Beam Test of Deep Diffused APDs some preliminary results

Matteo Centis Vignali[1], CERN EP-DT Fellow
on behalf of $(see next page)

27.11.2018
33rd RD50 Workshop, CERN

[1] matteo.centis.vignali@cern.ch

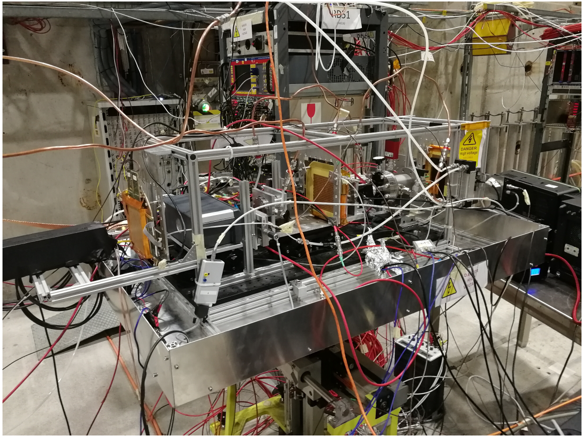
Authors

- **CERN, Geneva, Switzerland**:
  P. Almeida, M. Centis Vignali, Y. Gurimskaya, I. Mateu, M. Moll, S. Otero Ugobono⋆, M. Wiehe⋄
- **Lancaster University, Lancaster, UK**:
  W. Holmkvist
- **LIP, Lisbon, Portugal**:
  M. Gallinaro*
- **Princeton University, Princeton, USA**:
  B. Harrop, C. Lu, K. T. McDonald
- **Radiation Monitoring Devices, Watertown, USA**:
  M. McClish
- **University of Bern, Bern, Switzerland**:
  L. Franconi
- **University of Pennsylvania, Philadelphia, USA**:
  F. M. Newcomer
- **University of Virginia, Charlottesville, USA**:
  S. White*

⋆ also Universidade de Santiago de Compostela, Santiago de Compostela, Spain
⋄ also University of Freiburg, Freiburg, Germany
* also CERN

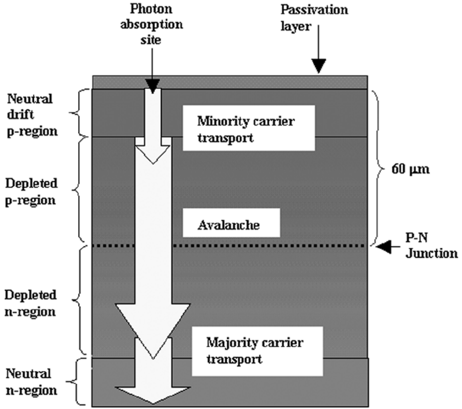
Acknowledgments

The authors would like to thank the RD51 and PICOSEC collaborations for the possibility to participate in the May and August 2018 beam tests.
We are particularly grateful to Eraldo, Paco, and Lukas.
We would like to thank Francisco for the coating of the detectors and PCB.



Deep Diffused Avalanche Photo Detectors

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

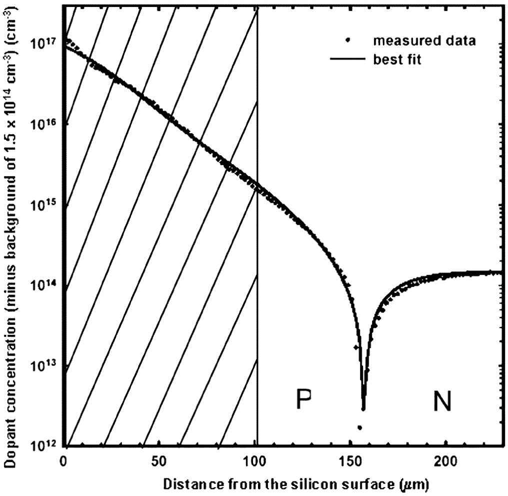


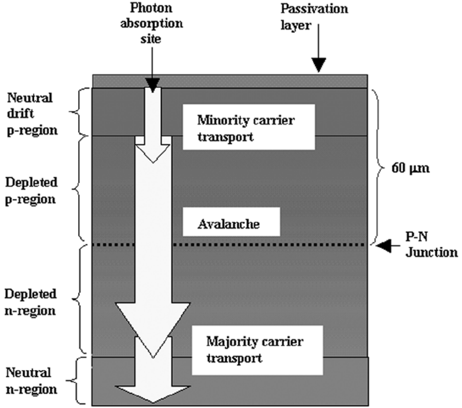
- Diffusion (non-depleted Si)
- Drift (depleted Si)
- Multiplication

M. McClish et. al. IEEE Trans. Nucl. Sci. Vol. 53, No. 5, 2006

Deep Diffused Avalanche Photo Detectors

Doping profile





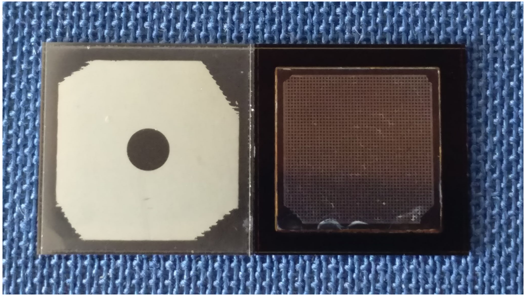
- Maximum of electric field at pn-junction
- Field exceeds 200 kV/cm enabling impact ionization

