- First pass of monitoring circuit also developed, using MPPC
- Early tests done, but full testing will commence in imminently.

LED driver with MPPC monitoring circuit idea

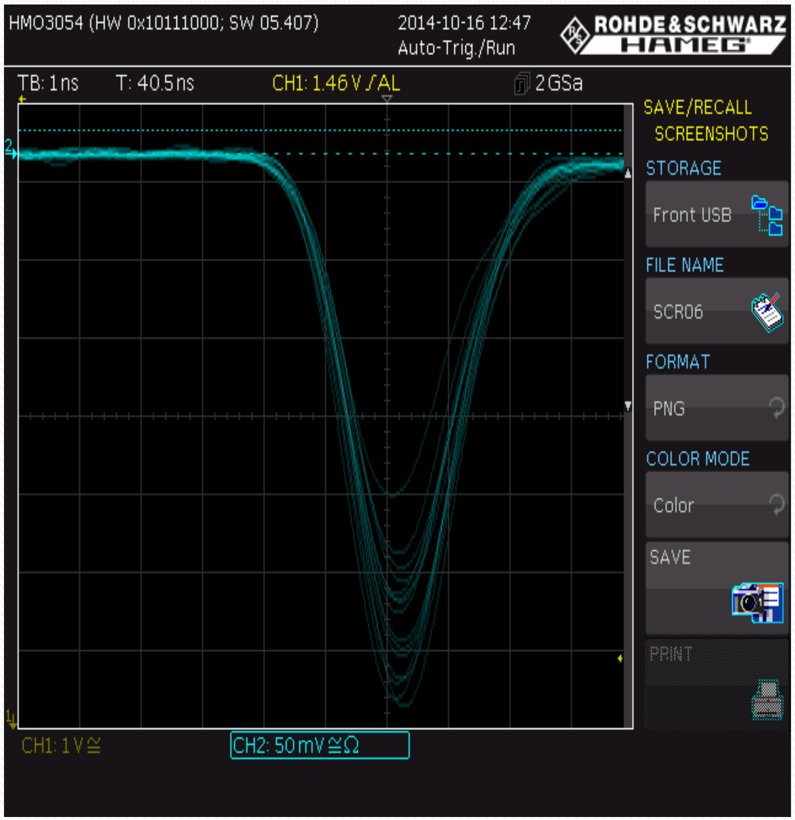




Quad-MOSFET LED driver
(inside large shielding box)

Pulse monitoring MPPC
with HV supply and
first stage amplifier

Very early development stage LED driver performance



Observed:

2 ns optical pulse width

Conditions:

435 nm (blue) LED

1 mm core short fiber

1e3 photons per pulse

0.8 ns rise time PMT

Driver operation:

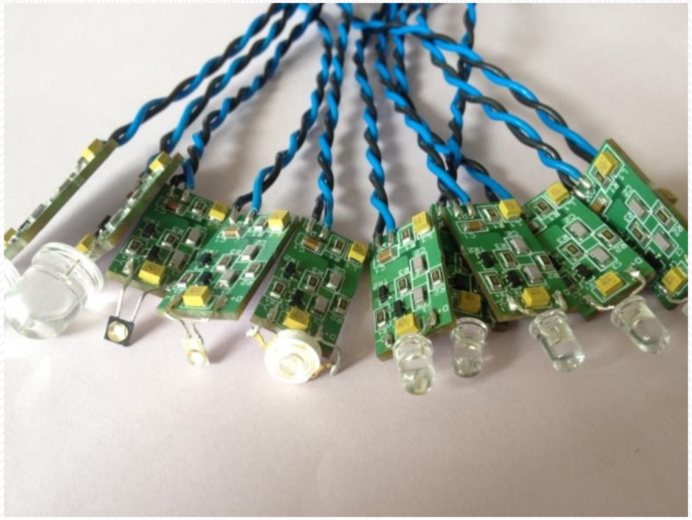
LED forward current only

No pre-bias voltage used yet

No reverse LED current yet

LED tests

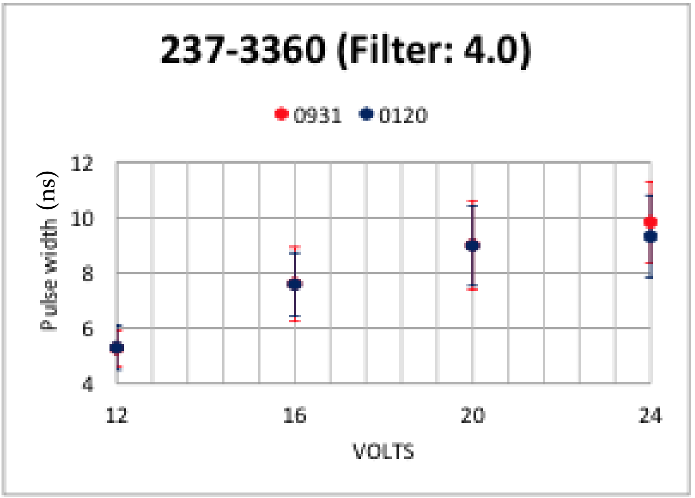
- Not all LEDs flash.
  - Samples of blue LEDs tested at Sheffield in the summer.
- Does the LEDs flash?
  - Used ANTARES pulser.
- Is there a correlation between electrical properties and those LEDs that flash?



