Beam Test of Deep Diffused APDs
some preliminary results

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on behalf of $(see next page)$

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Deep Diffused Avalanche Photo Detectors

- Charge multiplication
- Gain: $\approx 500$
- Bias: $\approx 1800$ V
- Never fully depleted
- Die dimensions: $2.8 \times 2.8$ mm$^2$ and $10 \times 10$ mm$^2$
- Nominal active area: $2 \times 2$ mm$^2$ and $8 \times 8$ mm$^2$
- Thickness: $230 - 280 \mu$m
- Custom fabrication process
- Produced by Radiation Monitoring Devices (RMD)

- Diffusion (non-depleted Si)
- Drift (depleted Si)
- Multiplication

Deep Diffused Avalanche Photo Detectors

Doping profile

- Maximum of electric field at pn-junction
- Field exceeds 200 kV/cm enabling impact ionization

8 × 8 mm² DD-APDs

Uniformity of response improved through metallization or mesh readout

DC coupled readout
- Aluminum deposited on both sides
- Metallization on single dies at CMi-EPFL

AC coupled readout
- Mesh on Kapton layer
- Sintered gold on back side
- Studied in previous beam tests ($\sigma_{\Delta t} = 19$ ps)
  S. White, CHEF 2013
  S. White, ps timing workshop 2014
Results from a previous beam test

HFS (mesh readout 8x8 mm RMD AD)
response uniformity measured w 150 GeV muon beam

Figure 10. A photograph of a 1st generation PCB with a mounted mesh APD seen on the right-hand side of the PCB.

Figure 11. (Left) A close up photograph showing the wire bonded APD diodes (Right) A close up photograph showing the wire bonded Ni mesh screen.

HFS Penn2 Peak vs. x -- -- -- -- -- -- -- and Peak vs. y and -- -- -- -- -- -- -- Full Landau Distribution
Setup

- 100 GeV $\mu$, a few runs with $\pi$
- CIVIDEC 2 GHz 40 dB ampli
- Agilent 2.5 GHz 10 Gs/s
- Temperature, bias, and current logged
- Tracking and timing provided by RD51
- MCP-PMT signal shaped to have a few points on leading edge
Detectors and Data set

Detectors at the beam test:

- Metallized $8 \times 8 \text{ mm}^2$ APDs
- Sintered gold on n-side $8 \times 8 \text{ mm}^2$ APD
- Mesh-readout $8 \times 8 \text{ mm}^2$ APDs
  (both custom made amplifier and CIVIDEC)
- $2 \times 2 \text{ mm}^2$ APD

Data:

- Several runs with different sensors
- Currently the tracking info is available for only one run ($\approx 12k$ events)
- The presentation focuses on this run
- Sensor under test: metallized APD at 1775 V, other ch not powered
- Peculiar trigger scintillator configuration (see next)

Today only preliminary results are presented
Hitmaps

Hitmap on APD plane

Hit Map Ch1

Hitmap on MCP-PMT plane, with threshold

Hit Map Ch4 0.03 < A < 0.79 V

- Shape determined by scintillator “finger”
- Not usual running condition
- A few tracks are outside the scintillator area

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APDs Beam Test

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Amplitude is fairly uniform on the APD
Some structure can be observed on the MCP-PMT
The amount of photons reaching the photocathode depends on the position
Selection Cuts

Geometrical cuts used to select interesting regions for projections and analysis

**APD metallized, 1775 V**

Median amplitude Map Ch1, 0.04 < A < 0.35 V

**MCP-PMT**

Median amplitude Map Ch4, 0.03 < A < 0.79 V

- Similar regions for both detectors
  - ⇒ the detectors were aligned
Signal Amplitude Projections

APD metallized, 1775 V

Section on X (between horizontal lines)
Amplitude Ch1 vs X, 23.0 < Y < 28.0 mm

Section on Y (between vertical lines)
Amplitude Ch1 vs Y, 26.0 < X < 33.0 mm

Red points represent the median, excluding events under threshold and saturating the scope scale

- The amplitude is fairly uniform on the APD
- The active area is around 9 mm (from section on X)
Signal Amplitude Projections

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Red points represent the median, excluding events under threshold and saturating the scope scale
20-80% Risetime

APD metallized, mean risetime, 1775 V

Section on X (between horizontal lines)

Distribution using data in the rectangle (all geom. cuts)

Red points represent the mean
Events under threshold or saturating are excluded

- Risetime shows a slight slope along X
- Not observed along Y
- Tails in the distribution are present
- Different risetimes in det. center
20-80% Risetime

APD metallized, mean risetime, 1775 V

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Distribution using data in the rectangle (all geom. cuts)

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20-80% Risetime

Metallized APD, mean risetime, 1775 V

MCP-PMT, mean risetime

The MCP-PMT shows values outside the peak, probably due to few points on leading edge.

