Direct MIP detection with sub-10 ps timing resolution Geiger-Mode APDs

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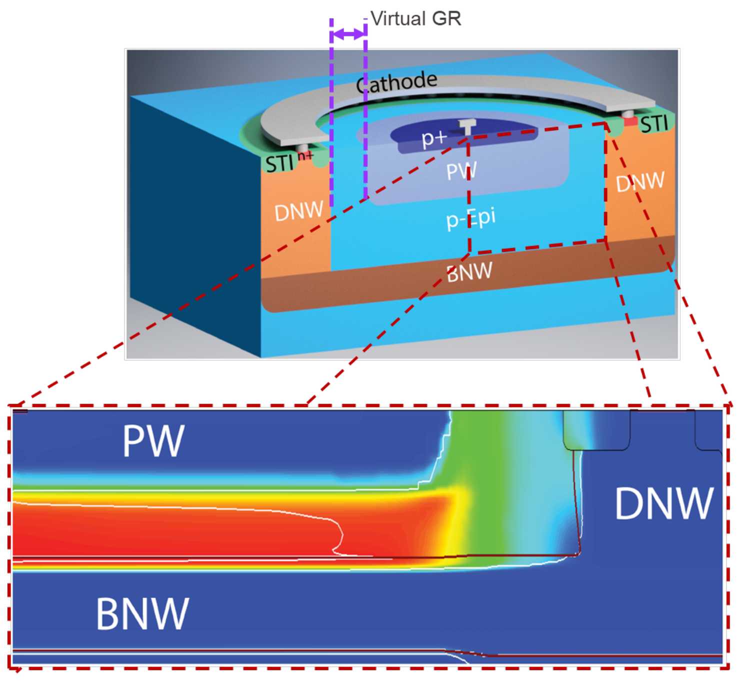
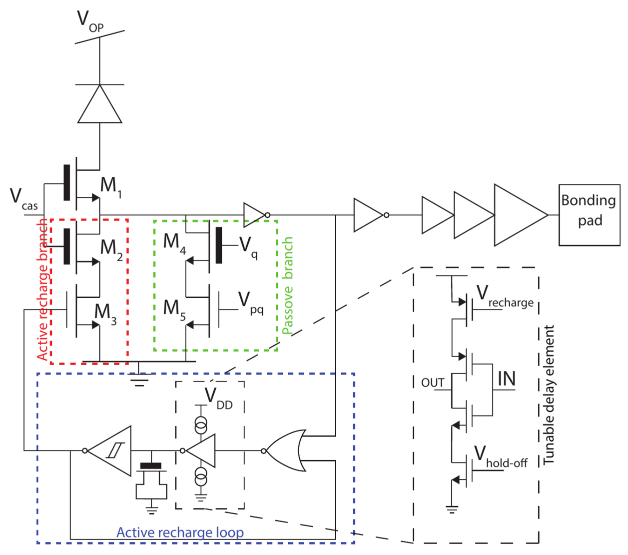
Device under test

SPAD [1]
- 180 nm CMOS technology
- P-I-N structure
- Substrate-Isolated type
- P-well anode, buried N-well cathode
- HV provided through a deep N-well