Pulsed LED optical characteristics

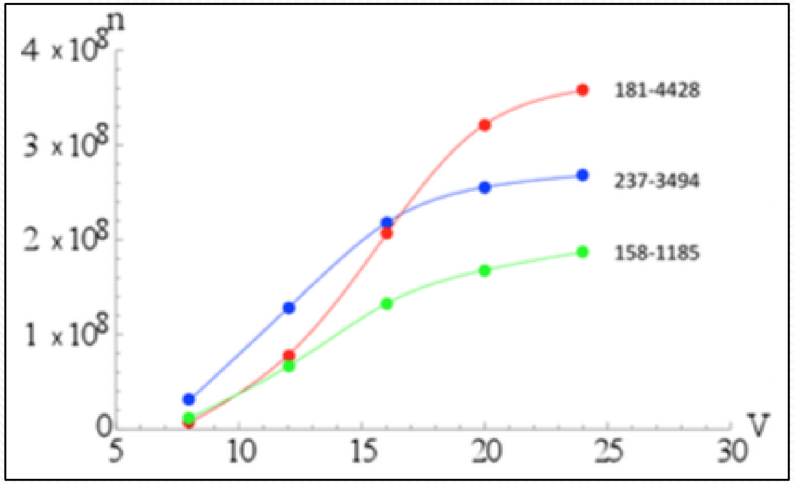
Farnell Reference Number	Manufacturer	Manufacturer's Reference	Peak Wavelength (nm)	Format (SM=surface mount)
137-6625	LUMILEDS	LXML-PB01-0023	470	SM
158-1185	MULTICOMP	MCL053SBLC	472	Standard, 5mm
181-4422	AVAGO TECHNOLOGIES	HLMP-CB1A-XY0DD	470	Standard, 5mm
181-4428	AVAGO TECHNOLOGIES	HLMP-CB3B-UV0DD	470	Standard, 5mm
208-0007	KINGBRIGHT	L-7113QBC-G	465	Standard, 5mm
211-2167	MULTICOMP	703-0147	~465	SM
211-5553	OSRAM	LBH9GP-GYHY-35-1	470	SM
233-5786	KINGBRIGHT	L-813PBC-Z	465	Standard, 10mm
237-3360	KINGBRIGHT	KA-3535QB25Z4S	450	SM
237-3492	KINGBRIGHT	L-10934VBC/DS-D	470	Standard, 3mm
237-3494	KINGBRIGHT	L-17114VBC/DS-D	470	Standard, 5mm

- A number of different commercially available blue LEDs have been tested using a modified Kapustinsky style (ANTARES) LED pulser
- Optical properties including rise time, FWHM, N(photons)/flash have been measured



Sample results:

- (above) LED pulse width as a function of applied pulser voltage
- (below) N(photons) per pulse as a function of applied pulser voltage

