UNIVERSITÄT BONN
Physikalisches Institut

Picosecond-Timing using Avalanche Photodiodes operated near breakdown*

P. Fischer [a], R. Henneberger [a], W. Lindenberg [a], M. Trauth [b], and N. Wermes [a]

[a] *Physikalisches Institut der Universität Bonn*
[b] *Physikalisches Institut der Universität Heidelberg*

Abstract: Using dark rate dependent feed back and quench circuitry avalanche photodiodes have been stably operated at voltages close to breakdown and above. Exploiting the large amplification in such operation time resolutions of 15ps for 10^8 incident photons have been measured at temperatures around 0°C.

*Work supported by the German Ministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF) under contracts no. 05 6*BN* 18*P* 4 and 05 6*BN* 10*I* and by the Ministerium für Wissenschaft und Forschung des Landes Nordrhein-Westfalen under contracts no. *IV A*5 – 106 001 94 and *IV A*5 – 9036.0.

Post address:
Nussallee 12
D-53115 Bonn
Germany

BONN-HE-95-02
Bonn University
May 1995
ISSN-0172-8733

Picosecond-Timing using Avalanche Photodiodes operated near breakdown ⋆

P. Fischer [a], R. Henneberger [a], W. Lindenberg [a], M. Trauth [b 1] and N. Wermes [a]

[a] *Physikalisches Institut der Universität Bonn Nußallee 12, D-53115 Bonn, Germany*

[b] *Physikalisches Institut der Universiät Heidelberg Philosophenweg 12, D-69120 Heidelberg, Germany*

Abstract

Using dark rate dependent feed back and quench circuitry, avalanche photodiodes have been stably operated at voltages close to breakdown and above. Exploiting the large amplification in such operation time resolutions of 15ps for 10^3 incident photons have been measured at temperatures around 0°C.

Introduction

Avalanche photodiodes (APD)[1] promise excellent energy resolution due to the low noise performance when used as readout devices resulting from their built in avalanche amplification. While large area planar photodiodes of the PIN type suffer from increased noise due to their large capacitances when coupled to charge sensitive preamplifiers, large area APDs have been produced [2] with excellent energy resolution [3,4]. Stable APD operation in an experiment has been proven difficult because operating conditions for constant APD gain varies much with temperature and with the rate of APD-breakdown. In particle physics experiments, in particular those operating at centre of mass energies up to 10 GeV, the detection of MeV photons with precise energy and

[1] present address: GSP GmbH, Auf dem Klöppel III 2, D-67098 Bad Dürkheim

⋆ Work supported by the Ministerium für Wissenschaft und Forschung des Landes Nordrhein-Westfalen under contracts no. $IV\ A5-106\,001\,94$ and $IV\ A5-9036.0$ and by the German Ministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF) under contracts no. $05\,6BN\,18P4$ and $05\,6BN\,10I$.

time measurements is often desired. When detected using crystal scintillators with photo - sensitive readout the number of optical photons produced per MeV energy deposit may be as large as some 10^4 distributed in time over a range of up to some microseconds. In such crystals sub-nanosecond timing on MeV photons is difficult and has thus far not been achieved to our knowledge. For applications in other fields where more light input can be obtained, time resolutions much below the ns range are desirable [6]. In this paper we show that using small diameter avalanche photodiodes operated close to the breakdown voltage, time resolutions well below 1ns for 5×10^4, and down to 15ps for 10^8 incident photons can be achieved. Stable operation at this high gain operation is obtained using a dedicated, dark rate dependent feedback and quench circuit.