M. McClish et. al. IEEE Trans. Nucl. Sci. Vol. 53, No. 5, 2006

8×8 mm^2 DD-APDs

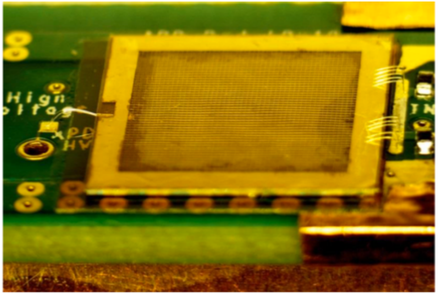
Uniformity of response improved through metallization or mesh readout

DC coupled readout



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

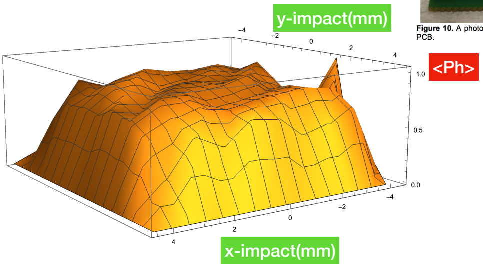
AC coupled readout



- 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



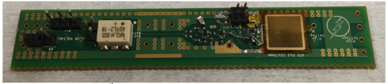


Figure 10. A photograph of a 1st generation PCB with a mounted mesh APD seen on the right-hand side of the PCB.

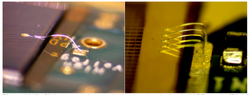
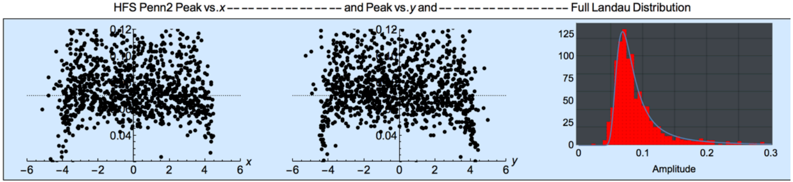
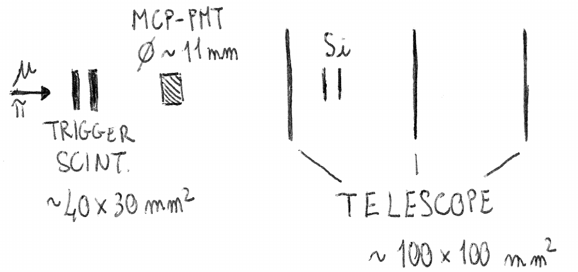
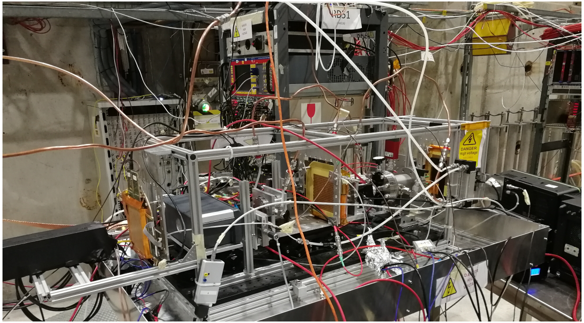


Figure 11. (Left) A close up photograph showing the wire bonded APD anode. **(Right)** A close up photograph showing the wire bonded Ni mesh screen.

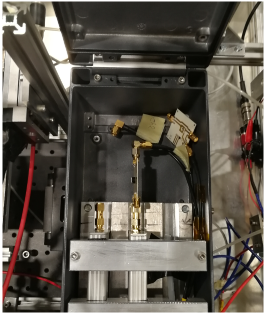


Setup





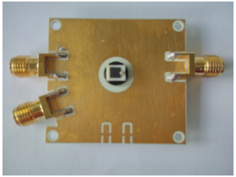
- 100 GeV μ, a few runs with π
- CIVIDEC 2 GHz 40 dB ampli
- Agilent 2.5 GHz 10 Gs/s
- Temperature, bias, and current logged
- Tracking and timing provided by RD51
- MCP-PMT signal shaped to have a few points on leading edge

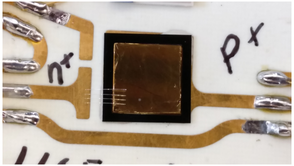


Detectors and Data set

Detectors at the beam test:

- Metallized 8×8 mm^2 APDs
- Sintered gold on n-side 8×8 mm^2 APD
- Mesh-readout 8×8 mm^2 APDs (both custom made amplifier and CIVIDEC)
- 2×2 mm^2 APD