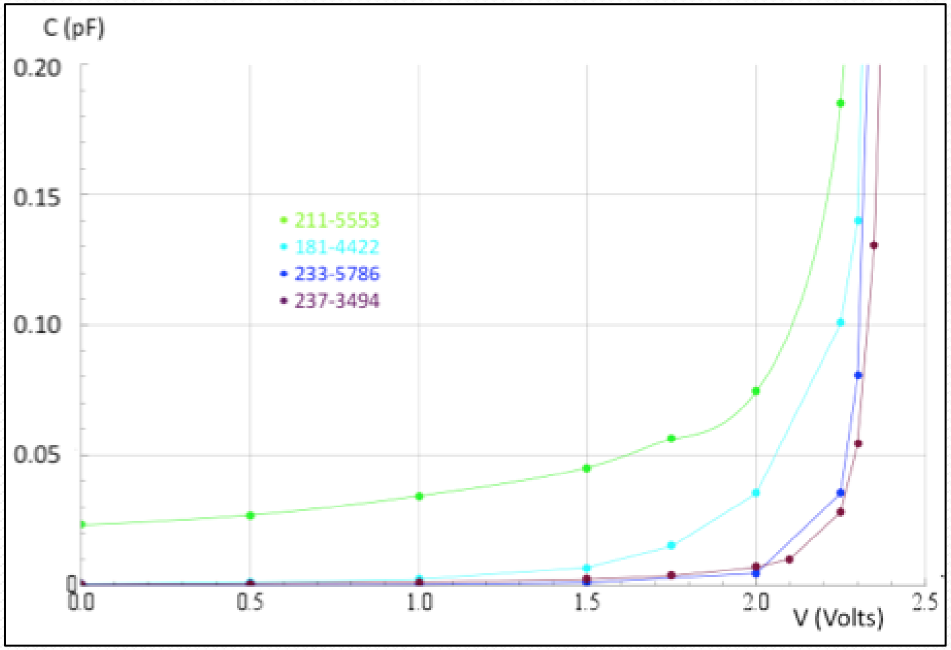


LED electrical characteristics

- Used an HP 4284A precision LCR meter (impedance analyser)
- For each LED a series of measurements of complex impedance (Z) and phase (θ) were taken as a function of applied bias voltage
- Enables the resistance and capacitance of each LED to be measured

$$Z = \underbrace{R_s + \frac{R_d}{1+(R_d\omega C)^2}}_{a} - i\underbrace{\frac{R_d^2\omega C}{1+(R_d\omega C)^2}}_{b}$$

- Example of results: fitted LED capacitance as a function of bias voltage for 4 different LED models



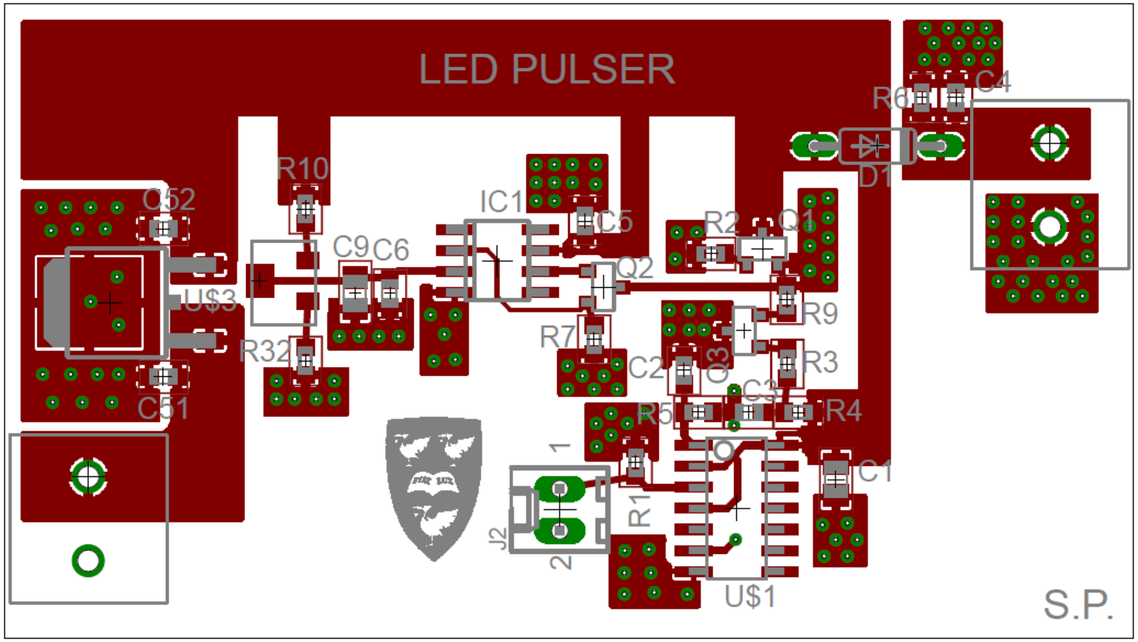
Plans for the current year

- Prototyping and testing of various options
  - LED Driver
  - Fibre Coupling
  - Monitoring Options
  - Fibre Housing
    - Different options for different calibrations?

- Analysis to develop calibration strategy

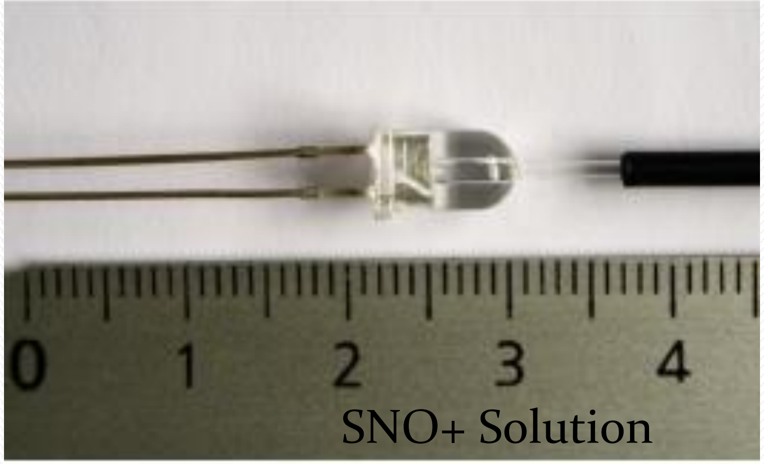
Continuing prototype development

- Continuing to develop prototype ideas.
- Aim for at least three different circuits
- Will test these against each other.

