MATHUSLA: MAssive Timing Hodoscope for Ultra-Stable neutraL pArticles

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INTRODUCTION

- MATHUSLA is a proposed detector to be installed at the Large Hadron Collider (LHC) at CERN
- Will search for long-lived particles (LLPs); predicted by Beyond the Standard Model theories [1]

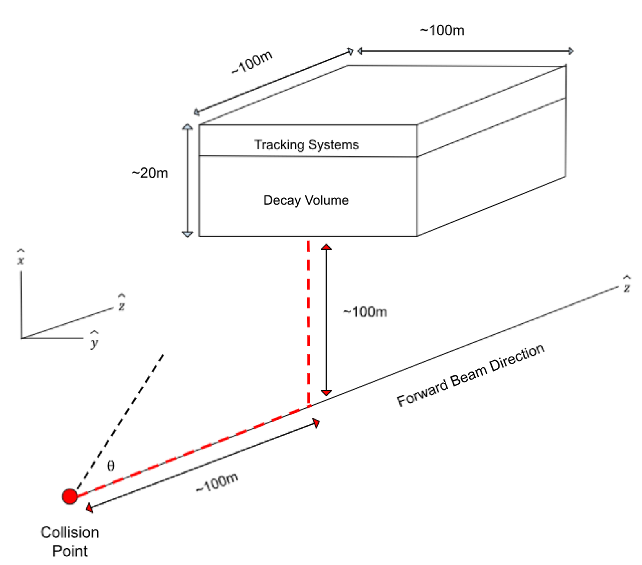


Fig. 1: Proposed design of MATHUSLA. From mathusla-experiment.web.cern.ch

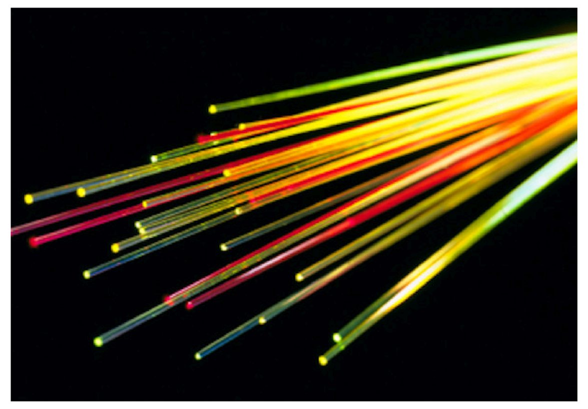


Fig. 2: Wavelength shifting fibres. From Luxium Solutions.

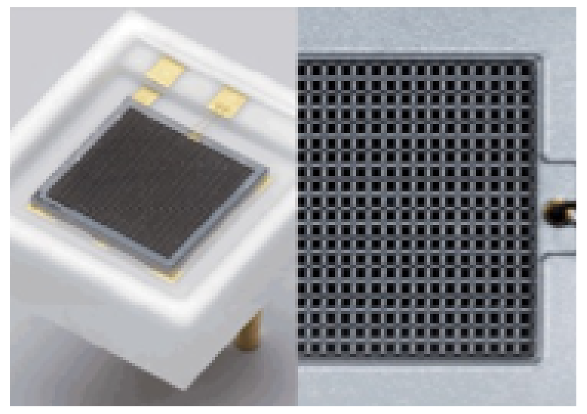


Fig. 3: Silicone photomultipliers. From Hamamatsu.