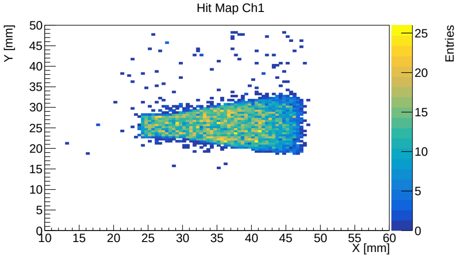
Data:

- 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)

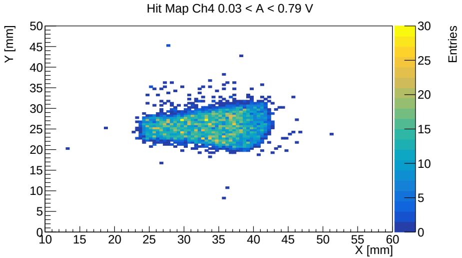
Today only preliminary results are presented

Hitmaps

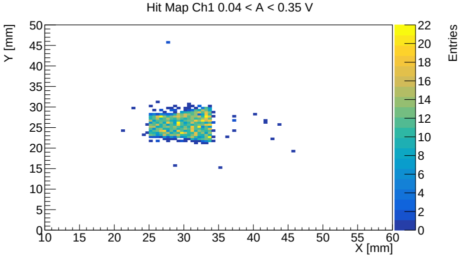
Hitmap on APD plane



Hitmap on MCP-PMT plane, with threshold



Hitmap on APD plane, with threshold



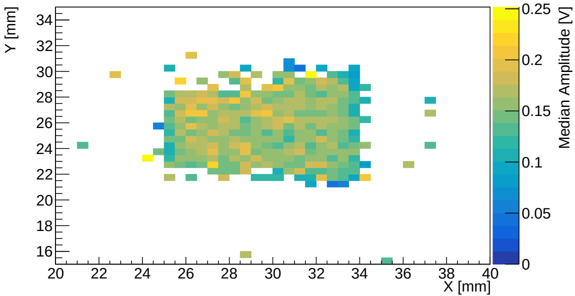
- Shape determined by scintillator “finger”
- Not usual running condition
- A few tracks are outside the scintillator area

Signal Amplitude

Maps of median amplitude excluding events under threshold and saturating the scope scale

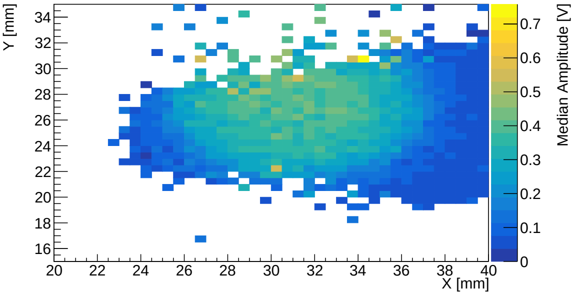
APD metallized, 1775 V

Median amplitude Map Ch1, 0.04 < A < 0.35 V



MCP-PMT

Median amplitude Map Ch4, 0.03 < A < 0.79 V

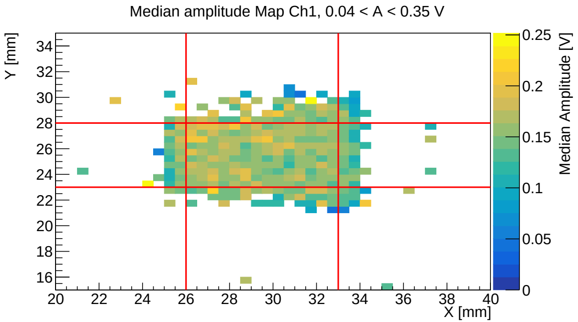


- Amplitude is fairly uniform on the APD
- Some structure can be observed on the MCP-PMT
- The amount of photons reaching the photocathode depends on the position

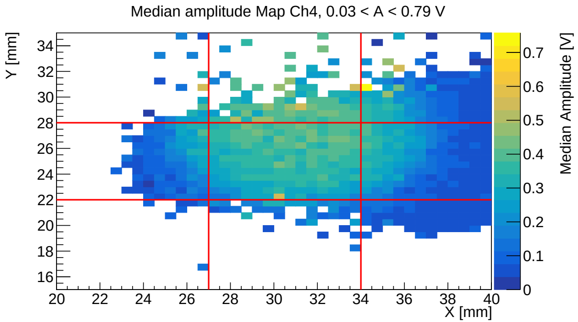
Selection Cuts

Geometrical cuts used to select interesting regions for projections and analysis

APD metallized, 1775 V



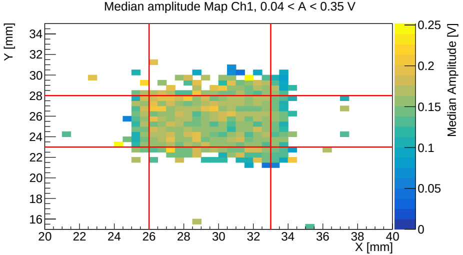
MCP-PMT



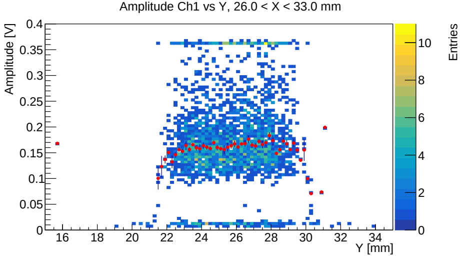
- Similar regions for both detectors
  $\Rightarrow$ the detectors were aligned

