Feasibility Study of a Photodetector with 10 Picosecond Time Resolution for a Fast-Timing Subsystem at the LHC

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Motivation and Introduction

At the high-luminosity LHC, the forward region has large particle flux and is particularly challenging. At high rapidities, fast timing can be used to distinguish collisions by measuring differences in arrival times from different locations in the interaction point.

Large-Area Picosecond Photodetectors (LAPPD's) are a developing detector technology that are intended to have a large area and fast timing. They are an excellent candidate for fast timing at the LHC.

To handle the large particle fluxes, the detector needs to be granular with pixels sufficiently small such that each pixel has a small number of hits per bunch crossing. This can be accomplished with a new configuration of the LAPPD's in which the readout is external to the detector and capacitively coupled, as shown in Figure 2.

Assuming a forward fast-timing detector project, I computed the necessary pixel sizes with a Pythia simulation, assuming no material between the interaction point and the detector. The results are shown in Table 1.

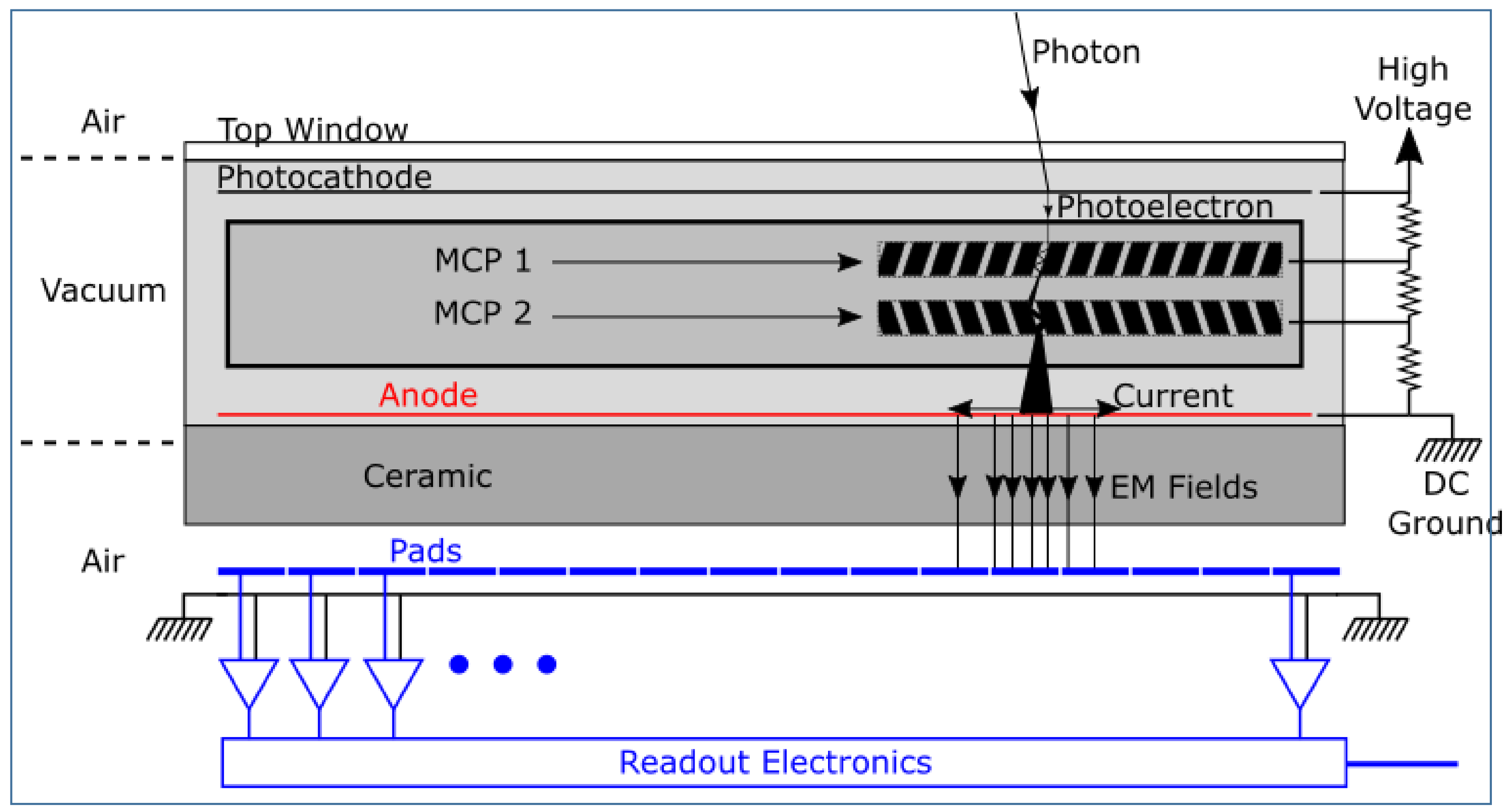


Figure 1: A schematic of an inside-out LAPPD.