- Detector design: layers of scintillating bars to detect LLPs, threaded through wavelength shifting fibres (WLSFs) fed to an array of silicone photomultipliers (SiPMs) [2]
- We characterize potential detector components & measurements from prototypes to ensure resolution requirements are met and informed design choices can be made

SET-UP

- We study properties of WLSFs and SiPMs in a dark-box using a well-characterized source: a variable intensity laser pulser. This allows us fine-tuned control over varied parameters
- Each pulse is carried to the SiPMs by the WLSF which is recorded as an event with an Analog-to-Digital count (ADC) corresponding to number of photoelectrons (PE) released by SiPM, and Time of Arrival (ToA)

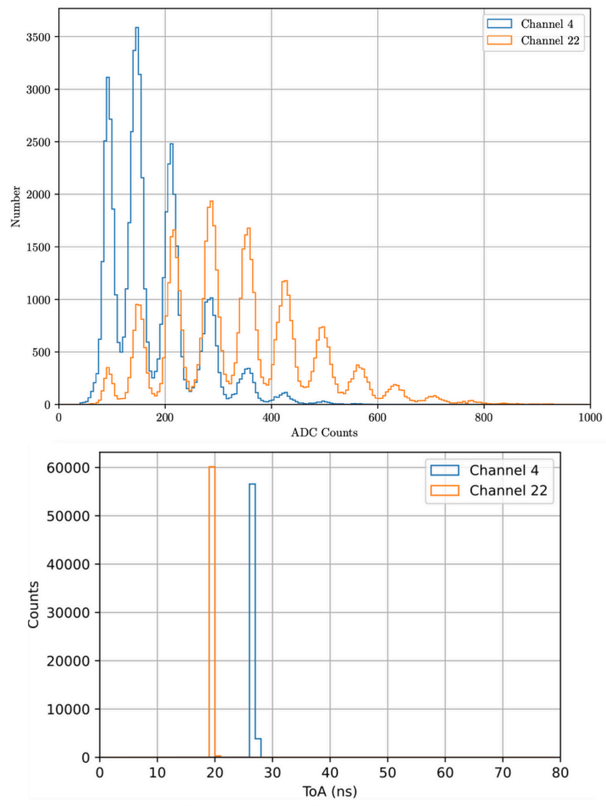
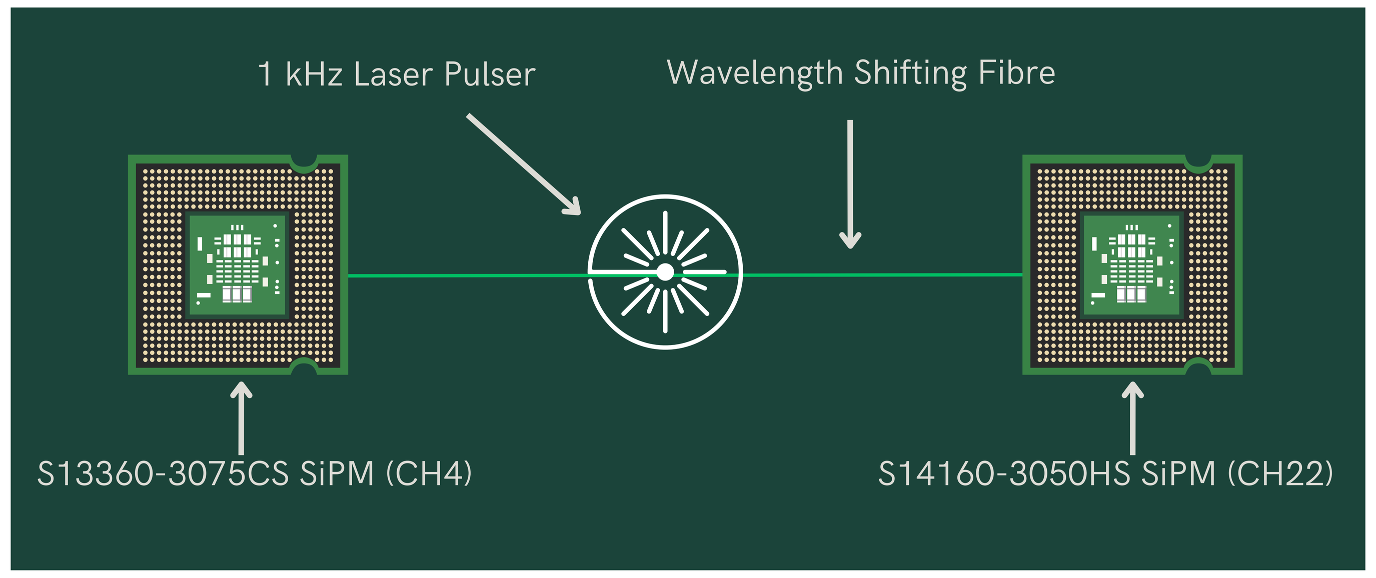


Fig. 4: Sample ToA and ADC histograms.