Signal Amplitude Projections

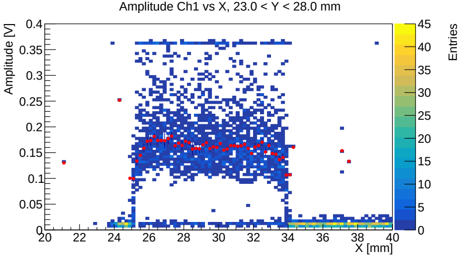
APD metallized, 1775 V



Section on Y (between vertical lines)



Section on X (between horizontal lines)

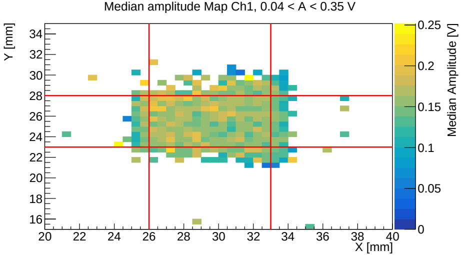


Red points represent the median, excluding events under threshold and saturating the scope scale

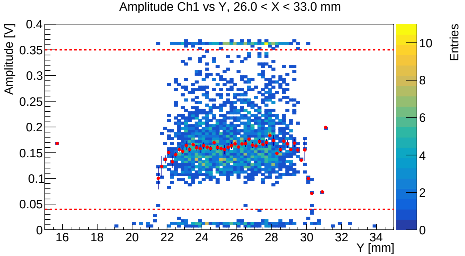
- The amplitude is fairly uniform on the APD
- The active area is around 9 mm (from section on X)

Signal Amplitude Projections

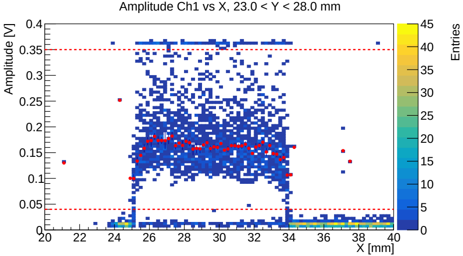
APD metallized, 1775 V



Section on Y (between vertical lines)



Section on X (between horizontal lines)

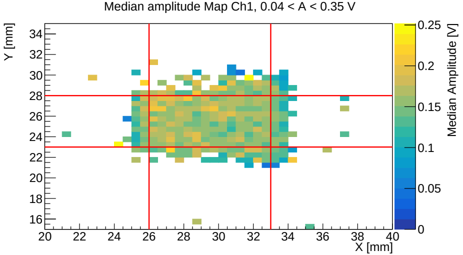


Red points represent the median, excluding events under threshold and saturating the scope scale

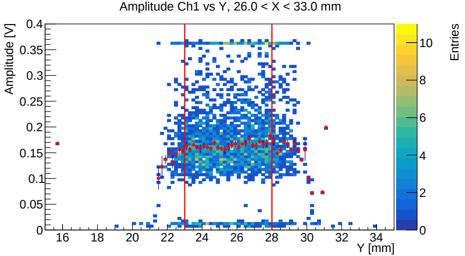
- The amplitude is fairly uniform on the APD
- The active area is around 9 mm (from section on X)

Signal Amplitude Projections

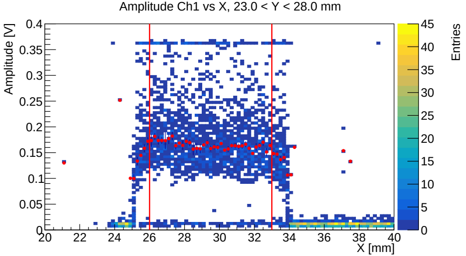
APD metallized, 1775 V



Section on Y (between vertical lines)



Section on X (between horizontal lines)

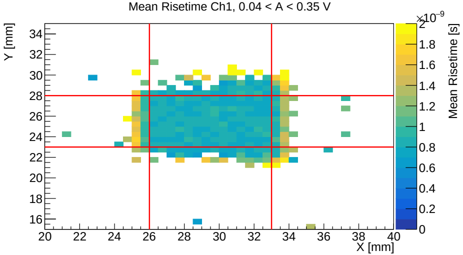


Red points represent the median, excluding events under threshold and saturating the scope scale

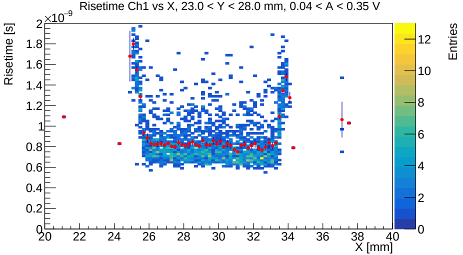
- The amplitude is fairly uniform on the APD
- The active area is around 9 mm (from section on X)