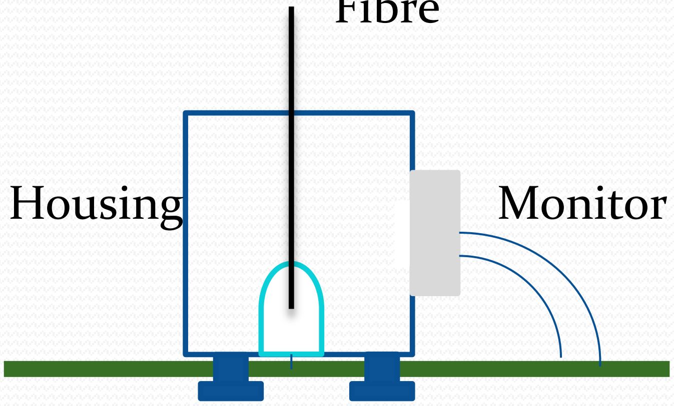


Fibres, Housing and Diffusers

- Physical integration
- We require graded index fibres, smaller core than in SNO+
- How best to couple fibre and LED
  - Drilled hole or other solution
- Monitoring solution
  - Physically integrated into the system
  - Monitor the light that doesn't go into the fibre:
    - Lots of photons
- Mechanical integration
  - Connect to electronics, fibre, led and monitor
- Diffuser
  - Light profile inside HK



SNO+ Solution



Warwick Plans

We are just getting started so none of this has happed yet except clearing the Lab, making an inventory of equipment and ordering the power meter.

Equipment:

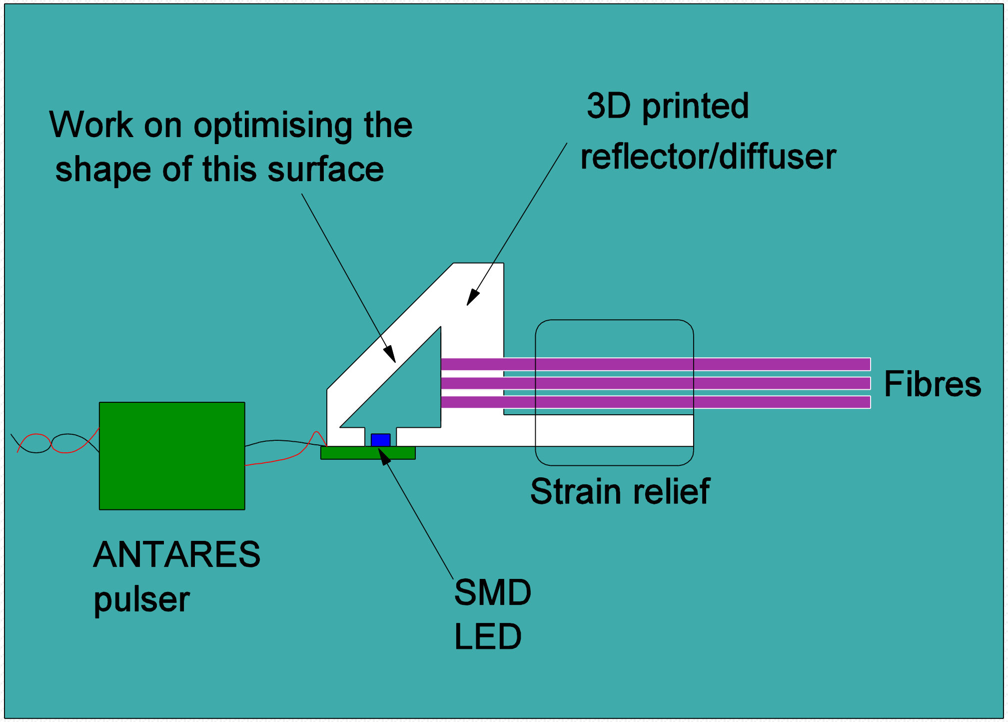
- Thorlabs PM100 USB with S150C sensor (10pW resolution),
- New Newport 1830-R power meter with 918D-UV-OD3R sensor (1pW resolution)
- 3 axis motorised micrometer stage
- Dark room, dark box
- Usual lab equipment, scope , NI-DAQ, PMs, MPPCs, etc

First Steps:

- Select a couple of likely fibres, one step-index and one graded index.
- Set up to reliably measure light power out from fibre, initially using Antares pulser and recommended blue LED to inject light into one fibre only.
- Make 3D printed diffuser to inject light from one LED into many fibres

– see next page

- The idea is that there must be a shape of the diffusely reflective surface that will distribute the light equally between the fibres.
- Easy to achieve uniformity if we can afford to waste most of the photons but we can not afford it.
- Iterate and repeat with both fibres types.