TIMING RESOLUTION

- Measure of the precision to which we can measure the position of a source along a WLSF
- Find difference in ToA between SiPMs for each event
  - Can be further refined to consider ToA values corresponding to some ADC range to find resolution of a given photoelectron
- Bin ToA differences according to precision of timing measurements (0.5 ns); fit binned data with a Gaussian; standard deviation is the timing resolution
- Fit ADC histograms of data with a sum of Gaussians to approximate the ADC to PE relationship
- Timing resolution has an inverse square root relation to min. PE: as light intensity increases, resolution is improved

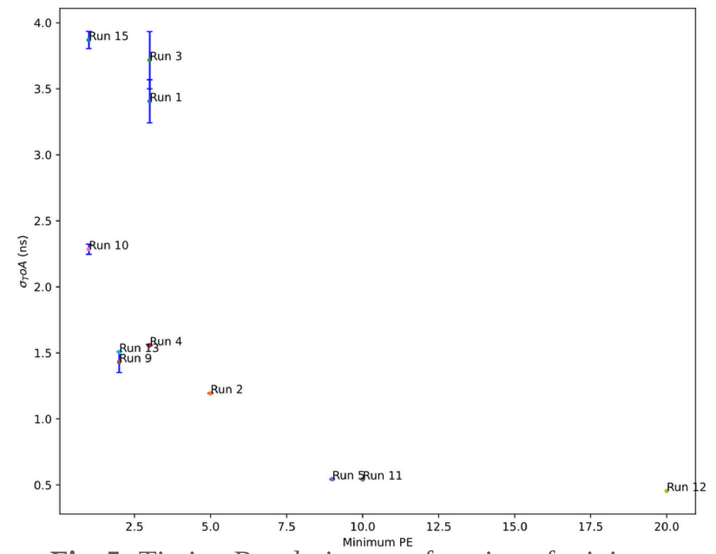


Fig. 5: Timing Resolution as a function of minimum PE number for various runs.

TEMPERATURE DEPENDENCE

- SiPMs are highly temperature dependent; must be corrected for
- Data collected in varied temperature ranges (12.9-35.7°C) on timescales of days to find temperature dependence of ToA and ADC measurements
- Overall non-linear response to increasing temperature due to changing SiPM gain.
- Correct for temperature by adjusting the bias voltage, related linearly to gain by a temperature coefficient, *A* [3].
- Temperature coefficient found by calculating the change in gain (*M*) of the SiPMs as a function of temperature [4], giving the following relation:

$$A = \frac{dM}{dT}\frac{q}{C}$$

where q is the charge of an electron, C is the capacitance of one pixel.