20-80% Risetime

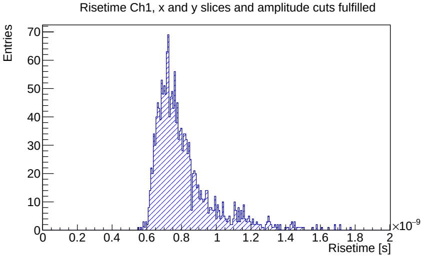
APD metallized, mean risetime, 1775 V



Section on X (between horizontal lines)



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

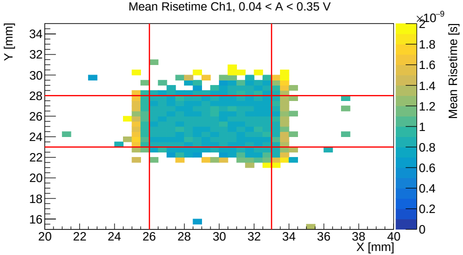


Red points represent the mean
Events under threshold or saturating are excluded

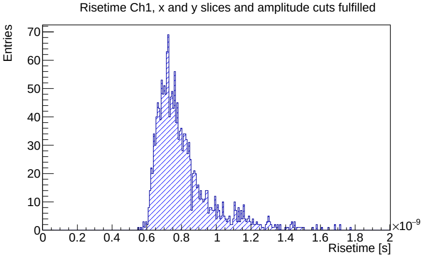
- Risetime shows a slight slope along X
- Not observed along Y
- Tails in the distribution are present
- Different risetimes in det. center

20-80% Risetime

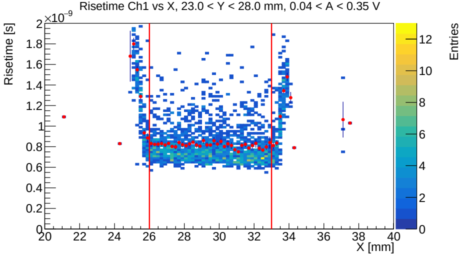
APD metallized, mean risetime, 1775 V



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



Section on X (between horizontal lines)

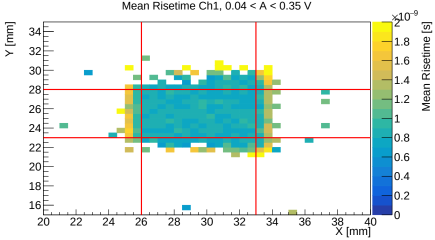


Red points represent the mean
Events under threshold or saturating are excluded

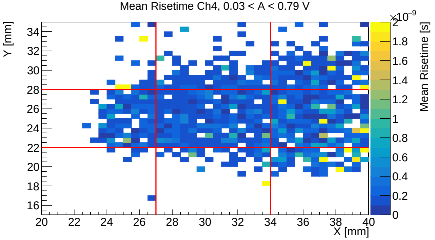
- Risetime shows a slight slope along X
- Not observed along Y
- Tails in the distribution are present
- Different risetimes in det. center

20-80% Risetime

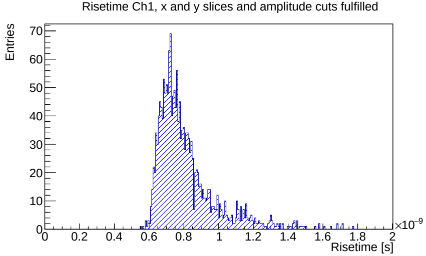
Metallized APD, mean risetime, 1775 V



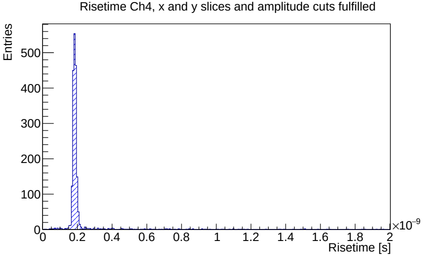
MCP-PMT, mean risetime



Distribution using data in the rectangle



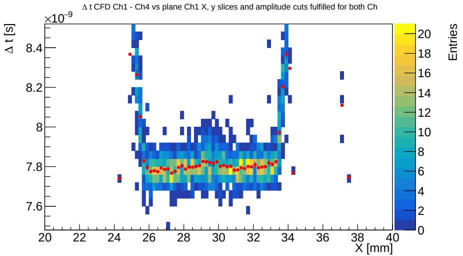
Distribution using data in the rectangle



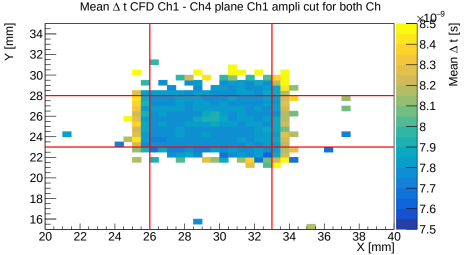
The MCP-PMT shows values outside the peak, probably due to few points on leading edge