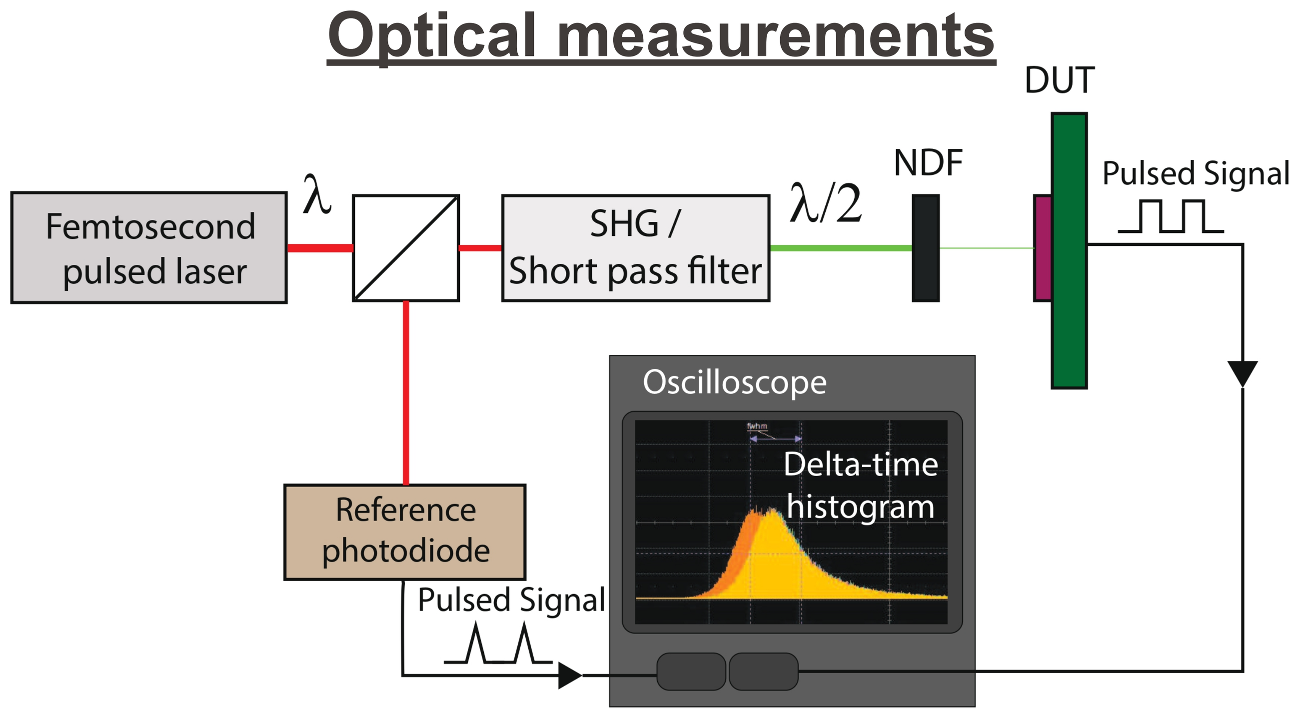


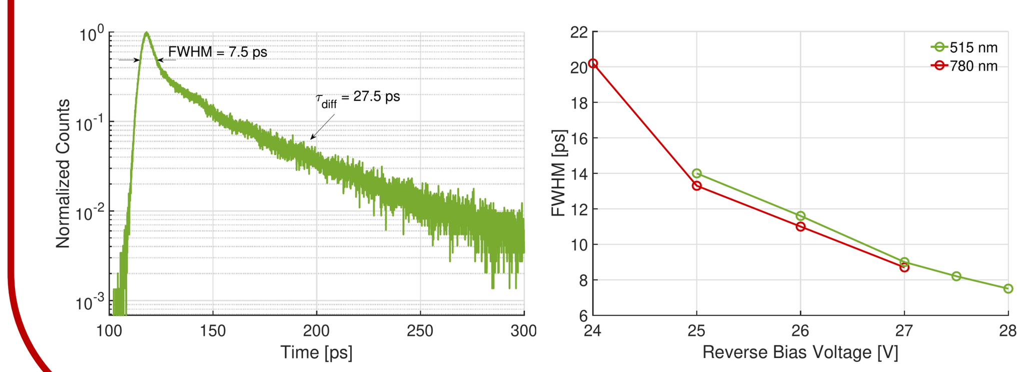
Chip
- 25 µm diameter CMOS SPAD
- Active quenching/recharge
- Tunable delay time (down to 3 ns)

System-on-board:
- Single external power supply source
- All voltages provided through DACs controlled with serial protocol
- Reduced cable noise
- Si-Ge comparator for 50 Ohm coupling
- High signal slew rate (≥ 1.6 V/ns)



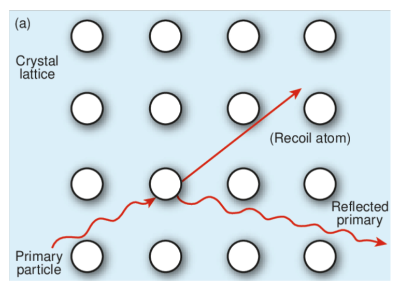
Optical measurements





- Unprecedented timing performance
- High PDP 55% @480 nm
- Low DCR and afterpulsing

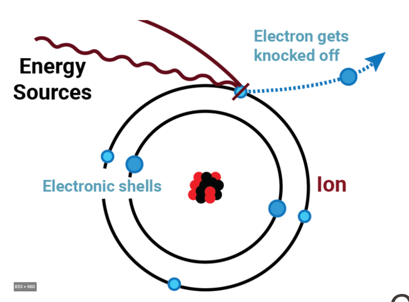
Radiation Hardness



Maurer, Richard et al. (2008).