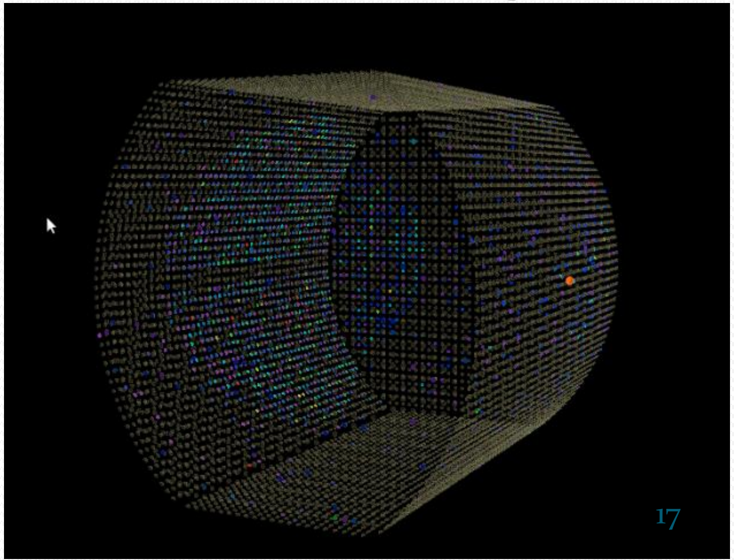
Developing a calibration strategy

- Add fibres to WCsim HK simulation

- Optimise the strategy for each calibration
  - PMT timing and gain
  - Scattering
  - Attenuation
- Questions to answer for each
  - Coverage
  - Redundancy
  - Intensity
  - Wavelength
  - Light profile

Scattering Calibration 1

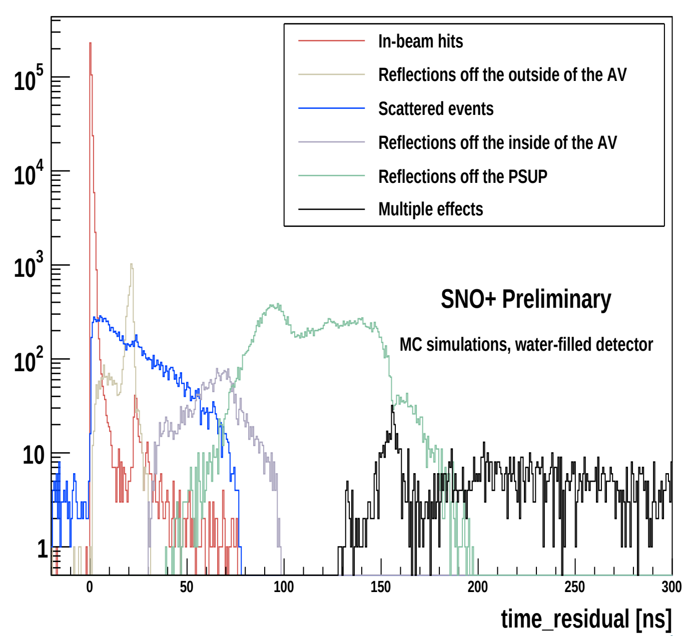
- Fibres mounted on PMT support structure with collimated (~few degree opening angle) beams fired across detector
- Fast pulses (~2ns, LED or laser) at 4-5 different wavelengths to probe λ^4 Rayleigh scattering dependence.
- Operate at low intensity so in-beam PMTs mostly in single pe regime.