Time of Arrival APD - MCP-PMT

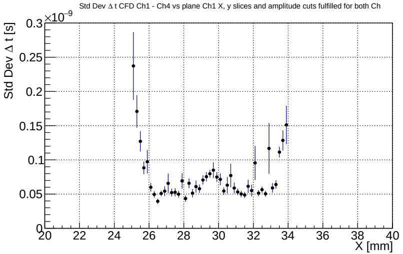
Δt Section on X (between horizontal lines)



APD metallized, mean Δt, 1775 V



Std. Dev of Δt (not a fit)

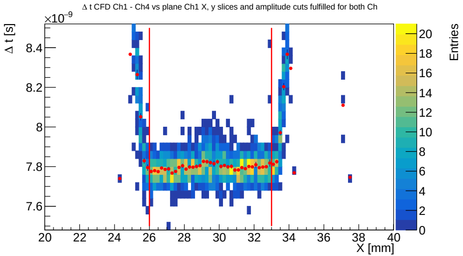


Red points represent the mean
Cut for threshold and saturation
All geom. cuts fulfilled by both ch.

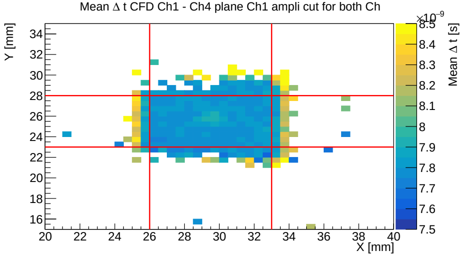
- CFD, 2 pt interpolation: APD 0.2, MCP 0.5
- Δt fairly homogeneous on the detector
- There is a region of broader Δt in det. center
- Similar effect as edges of det. as for risetime

Time of Arrival APD - MCP-PMT

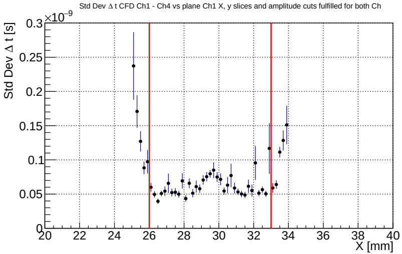
Δt Section on X (between horizontal lines)



APD metallized, mean Δt, 1775 V



Std. Dev of Δt (not a fit)

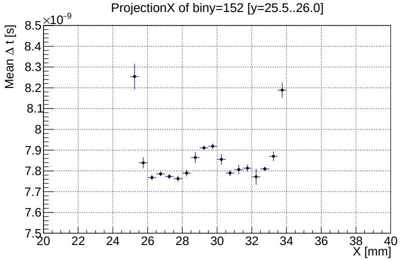


Red points represent the mean
Cut for threshold and saturation
All geom. cuts fulfilled by both ch.

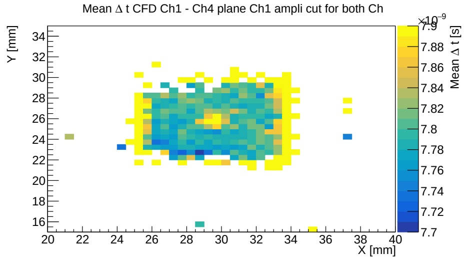
- CFD, 2 pt interpolation: APD 0.2, MCP 0.5
- Δt fairly homogeneous on the detector
- There is a region of broader Δt in det. center
- Similar effect as edges of det. as for risetime

Time of Arrival APD - MCP-PMT

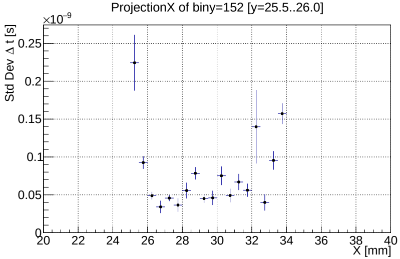
Mean Δt vs X for one bin [25.5,26] mm



Mean Δt (zoomed Z to see effect)



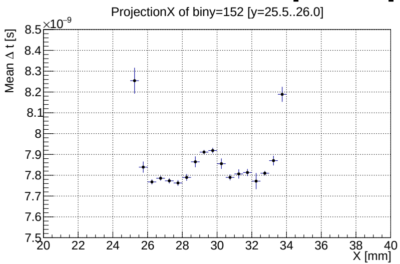
Std Dev Δt vs X for one bin (no fit)



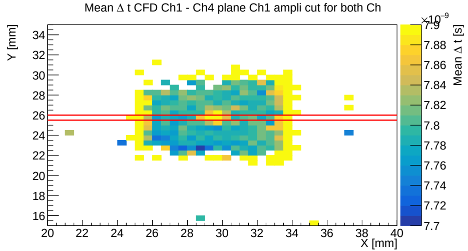
- There is a region in det. center with different Δt
- Its std. dev. is similar to the rest of the detector
- Its position corresponds to the hole in the metallization of p-side

Time of Arrival APD - MCP-PMT

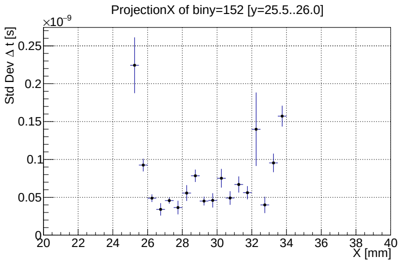
Mean Δt vs X for one bin [25.5,26] mm



Mean Δt (zoomed Z to see effect)



