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Beam test results of a 16ps timing system based on ultra-fast silicon detector

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Introduction

- Ultra-Fast Silicon Detectors are based on the Low-Gain Avalanche Detector design, employing n-on-p silicon sensors with internal charge multiplication due to the presence of a thin, low-resistivity diffusion layer below the junction.

- UFSD is a single device that ultimately will measure with high precision concurrently the space(~10 um) and time(~10 ps) coordinates of a particle, and helps to reduce frastically pile-up effects due to the large number of individual interaction vertices.

Properties of thin UFSD

- Capacitance-voltage(C-V) and current-voltage(I-V) measurements were performed. With grounded guard ring and resulted in a depletion voltage below 50V.

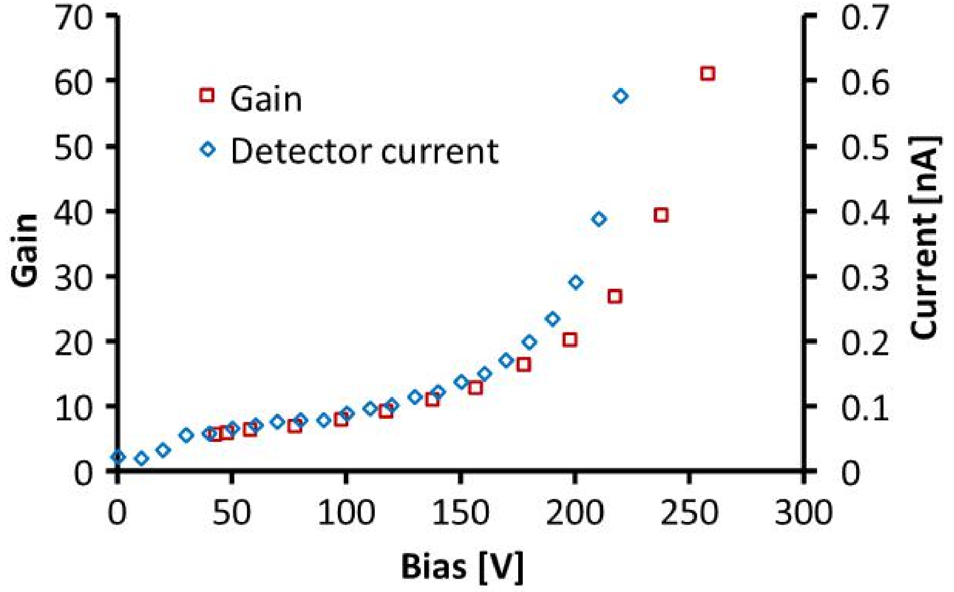

Fig. 1. Bias dependence of the leakage current and the signal gain for a 45 μm-thick UFSD sensor with an area of 1.7 mm^2. The gain determination is subject to an overall scale uncertainty of 20%. The similar exponential behaviour of gain and sensor current below 200 V bias is due to the common charge multiplication mechanism.