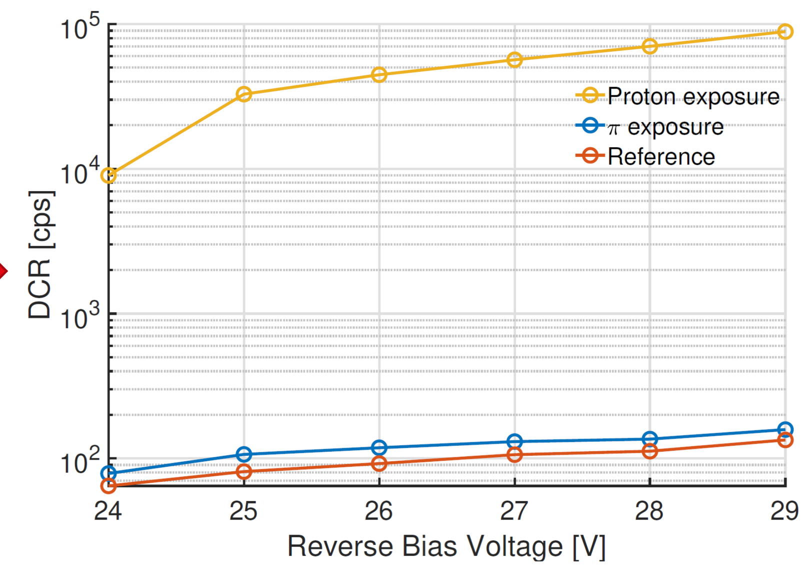
Displacement damage

Annealing required



Ionisation damage (necessary for detection!)