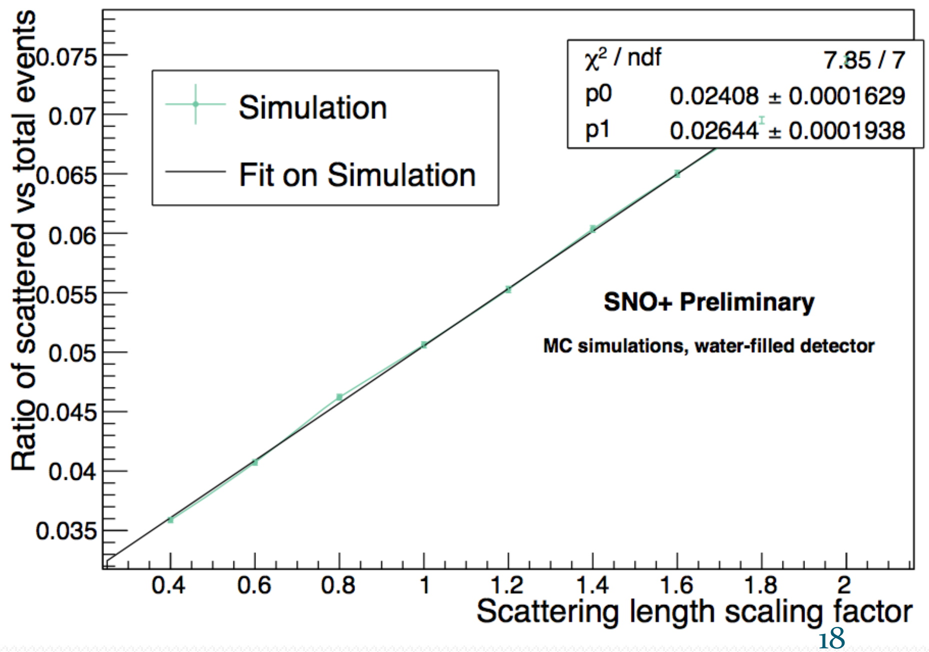


Scattering Calibration 2 - Analysis

- Analyse through summation of hits over run
- Use timing and spatial cuts to select analysis regions dominated by direct, reflected and scattered hits.
- Scale scattering in MC to match data scattered hits
- Use in-beam hits for normalisation

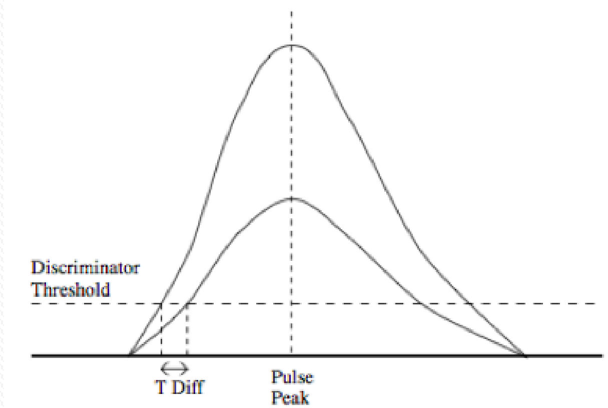
Method adopted for SNO+





PMT Timing Calibration 1

- To remove time offsets between PMTs (arising from eg. Cable delays)
- Correct for discriminator 'walk' effect.



Small pulses take longer to cross the discriminator threshold with respect to
f the peak than large pulses.

J. Cameron, PhD thesis, Oxford, 2001

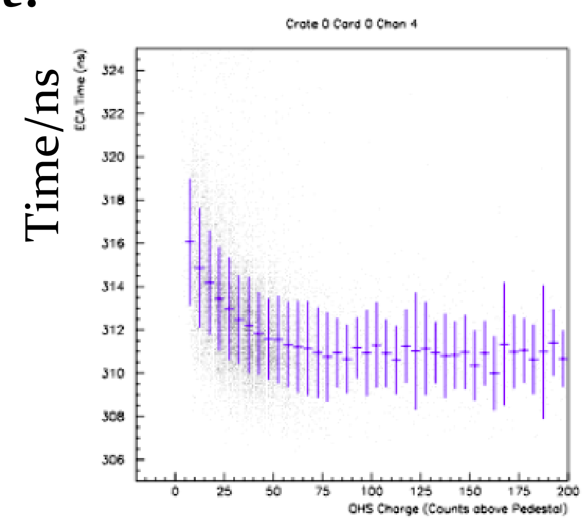


Figure 3.2: An example of discriminator walk. It shows ECA time ag
for data collected from an external asynchronously triggered laserbal
card 0, channel 4. The blue crosses are a profile histogram of the data
bars showing the RMS spread. The size of the walk is about 5 ns.

- Inner and Outer Detector?