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APDs Beam Test

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Time of Arrival APD - MCP-PMT

\[ \Delta t \text{ Section on X (between horizontal lines)} \]

\[ \Delta t \text{ CFD Ch1 - Ch4 vs plane Ch1 X, y slices and amplitude cuts fulfilled for both Ch} \]

\[ \text{Std. Dev of } \Delta t \text{ (not a fit)} \]

\[ \text{Red points represent the mean} \]

\[ \text{Cut for threshold and saturation} \]

\[ \text{All geom. cuts fulfilled by both ch.} \]

- CFD, 2 pt interpolation: APD 0.2, MCP 0.5
- \( \Delta t \) fairly homogeneous on the detector
- There is a region of broader \( \Delta t \) in det. center
- Similar effect as edges of det. as for risetime
Time of Arrival APD - MCP-PMT

Δt Section on X (between horizontal lines)

APD metallized, mean Δt, 1775 V

Red points represent the mean
Cut for threshold and saturation
All geom. cuts fulfilled by both ch.

- CFD, 2 pt interpolation: APD 0.2, MCP 0.5
- Δt fairly homogeneous on the detector
- There is a region of broader Δt in det. center
- Similar effect as edges of det. as for risetime
Time of Arrival APD - MCP-PMT

Mean $\Delta t$ vs $X$ for one bin $[25.5,26]$ mm

There is a region in det. center with different $\Delta t$

- Its std. dev. is similar to the rest of the detector
- Its position corresponds to the hole in the metallization of p-side

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APDs Beam Test
Time of Arrival APD - MCP-PMT

Mean $\Delta t$ vs $X$ for one bin [25.5,26] mm

Mean $\Delta t$ (zoomed Z to see effect)

Std Dev $\Delta t$ vs $X$ for one bin (no fit)

- There is a region in det. center with different $\Delta t$
- Its std. dev. is similar to the rest of the detector
- Its position corresponds to the hole in the metallization of p-side
Time of Arrival APD - MCP-PMT

Mean $\Delta t$ vs $X$ for one bin [25.5,26] mm

- There is a region in det. center with different $\Delta t$
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- Its position corresponds to the hole in the metallization of p-side

Std Dev $\Delta t$ vs $X$ for one bin (no fit)
Time Resolution of the System

- Time resolution from fit $\sigma_{\Delta t} = 54.9 \pm 1.3$ ps (using an $8 \times 8$ mm$^2$ detector)
- Time resolution of the MCP-PMT with the current readout has to be determined
- Excess at $\approx 8$ ns due to the non-uniformity at det. center
Time resolution from fit $\sigma_{\Delta t} = 54.9 \pm 1.3$ ps (using an $8 \times 8$ mm$^2$ detector)

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Summary

- Acquired data for APDs in beam tests, \( \approx 7 \text{M events} \)
- Both tracking and time references were available
- Preliminary results from analysis of one run

Outlook:
- More runs will be analyzed, the tracking information will soon be available
- Separate the different components of the time resolution
Backup Material
APD Section (Not to Scale)

- p-side
- n-side
- conductive layer
- polyimide

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APDs Beam Test
$2 \times 2 \text{ mm}^2$ DD-APDs

- Packaged
- Usually employed in irradiation studies
Beam Test Setup

- Sensor box placed downstream first tracking GEM
- Detectors and PCBs coated with FSC 400 to reduce discharges
- Amplifiers: CIVIDEC 2 GHz, 40 dB
- Data acquisition: Agilent 2.5 GHz, 10 Gs/s
  - Ch1: APD
  - Ch2: APD
  - Ch3: Telescope bit pattern (Trigger)
  - Ch4: MCP-PMT
- Temperature, bias, and current logged
  - MCP-PMT readout and shaping

![Sensor box](image)

![APD readout](image)
Run Conditions


Voltage log

Temperature log

Current log

- Run went on till $\approx 18.55$
- Current increases due to rampling down
- Access at $\approx 19.15$ (dip in temperature)
Analysis:

- Extract signal properties (ampli, risetime, tCFD, ....)
- The signal is selected in a window around the peak
- Points preceding the selection are used for baseline
- The leading edge is isolated to extract risetime and tCFD
- The tracking info is extrapolated to each plane
- Only events with one track are used