Collection of the free charges by the electric field

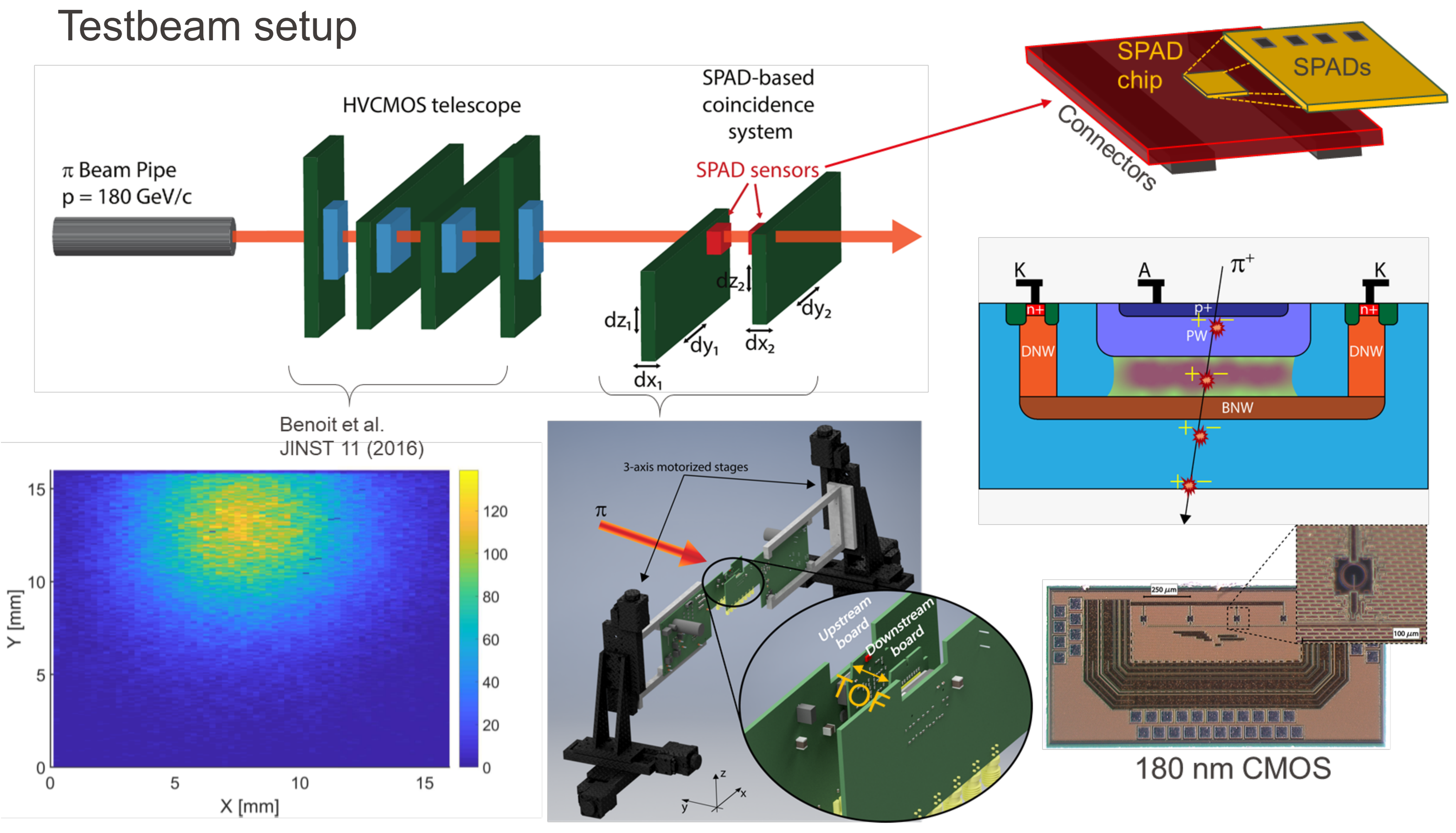


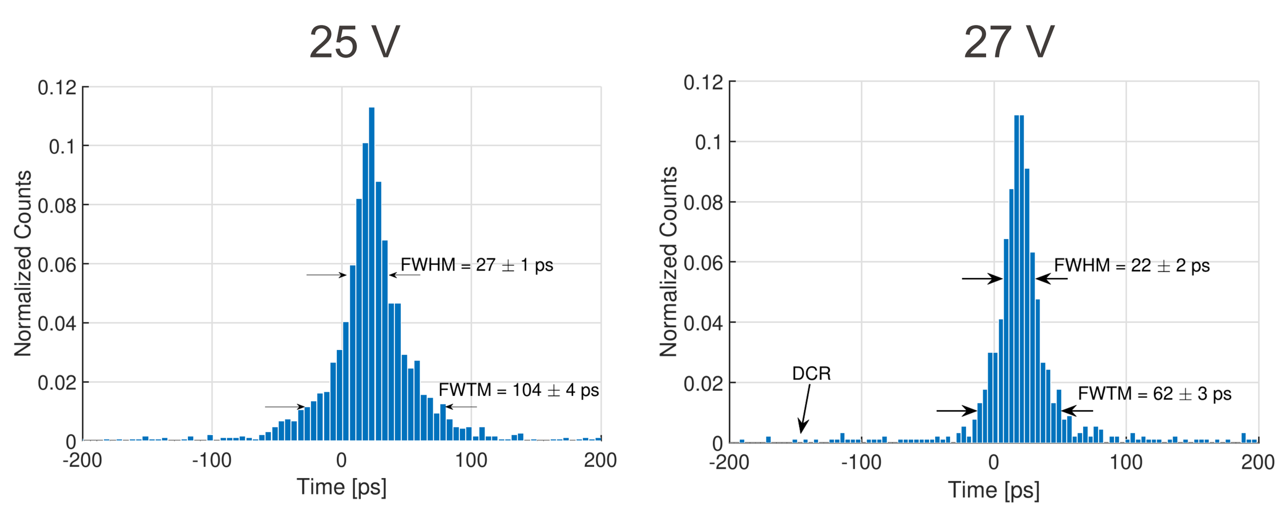
- 100 MeV proton exposure (heavy ionisation)
- 180 GeV/c pions exposure (MIP)

Direct Minimum Ionizing Particle Detection

Time-of-flight measurement of Minimum ionizing particles with SPADs [2]
- Coincidence to eliminate noise background
- Excellent timing resolution → 6.4 ps sigma