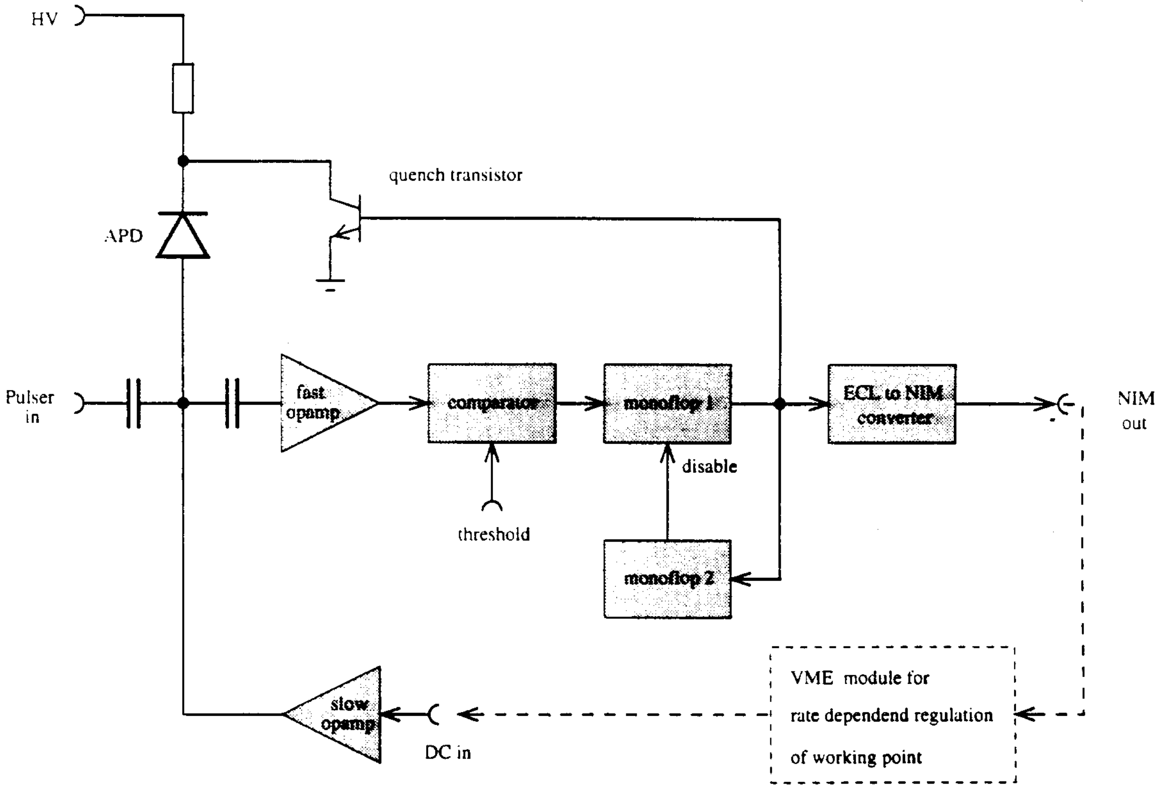

Fig. 1. Block diagram of the APD quench and stabilization circuit.

APD and Quench-Circuit

We have used a 1mm diameter APD [2] which has a breakdown voltage around 120V according to the manufacturer. Details of APD operation can be found elsewhere [1,5]. The quench circuitry is shown schematically in fig. 1. Upon an APD breakdown, initiated by an incident light quantum or by random

[2] Hamamatsu ser.no. S 5343

breakdown (dark rate). the current signal from the APD is amplified by a fast. current sensitive amplifier (HFA1100) and compared to a comparator threshold which is. for optimum operation. set very close to the noise limit.

