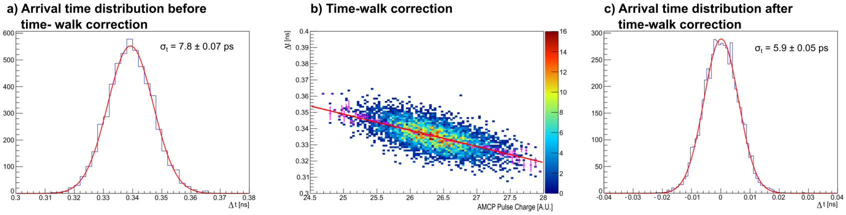
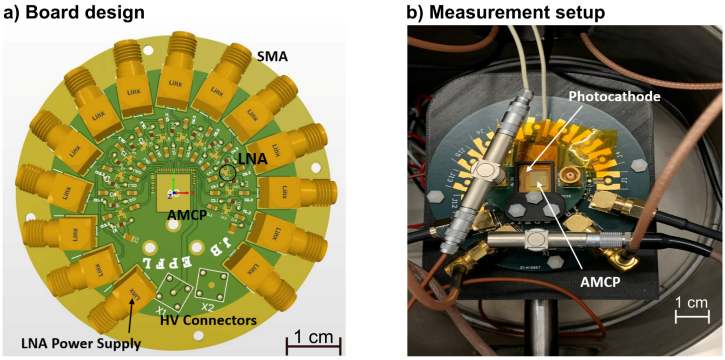
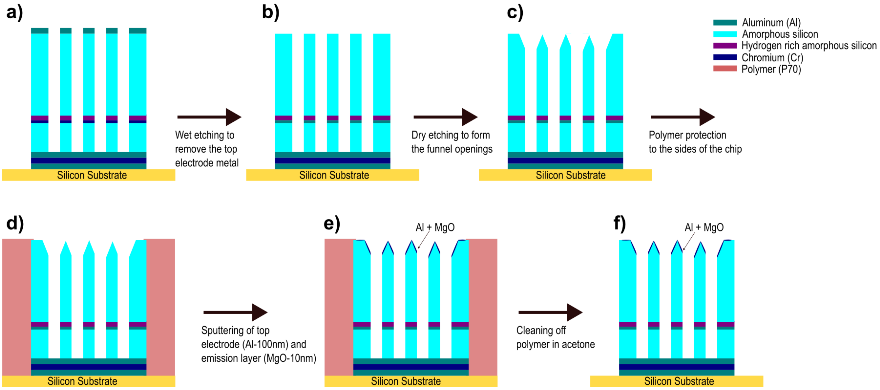
Supplementary Information



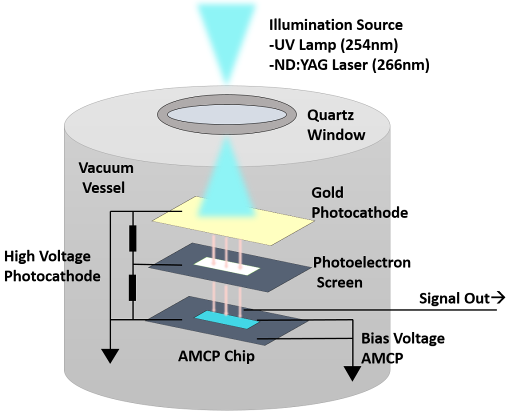
Supplementary Figure 1: Example of a time-walk correction. a) Arrival time distribution before time-walk correction. A Gaussian function (red line) was fitted to the histogram of the arrival times. The time resolution σ_t is then defined as the full width at half-maximum (FWHM) of the fitted Gaussian. b) Pulse charge of the amorphous silicon-based microchannel plate (AMCP) vs. arrival time (Δt). A linear dependence $dt(Q)$ could be fitted, and the corrected arrival time difference was then given by $\Delta t' = \Delta t - dt(Q)$. c) Arrival time distribution after the time-walk correction. The uncertainties in the Δt were obtained from the covariance matrices of the Gaussian fit.



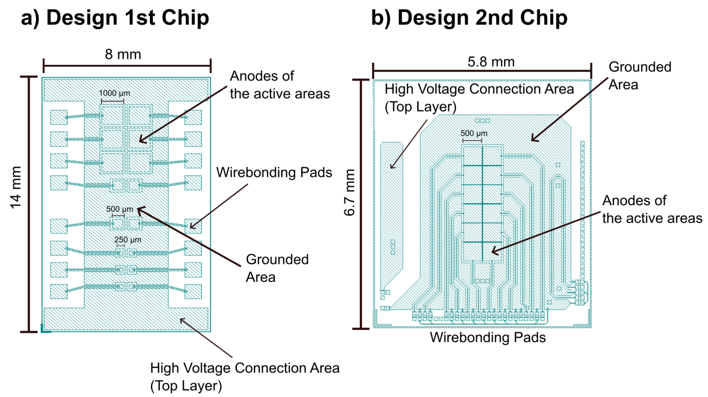
Supplementary Figure 2: Board design and setup of the timing resolution measurement. a) Design of the printed circuit board used for the timing measurements. The amorphous silicon-based microchannel (AMCP) chip is positioned at the center of the board. Several low-noise amplifiers (LNAs) are connected to different sensor areas on the AMCP on the same board. SubMiniature version A (SMA) connectors transmit the amplified signals from the LNAs to an oscilloscope outside the vacuum chamber. High voltage (HV) is supplied via dedicated connectors on the board's edge. b) A photograph of the experimental setup showing the board with two connected channels. The AMCP is visible in the center, beneath the gold photocathode.