Testbeam setup



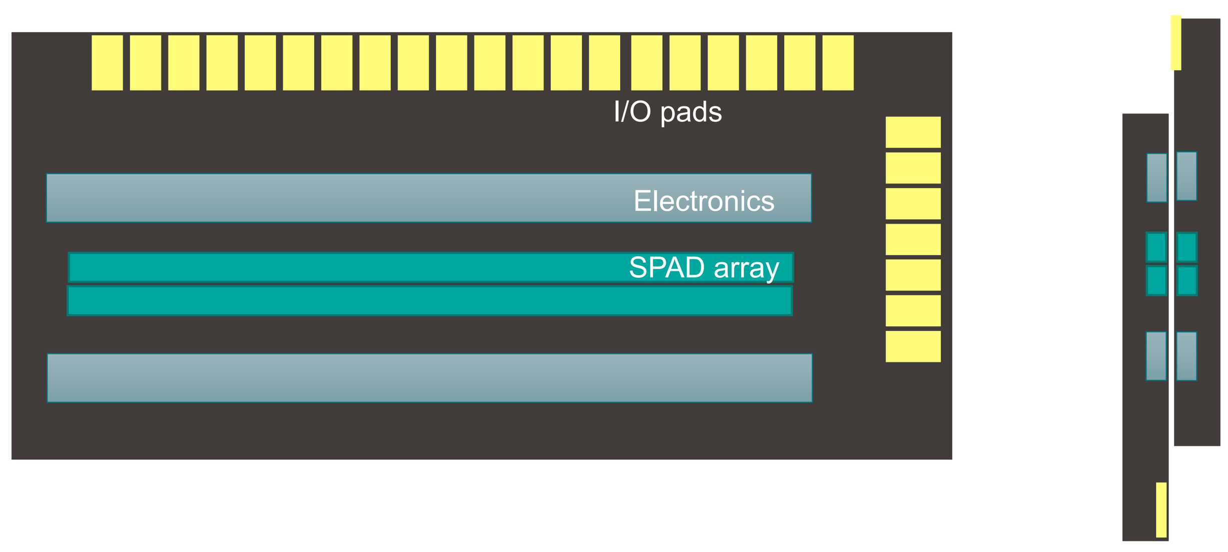


Bias (V)	FWHM (ps)	FWTM (ps)	σ (ps)	σ_{single} (ps)
24	27 ± 1	104 ± 4	11.5 ± 0.4	8.1 ± 0.3
27	22 ± 2	62 ± 3	9.4 ± 0.7	6.4 ± 0.5

Future developments

Next steps
- MIP Detection efficiency measurements (Oct 2022)
- Design of a multichannel prototype
- Feasibility study for the implementation of high timing resolution particle tracker:
  - Monolithic chip with two rows of N SPADs (like the one presented, possibly in 55 nm) each
  - Electronics on the periphery
  - Facing SPADs in coincidence to suppress the DCR
  - Cooling system

Chips glued on the front-side with flip chip machine: 1 µm precision



State of the art

Device	σ_{single} (ps)	Time walk correction	Pre-amplifier	MIP Detection efficiency
SPAD AQUA	6.4	No	No	~99% [3]
TIMESPOT	19 [5]	Yes	Yes	99%
UFSD (LGAD)	27 [4]	Yes	Yes	99%

[1] F. Gramuglia, et al., "A low-noise CMOS SPAD pixel with 12.1 ps SPTR and 3 ns dead time", IEEE JSTQE, 2021. 2021
[2] F. Gramuglia, E. Ripiccini et al., "Sub-10 ps minimum ionizing particle detection with Geiger-Mode APDs",. Front. Phys., 2022, 10, 10.3389/fphy.2022.849237
[3] W. Riegler, P. Windischhofer, Time Resolution and Efficiency of SPADs and SiPMs for Photons and Charged Particles. Nucl Instr Methods Phys Res Section A: Acc Spectrometers, Detectors Associated Equipment (2021)
[4] N. Cartiglia et al. Beam Test Results of a 16 ps Timing System Based on Ultra-fast Silicon Detectors. Nucl Instr Methods Phys Res Section A: Acc Spectrometers, Detectors Associated Equipment (2017) 850:83–8
[5] D. Brundu et al., Accurate modelling of 3D-trench silicon sensor with enhanced timing performance and comparison with test beam measurements, JINST 16 (2021) 09, P09028