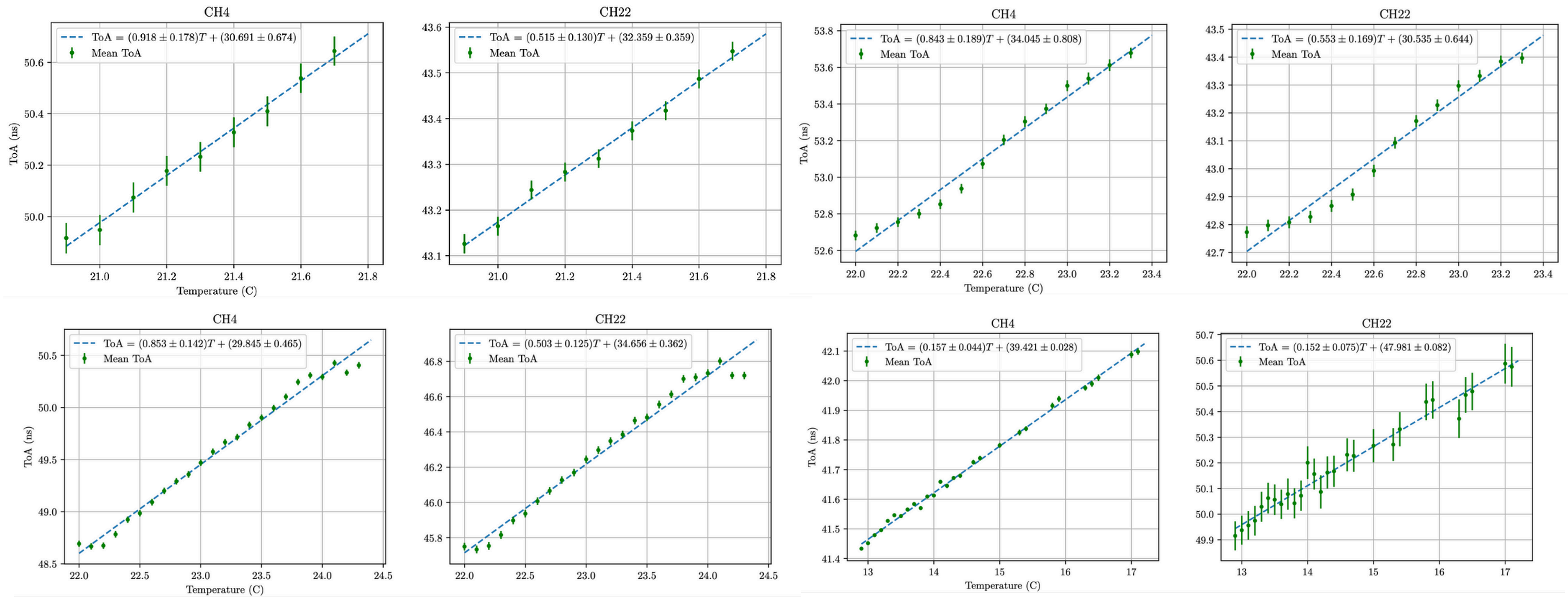


Fig. 6: ToA as a function of temperature for 4 runs in temperatures ranging from 12.9 - 35.7°C. SiPM response is linear in each limited range; ADC response (not pictured here) is similiarly linear for small temperature ranges.

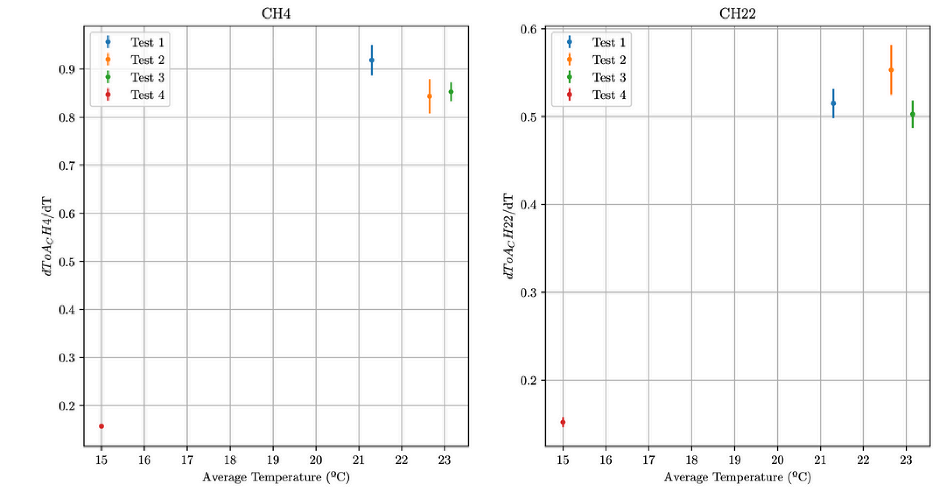


Fig. 7: Overall non-linear response of ToA as a function of temperature.