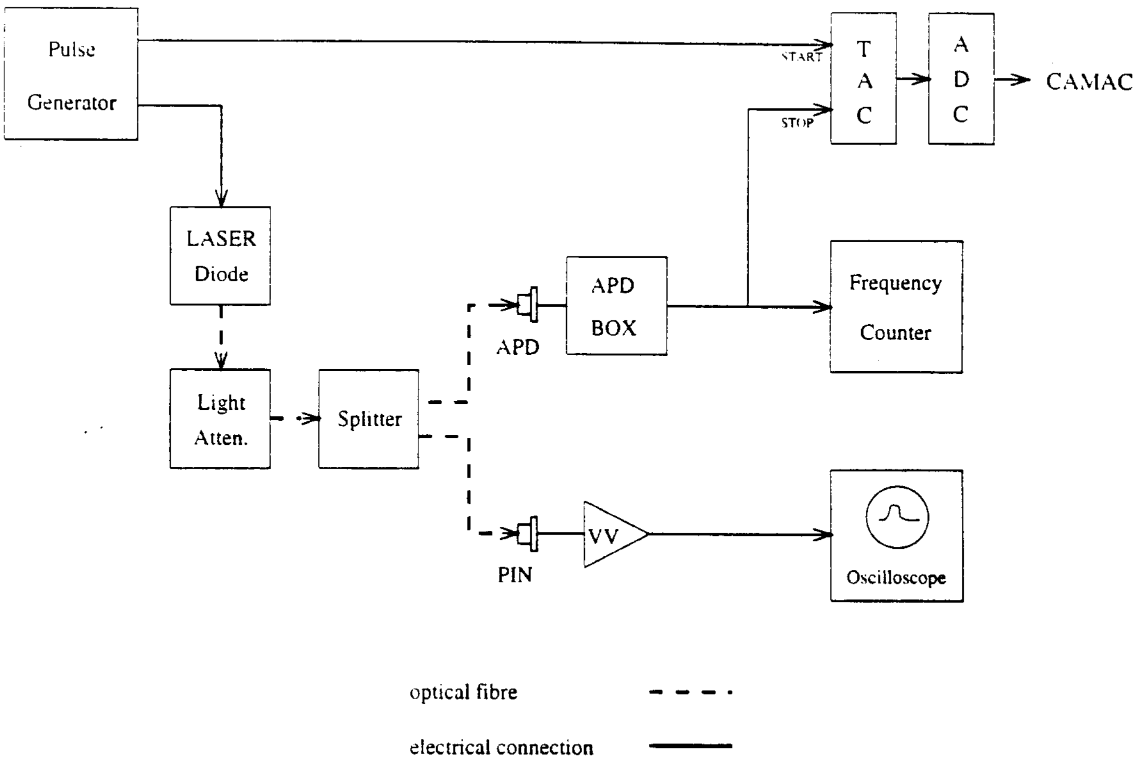

Fig. 2. Block diagram of the measurement setup.

The comparator (1/2MC10E1651) triggers a monoflop of 200ns pulse length which after level changing activates the quench transistor. The circuit is disabled for a fixed delay (typically 500 ns) by monoflop 2 to prevent fake triggers induced by the quench operation (self triggering). An additional feed-back loop activated by the same quench pulse is used to operate the APD at a constant breakdown rate (dark rate). This is achieved by means of an external VME module which compares the actual counting rate with a programmable rate setting. Upon a detected difference between the actual and the programmed rate an appropriate offset voltage is forwarded to the APD adjusting the operating point accordingly. The time constant of this feed back loop is slow ($\sim$ 1s) to average out statistical fluctuations in the counting rate. This way operation very close to the breakdown voltage is possible. Here we determine the breakdown voltage experimentally as the operation voltage at which a dramatic increase of the darkrate is observed. All operation parameters can be adjusted and must be optimized for best results.