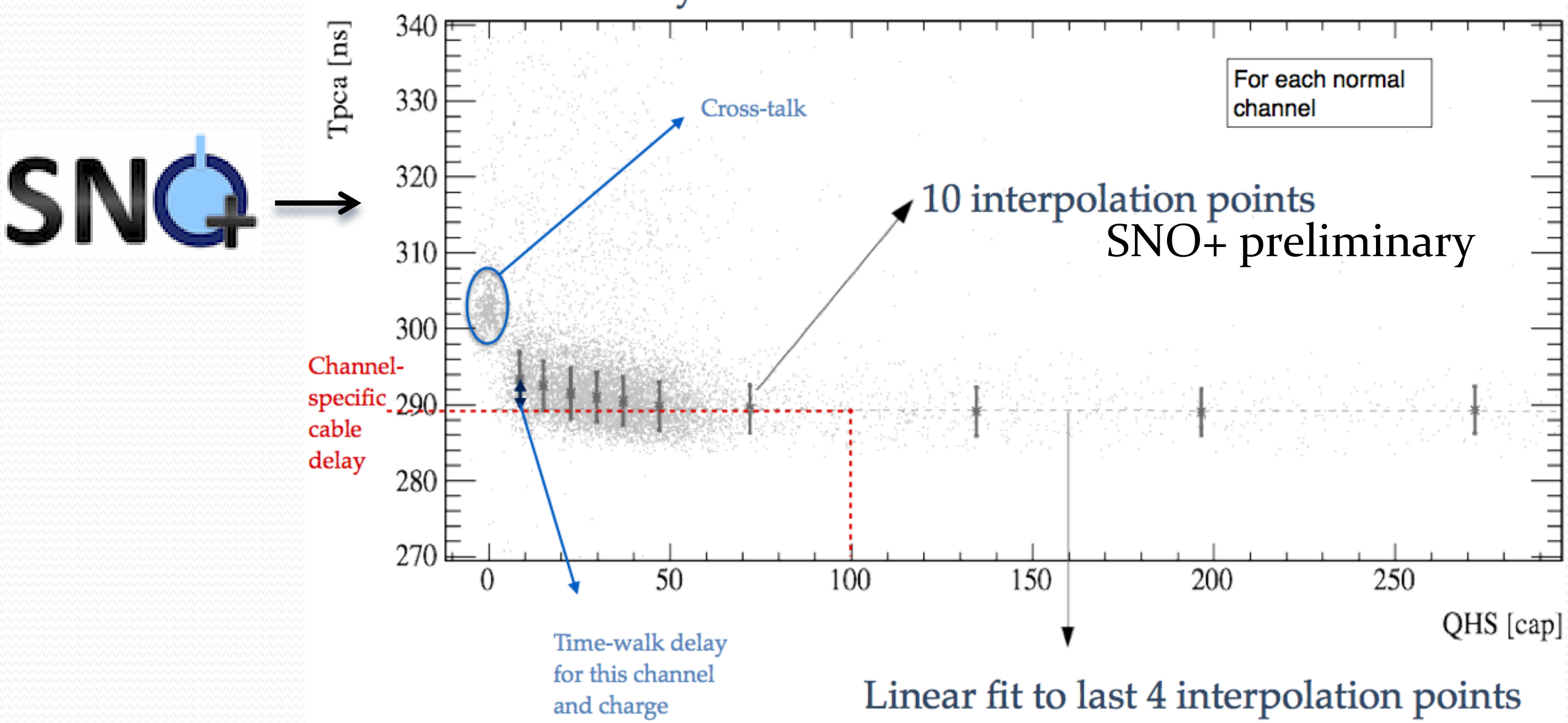
PMT Timing Calibration 2

- Propose similar approach to SNO+
- SNO used centrally deployed isotropic laserball
- SNO+ will use embedded fibres, ~30 degree opening angle, sharp LED pulses
- To account for different delays for each LED driver relative to trigger, ensure each PMT sees light from ≥ 2 fibres. (more for redundancy)
- Cycle through all fibres at high rate
- Scan LED intensities to sample whole charge range.

PMT Timing Calibration 3 - Analysis

- Plot PMT hit times vs charge for each channel
- Linear offset = PMT cable delay
- Low charge turn up = time walk effect