	0.1 Occupancy		0.01 Occupancy	
Rapidity Region	Pad Size (mm)	Channels	Pade Size (mm)	Channels
$2.4 < \eta < 3.0$	8.3	1.3×10^4	2.3	1.8×10^5
$3.0 < \eta < 3.7$	4.7	1.2×10^4	1.5	1.7×10^5
$3.7 < \eta < 4.3$	2.5	1.1×10^4	0.8	1.2×10^5

Table 1: The necessary pad sizes and number of channels necessary to achieve small enough pixel occupancies (events per pixel per bunch crossing). These numbers are computed assuming use in the High Granularity Timing Detector in ATLAS and roughly agree with earlier independent estimates.

Setup

As a model for an inside-out LAPPD, a PLANACONis coupled to a 10 nm, grounded layer of Nickel Chromium deposited onto a ceramic plate. Consistent, removable coupling is achieved with uncured conductive silver epoxy. Beneath the ceramic is placed a printed circuit board with differently sized pads, each connected to an SMA readout. A pulsed 405 nm laser is fed through a fiber optic attached to a motorized stage that allowed for position adjustments. This setup is shown in Figure 2.

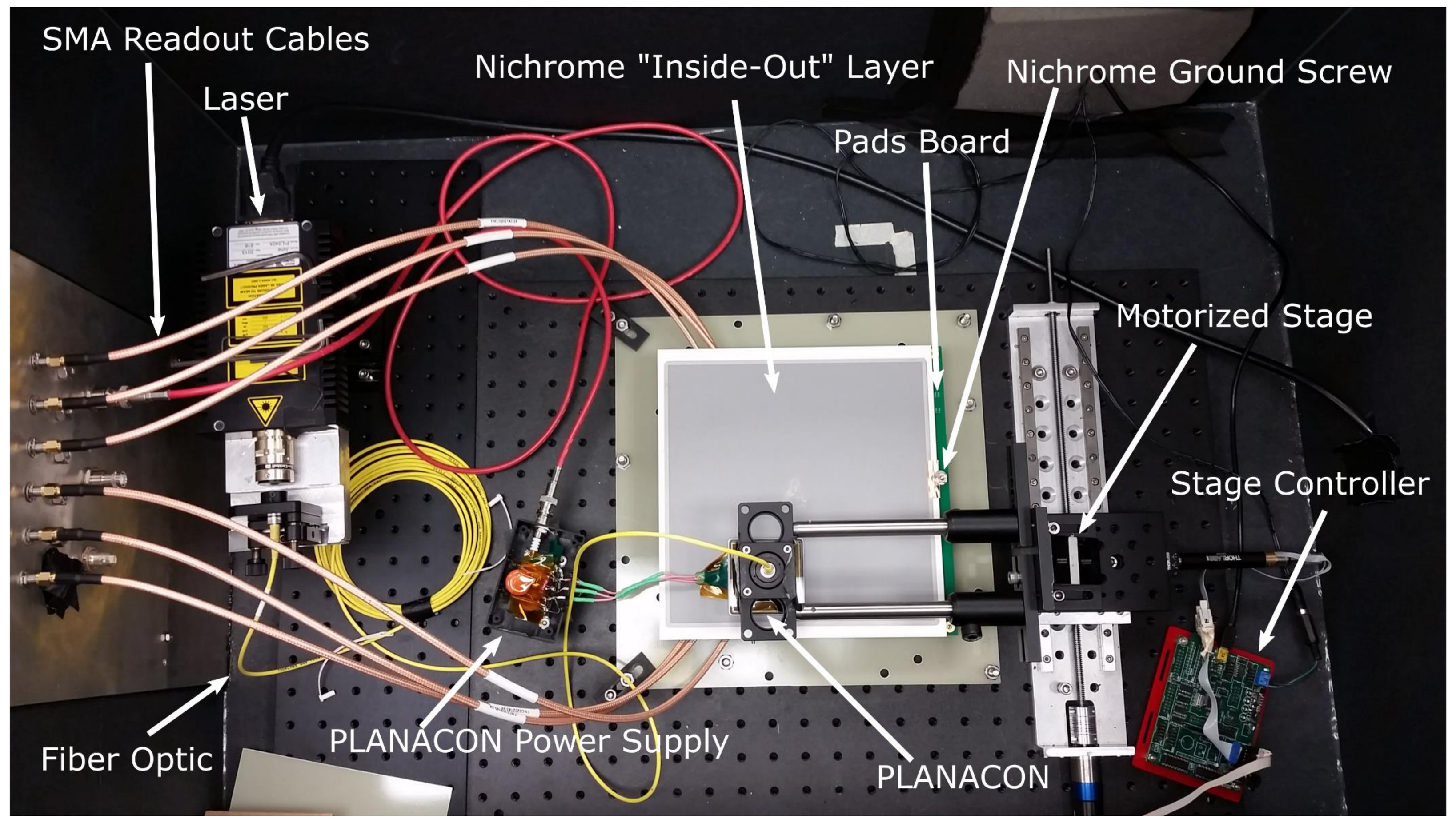
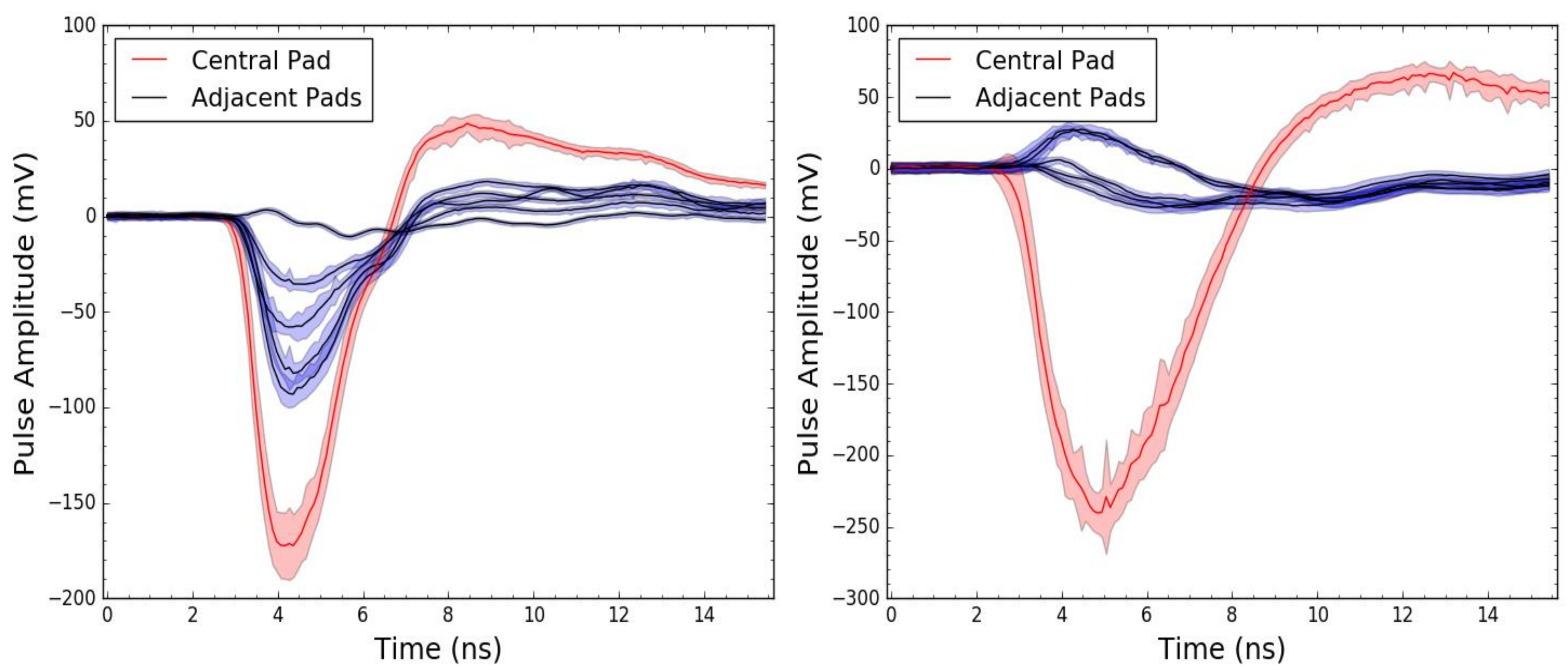


Figure 2: The experimental setup used to test capacitive coupling readout.



0.5” x 0.5” (12.7 x 12.7 mm² pads) 1.0” x 1.0” (25.4 x 25.4 mm² pads)

Figure 3: Typical pulse shapes for different pixel sizes. The shaded region is ±1σ noise. The laser is centered over the red channel.

Results

The average pulse shape for two different sizes of pads is shown in Figure 3. For 1” pads, there is very little signal on adjacent pads, indicating effective pixelization. For the 0.5” pads the pixelization is not as strong, though still good. For real LAPPD's, the pixelization is expected to be better than shown.

As shown in Table 2, the 0.5” pads also have a lower amplitude on the central pulse compared to larger pads, since the induced charge is now shared among several pads. Furthermore, the capacitance in this configuration acts as a high-pass filter, so smaller capacitance (smaller pad sizes) leads to faster signals.