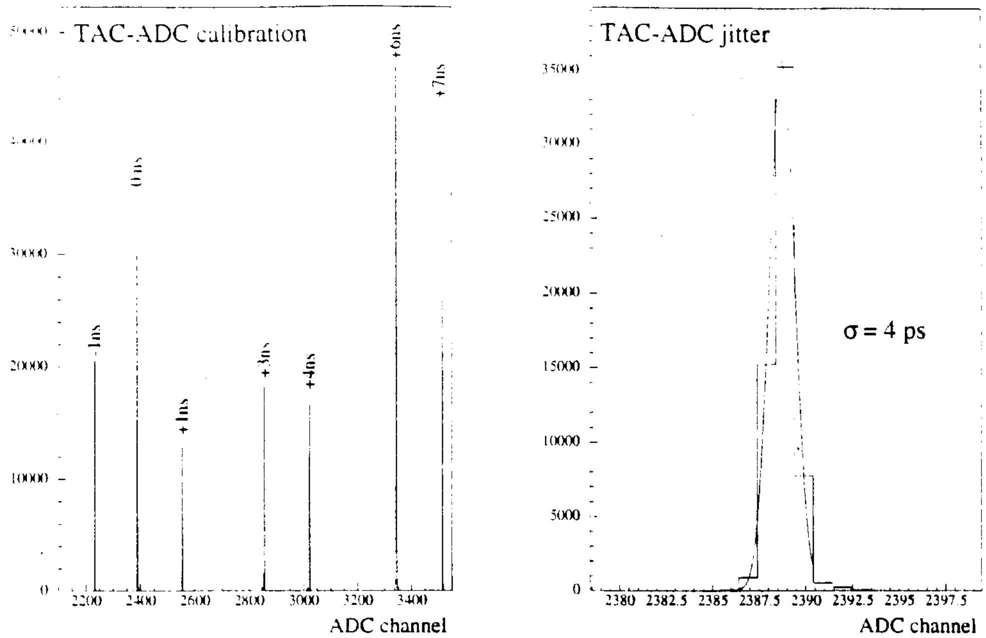

Fig. 3. (a) Time spectra obtained by bypassing the APD branch for different START - STOP delays. (b) Intrinsic resolution of the TDC-ADC system without APD.

Measurement setup

The setup of the measurement is shown in fig. 2. The output pulse from a pulse generator (model HP8116A) triggers a GaAs laser diode pulser[3] and, simultaneously, is the START pulse for a time-to-amplitude converter (TAC)[4]. The laser diode emits laser light of wavelength 810 nm, pulsewidth 3ns, and a risetime of well below 1ns. The light pulse travels in an optical fibre (monomode, 0.125mm diameter) through a light attenuating element and a 50:50 light splitter to the entrance window of the APD.

The light yield is measured and calibrated by means of a PIN diode with calibrated preamp and shaper electronics using the calibration branch behind the splitter. The item labelled APD box contains the APD including the quench and feed-back circuit of fig. 1. The NIM signal behind monoflop 1 is used to stop the TAC. The time proportional TAC amplitude is digitized by the subsequent ADC. A frequency counter is added for monitoring purposes. The APD was operated at 0°C where a more stable operation and slightly (about 20%) better resolutions than at room temperature were achieved.

[3] model RLM-03-96E13/810

[4] ORTEC 437A, specified time resolution is 10ps

Timing Resolution

First, the intrinsic resolution of the entire system and the influence of the time jitter in the pulser - TAC - ADC chain is measured.

Fig. 3(a) is used to calibrate the system. The distinct spikes, each spread over 3-6 ADC channels are produced using the pulser output as START and - delayed by a fixed cable length - as STOP signal for the TAC, bypassing the APD branch. Fig. 3(b) is an enlaged view of one spike. Fig. 3(a) shows that the time measurement is linear to within 3% with a conversion prescription of

$$(6.3 \pm 0.2)\text{ps} \quad / \quad \text{ADC} - \text{channel} \quad .$$

Fig. 3(b) shows that the intrinsic resolution of the pulser - TAC - ADC system is around 4ps.

We now add the light fibre and the APD-branch to the measurement. Calibration of the photon yield is obtained using a PIN photodiode with a quantum efficiency of $\sim 80\%$ at 810nm. The preamplifier has a gain of 0.5V/pC. Assuming a 50:50 splitting in the LL-splitter which was measured to be accurate to within 2% an absolute calibration of the photon yield is obtained.