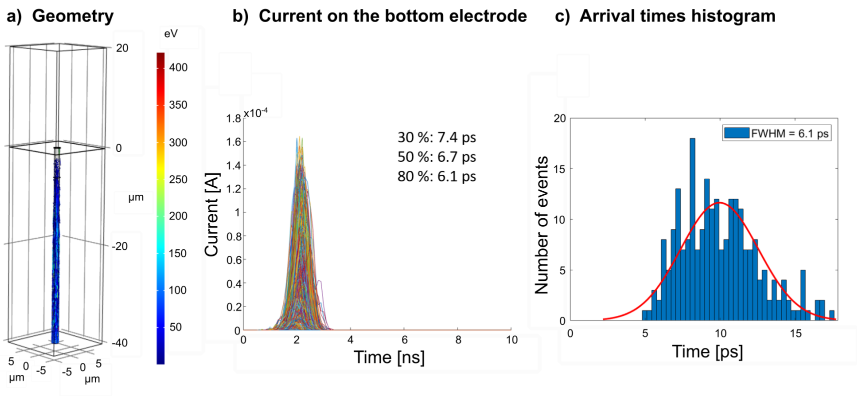
Supplementary Figure 3: Process flow to fabricate funnel-shaped amorphous silicon-based microchannel plates. a) The process starts with a regular straight-channel amorphous silicon- based microchannel plate (AMCP). b) The top metal is removed using a wet etching step, assuring better access of the etching gas in the following step. c) A dry etching step is used to create the funnel openings. d) A polymer-based protective layer is applied to the side of the chip. e) An aluminum-based top electrode is sputtered onto the funnel openings, followed by the deposition of a magnesium oxide (MgO) layer via sputtering. f) The polymer protection is removed in the final cleaning step using acetone.



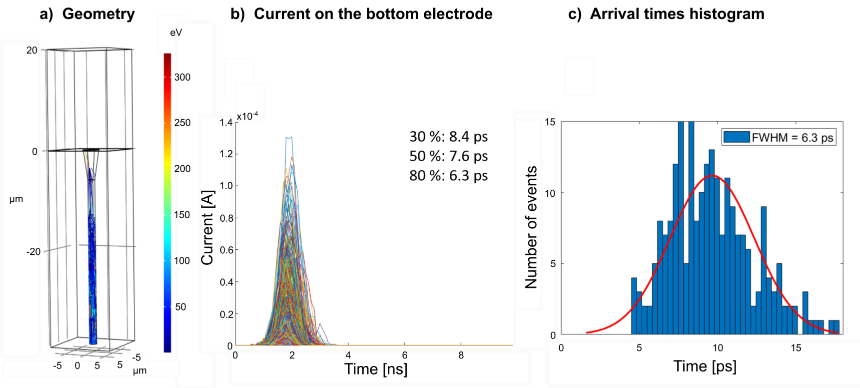
Supplementary Figure 4: Gain characterization setup. Schematic representation of the gain characterization setup. The amorphous silicon-based microchannel plate (AMCP) chip is connected to a printed circuit board and placed inside the vacuum vessel. Either an ultraviolet lamp or a laser (neodymium-doped yttrium aluminum garnet (ND:YAG)) is used as an illumination source. The light enters the chamber through an optical window onto a gold photocathode. A photoelectron screen shields the bonding pads and wires from the incoming photoelectrons.



Supplementary Figure 5: Comparison between the different chip designs. Only the design of the first metal layer (green) is shown for simplicity. a) Design of the first amorphous silicon-based microchannel plate test structure. This design has 16 individual sensors of three different sizes (1,000 µm × 1,000 µm, 500 µm × 500 µm and 250 µm × 250 µm) in the middle of the chip, connected to wire-bonding pads on the side and surrounded by a grounded area. The high voltage is connected on the top metal layer (not shown) above the indicated area on the bottom right of the chip. b) The test structure was redesigned to fit the board with the low-noise amplifier. This design has 12 individual sensors, each with an area of 500 µm × 500 µm, surrounded by a grounded area. The wire-bonding pads are placed on the lower part of the chip. The high voltage to bias the sensor is connected on the top metal layer (not shown) above the indicated area on the left side of the chip.



Supplementary Figure 6: Simulation of the time resolution of a straight channel detector. The time resolution of an amorphous silicon-based microchannel plate (AMCP) channel was simulated using COMSOL® multiphysics. a) Geometry of the simulation and example trajectories of the electrons inside the channel. The color scale shows the energy of electrons. b) Resulting current at the bottom electrode over time for 500 runs and the calculated time resolution at different thresholds (30%, 50%, and 80%) of the average signal amplitude. c) Histogram of the arrival times with the threshold set at 80 % of the average signal amplitude and the fitted Gaussian distribution in red. The time resolution is defined as the full width at half maximum of the Gaussian fit.



Supplementary Figure 7: Simulation of the time resolution of a funnel-shaped detector. The time resolution of an amorphous silicon-based microchannel plate (AMCP) channel with a funnel-shaped opening was simulated using COMSOL® multiphysics. a) Geometry of the simulation and example trajectories of the electrons inside the channel. The color scale shows the energy of electrons. b) Resulting current at the bottom electrode over time for 500 runs and the calculated time resolution at different thresholds (30%, 50%, and 80%) of the average signal amplitude. c) Histogram of the arrival times with the threshold set at 80 % of the average signal amplitude and the fitted Gaussian distribution in red. The time resolution is defined as the full width at half maximum of the Gaussian fit.