A laser position scan over two 0.5” pads is shown in Figure 4. Because of the charge sharing, position resolution can be significantly better than the pad size. Simple, naïve calculations give a nearly uniform position resolution of around 300 µm using two 0.5” (12.7 mm²) pads, but this can be improved.

Conclusion: This seems like a promising technology for high luminosity collider detectors. For now, there appear to be **no fundamental setbacks**.

	Direct	0.5”	1.0”	1.5”
Amplitude (mV)	312 ± 24	186 ± 14	252 ± 19	218 ± 16
Rise Time (ns)	1.71 ± 0.22	0.77 ± 0.12	1.31 ± 0.18	1.58 ± 0.20

Table 2: The average amplitude and rise time for various square pad sizes. The direct column uses direct electrical connection to 1.0” x 1.0” pads.

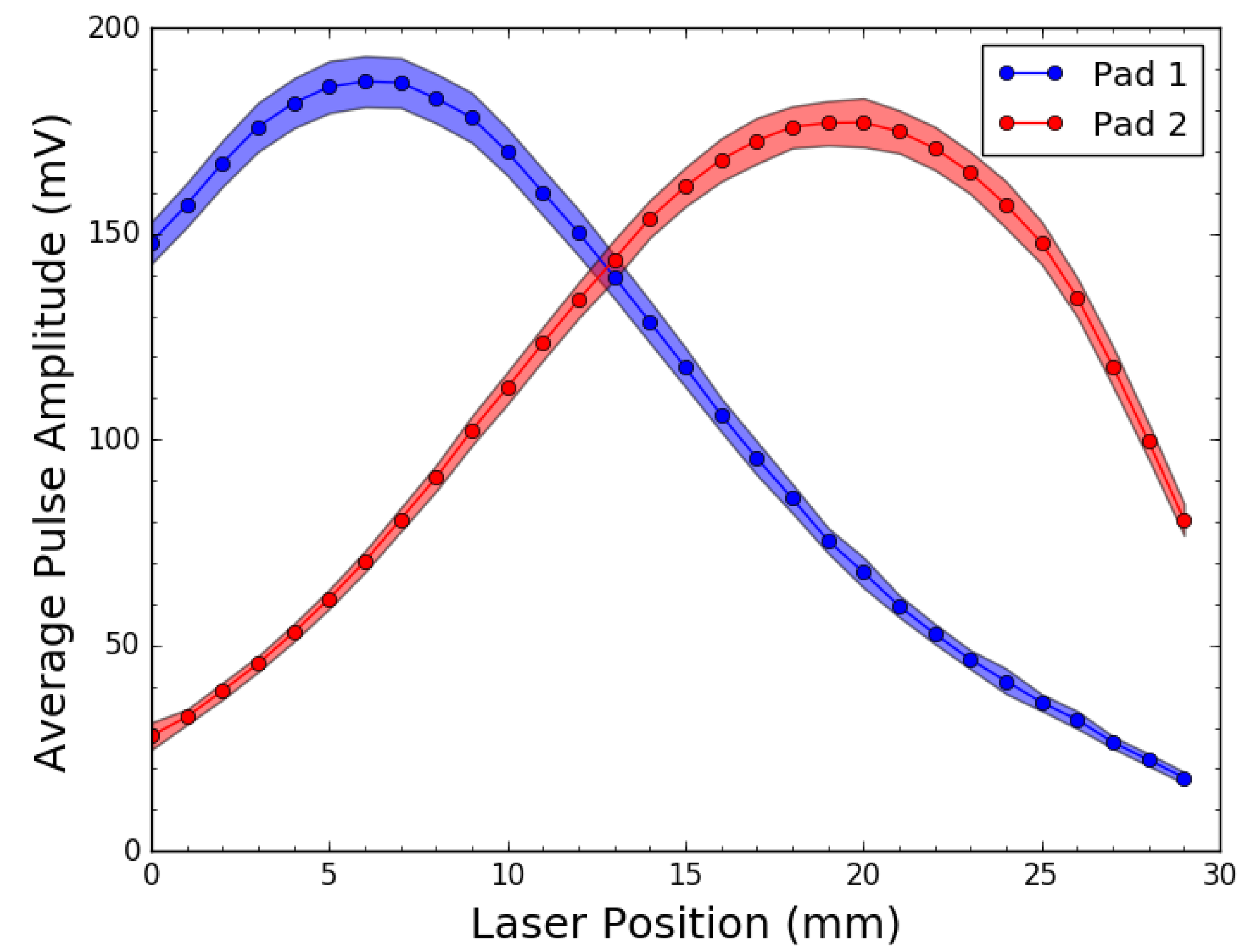


Figure 4: The average amplitude on two adjacent 0.5” x 0.5” pads as a laser is scanned over the photodetector. The shaded region is ±1σ noise.