Figs. 4(a)-(d) show time resolutions obtained for different amounts of light input, from 1.2×10^5 photons in (a) to 1.5×10^8 photons in (d). Fig. 4(e) shows the superposition of two spectra obtained for 4×10^5 photons delayed by 1ns with respect to each other. The resolution dependence as a function of the light input is shown in fig. 5. Best resolutions were obtained operating the APD only a few 100 mV below the breakdown voltage.

In summary, we have shown that time resolutions in the ps range can be obtained operating small diameter avalanche photodiodes at high gains close to the breakdown voltage. Stable operation to perform such measurements was achieved using dedicated quench circuitry and a dark rate dependent feed back loop. For 10^8 photons incident on the APD cathode time resolutions as good as 15ps have been measured.

Acknowledgements

We thank Sven Menke for help in editing the figures.

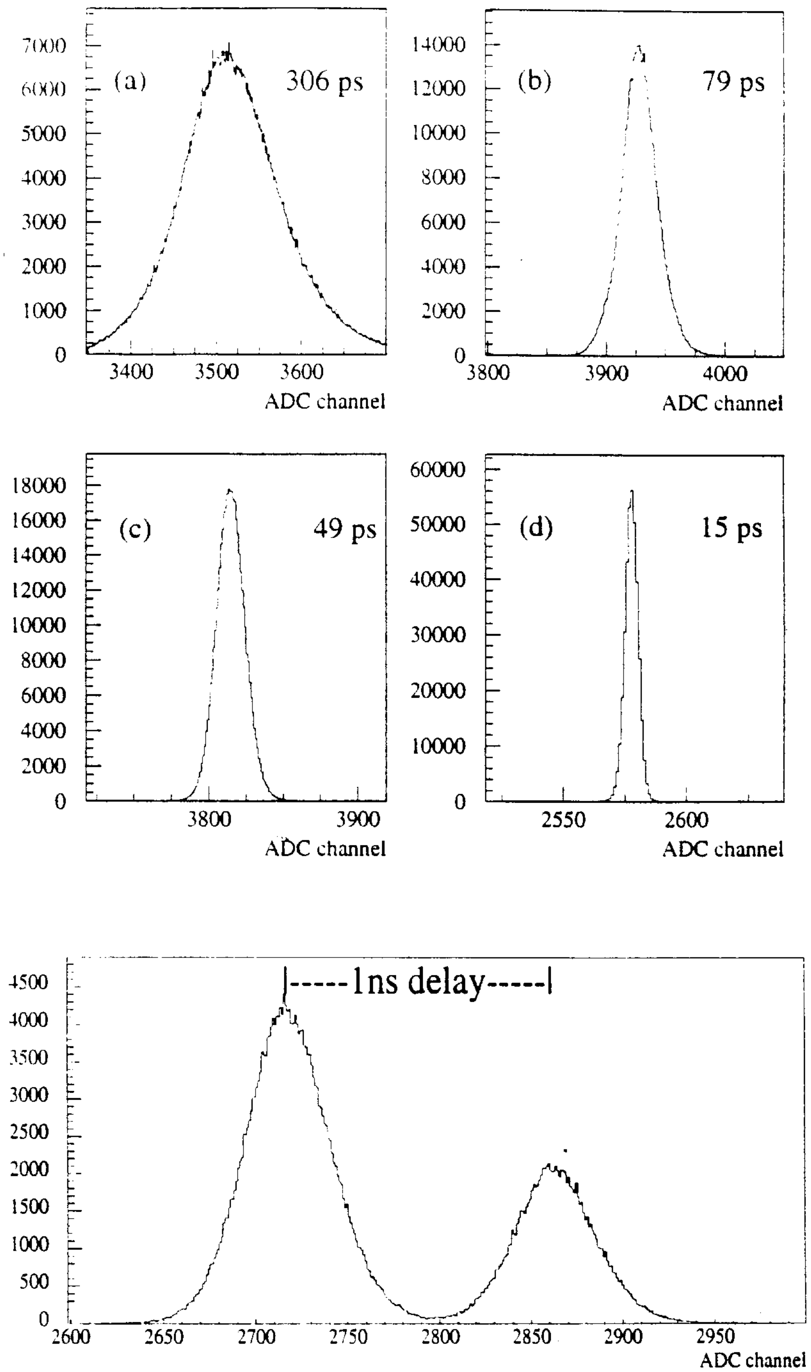

Fig. 4. Resolution spectra for increasing light input: (a) 1.2×10^5, (b) 6.7×10^5, (c) 1.7×10^6, (d) 1.5×10^8 photons. The numbers show the extrated resolutions (rms). (e) Two resolution spectra for 4×10^5 photons delayed by 1ns and superimposed