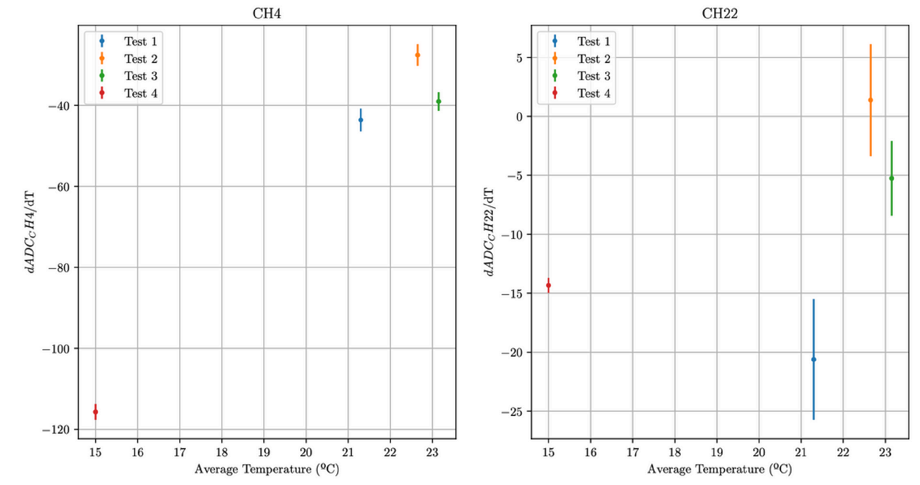


Fig. 8: Overall non-linear response of ADC as a function of temperature.

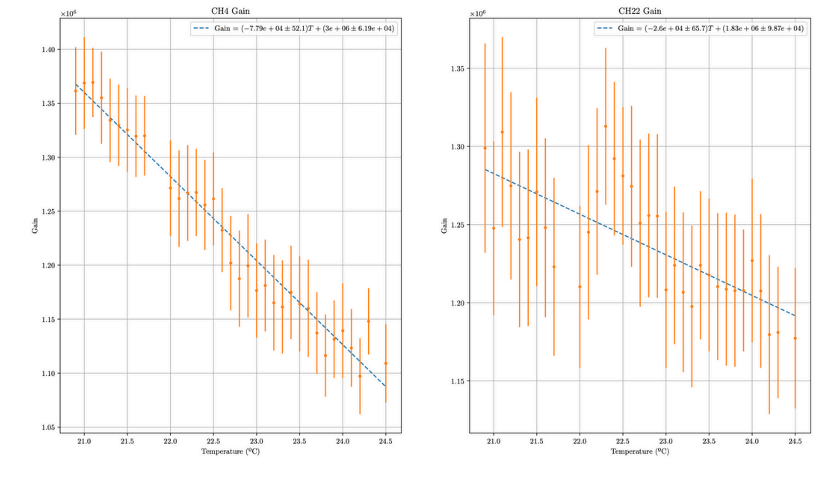


Fig. 9: dM/dT derived from data and relation in [5].

RESULTS & CONCLUSION

- For MATHUSLA to meet theoretical specifications, comprehensive characterization of components is required
- **Timing Resolution**: MATHUSLA necessitates <1 ns resolution; we found this was met for runs with min. PEs >8. This allows us to optimize fibre choices
- **Temperature Dependence**: we found temperature coefficients for CH4 & CH22 respectively to be (62.41 ± 0.04) mV/°C and (46.8 ± 0.1) mV/°C. Temperature correction is essential to gather usable data under diverse operating conditions

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[4] "Application Note AN2502 SiPM Characterization," Mar. 2011. [Online]. Available: https://edu.caen.it/wp-content/uploads/2021/09/AN2502_SiPM_Characterization.pdf