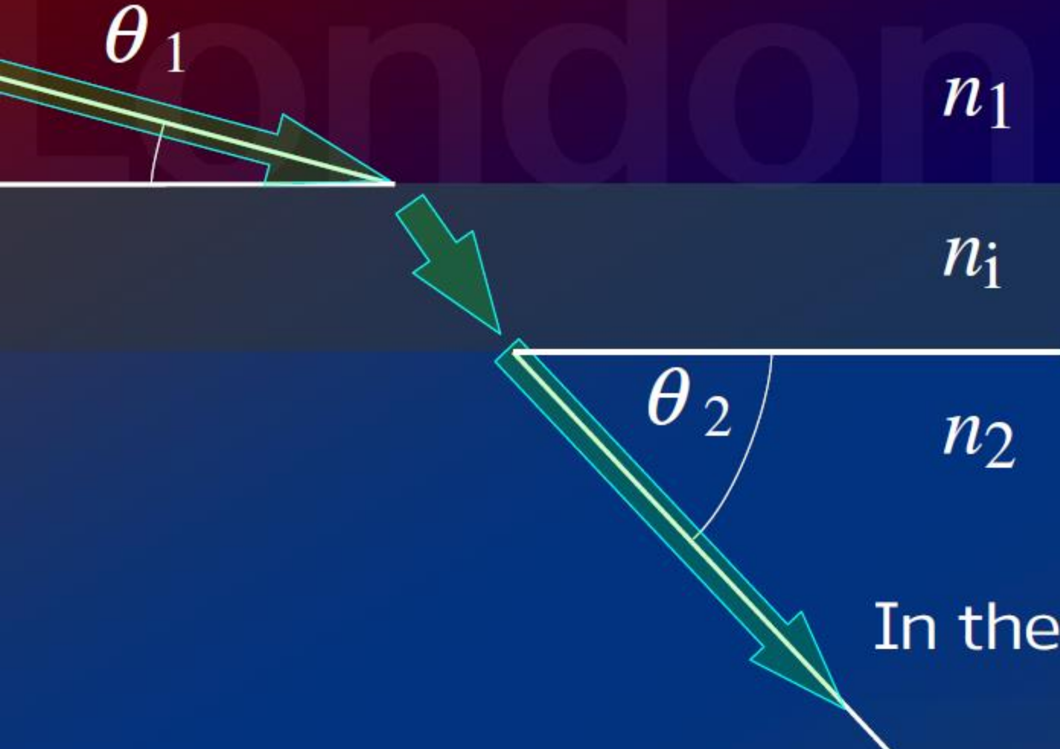
Low-intensity air fill data



Pseudo Muon Light Source

- Exploit refraction to build a source simulating a muon.
- Longer term but part of the UK R&D proposal
- 2015 Monte Carlo design study
- 2016 Design/construction of a short prototype
- 2017 Tests and continued development
    - Will use a fish tank at Liverpool or Sheffield for proof of principle tests.

Refraction of Light Across a Boundary

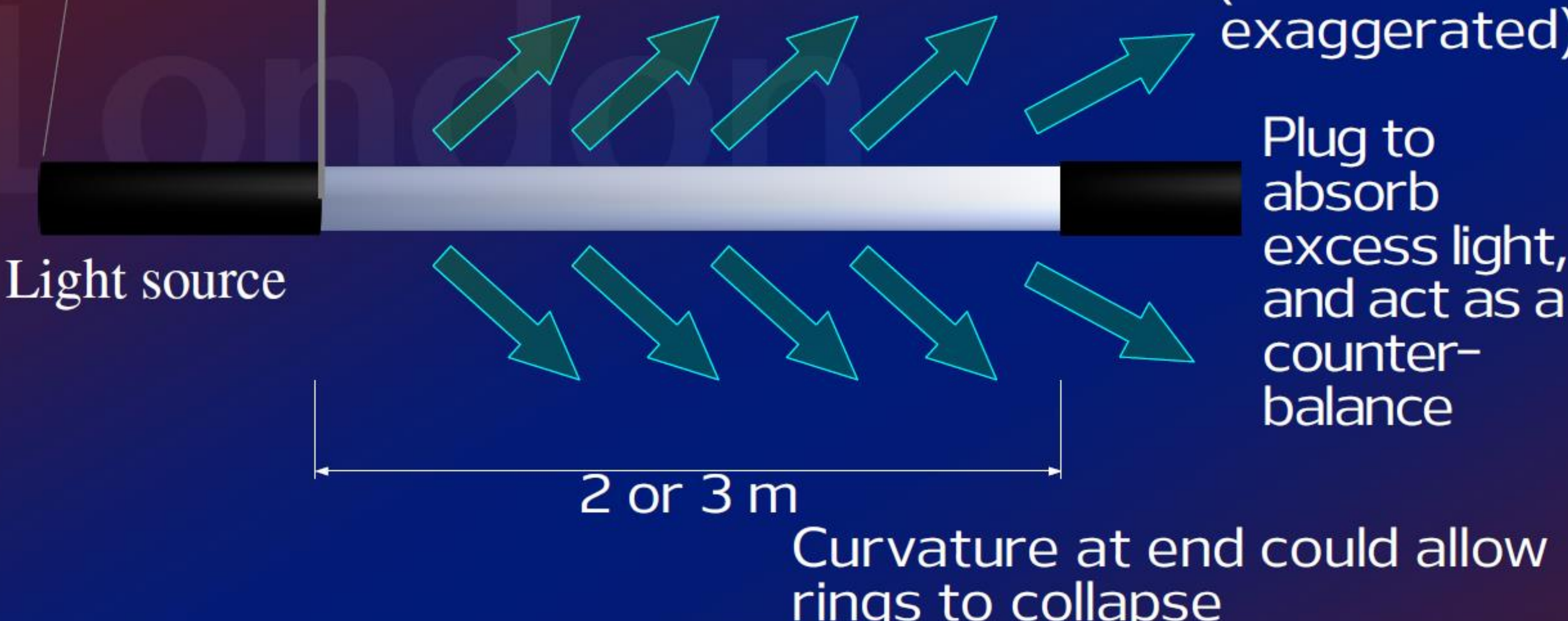


In the limit $\theta_1 \rightarrow 0^\circ$ & $n_1 \rightarrow \beta (\approx 1)$,

$$\theta_2 \rightarrow \theta_{\text{Cherenkov}}$$

independently of value of n_i
and of wavelength

μ-Calibration with Production of Fake Cerenkov



Light travels at c inside cavity, c/n outside

2.5 m line source for 500 MeV muon simulation

Much shorter version would still be useful for MC comparisons

Summary

- 3 year R&D program now funded by STFC
- Development of
  - LED Pulser
  - Fibre coupling
  - Monitoring
  - Diffusers
  - Calibration Strategy
  - Pseudo-Muon Light source