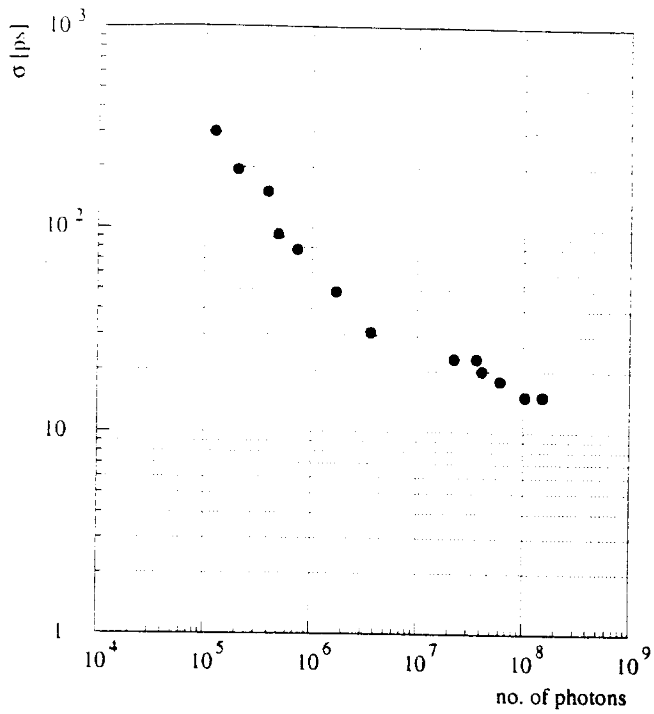

Fig. 5. Measured timing resolution as a function of light input.

References

[1] R.J. McIntyre, IEEE Trans. Electr. Dev. Vol ED-13 (1966) 164;
J. Conradi, IEEE Trans. Electr. Dev. Vol ED-19 (1972) 713;
R.J. McIntyre, IEEE Trans. Elektr. Dev. Vol ED-20 (1973) 637.

[2] Advanced Photonix, APD model TL-15-CA2, Camarillo, CA 93012, USA.

[3] G. Eigen, Proceedings of the CRYSTAL 2000 Intl. Workshop, Chamonix, France, September 22-26, 1992, eds. F. de Notaristefani, P. Lecoq, M. Schneegans.

[4] E. Lorenz, S. Natkaniez, S. Renker, D. Schwarz, MPI Munich preprint MPI-PhE/93-23 (1993);
W. Lachnit, Bonn University, Internal Report BONN-IR-93-49 (1993);
R. Henneberger, Bonn University, Internal Report BONN-IB-94-32 (1994).

[5] R.S. Gilmore et al., Proc. of the Intl. Conference on Applications of Photonic Technology (ICAPT94), Toronto, June 21-23, 1994, and preprint Bristol Univ. BR-HEP 94-3 (1994).

[6] A. Lacaita, S. Cova, M. Ghioni, Rev.Sci.Instr. 59 (7) (1988) 1115;
M. Ghioni and G. Ripamonti, Rev.Sci.Instr. 62 (1) (1991) 163;
A. Lacaita, M. Ghioni, F. Zappa, G. Ripamonti, S. Cova, Nucl. Inst. Meth. A326 (1993) 290.