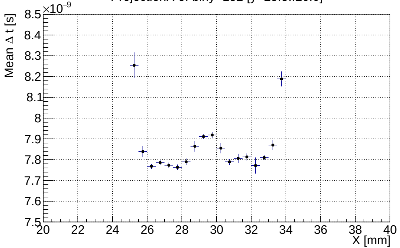
Std Dev Δt vs X for one bin (no fit)



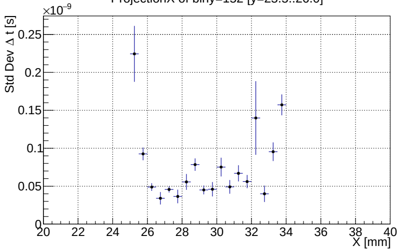
- There is a region in det. center with different Δt
- Its std. dev. is similar to the rest of the detector
- Its position corresponds to the hole in the metallization of p-side

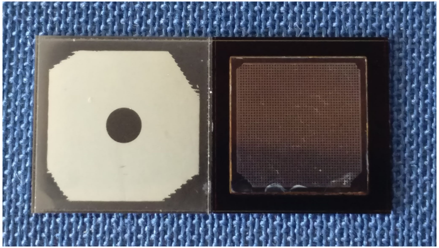
Time of Arrival APD - MCP-PMT

Mean Δt vs X for one bin [25.5,26] mm



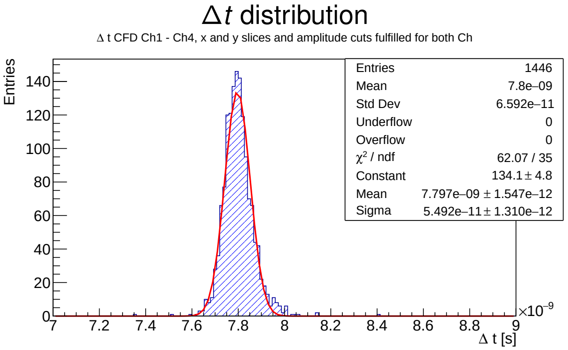
Std Dev Δt vs X for one bin (no fit)

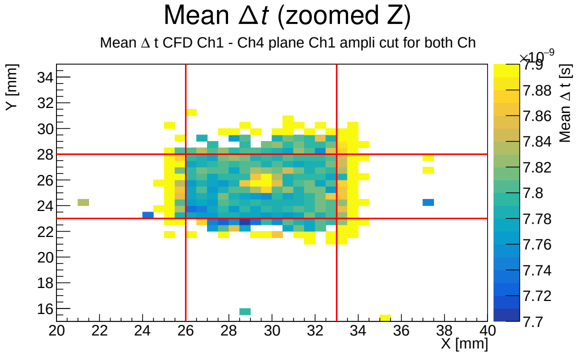




- There is a region in det. center with different Δt
- Its std. dev. is similar to the rest of the detector
- Its position corresponds to the hole in the metallization of p-side

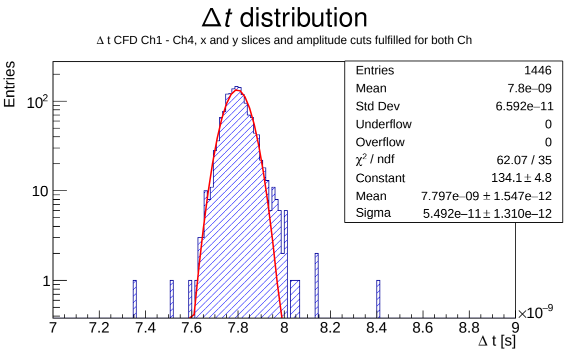
Time Resolution of the System

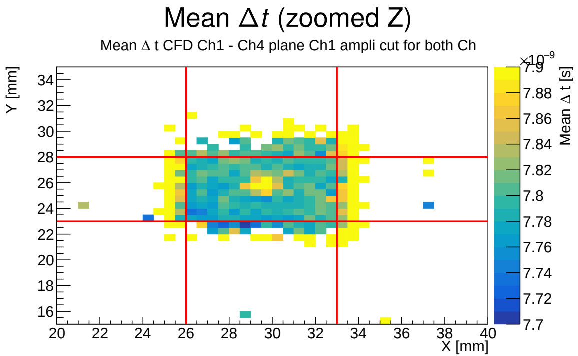




- Time resolution from fit $\sigma_{\Delta t} = 54.9 \pm 1.3$ ps (using an 8×8 mm^2 detector)
- Time resolution of the MCP-PMT with the current readout has to be determined
- Excess at $\approx$8 ns due to the non-uniformity at det. center

Time Resolution of the System





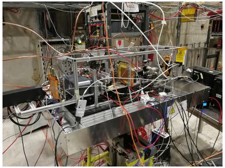
- Time resolution from fit $\sigma_{\Delta t} = 54.9 \pm 1.3$ ps (using an 8×8 mm^2 detector)
- Time resolution of the MCP-PMT with the current readout has to be determined
- Excess at ≈8 ns due to the non-uniformity at det. center

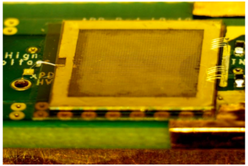
Summary

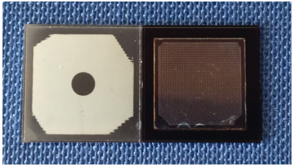
- Acquired data for APDs in beam tests, ≈7M events
- Both tracking and time references were available
- Preliminary results from analysis of one run

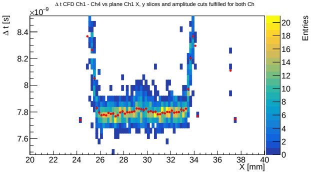
Outlook:

- More runs will be analyzed, the tracking information will soon be available
- Separate the different components of the time resolution



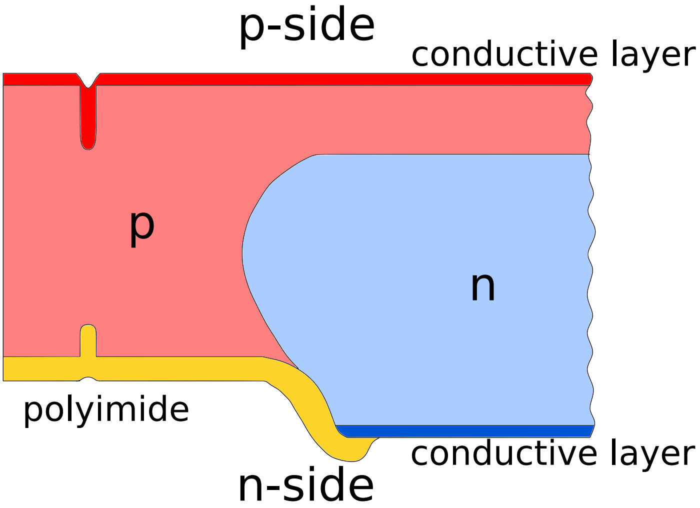




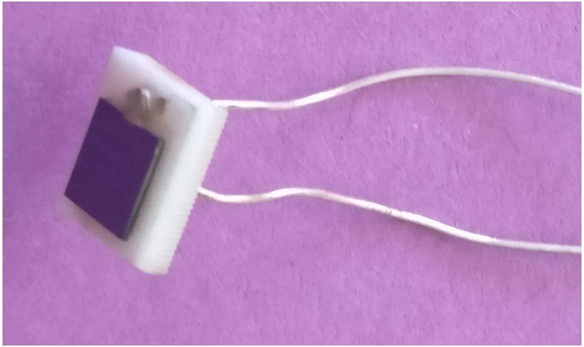


Backup Material

APD Section (Not to Scale)



$2 \times 2\,mm^2$ DD-APDs

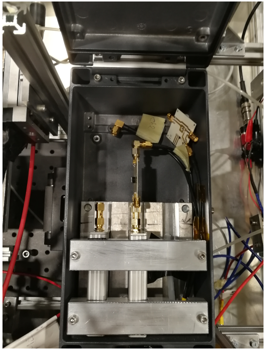


- Packaged
- Usually employed in irradiation studies

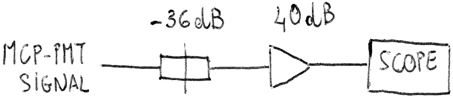
Beam Test Setup

- 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

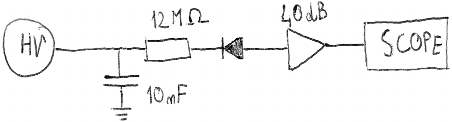
Sensor box



MCP-PMT readout and shaping



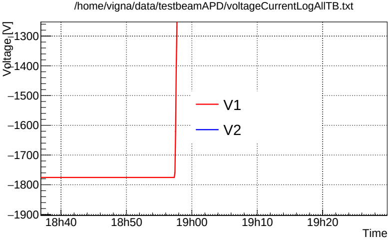
APD readout



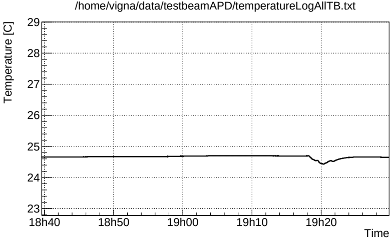
Run Conditions

Run: 2018-05-03_18-40-04, Det: 430-2-20 (metallized), Tot evt: 12642

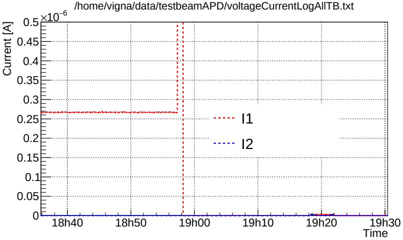
Voltage log



Temperature log



Current log



- Run went on till ≈18.55
- Current increases due to rampling down
- Access at ≈ 19.15 (dip in temperature)

Analysis

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