Beam test results ---- Gain and Landau distribution

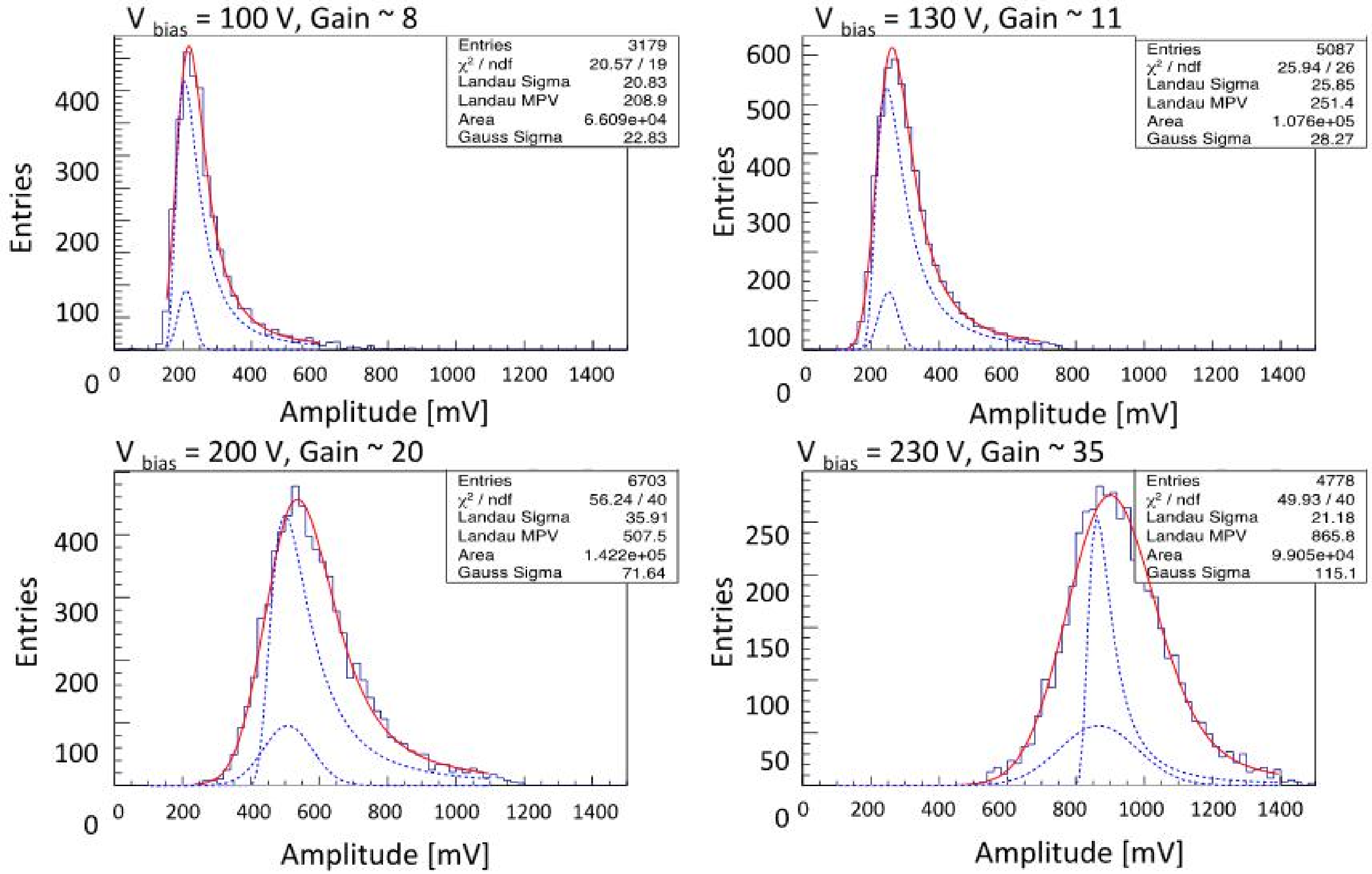

Fig. 6. Distribution of the signal amplitude at four values of the detector Vbias: (100 V, 130 V , 200 V and 230 V), with superposed the curves from a Landau-Gauss convolution fit (solid red curve). On each graph, the normalizations of the Landau and Gauss components are arbitrary as only their product is defined. Likewise, for explanation purposes only, the gaussian curve is arbitarly aligned with the Landau MPV value. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Beam test results ---- Timing resolution

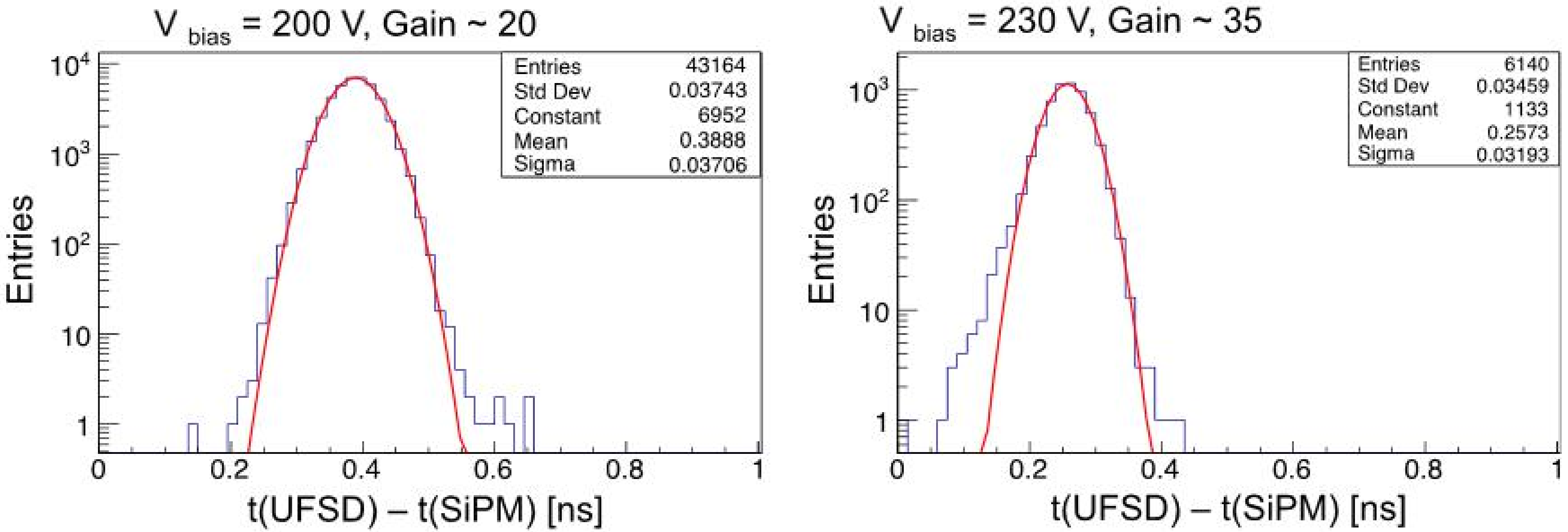

Fig. 7. Time difference UFSD-SiPM at 2 different UFSD bias voltages: 200 V with sigma=37 ps, and 230 V with sigma=32 ps.

Beam test results ---- Timing resolution

Table 1
Averages of timing resolution for single UFSD (N=1), and for pairs of UFSD (N=2), and the timing resolution for the triplet UFSD (N=3) for two bias voltages. The trigger counter resolution has been subtracted in quadrature to obtain the quoted results.

	UFSD Timing resolution	
	Vbias=200 V	Vbias=230 V
N=1	34 ps	27 ps
N=2	24 ps	20 ps
N=3	20 ps	16 ps

Beam test results ---- Timing resolution

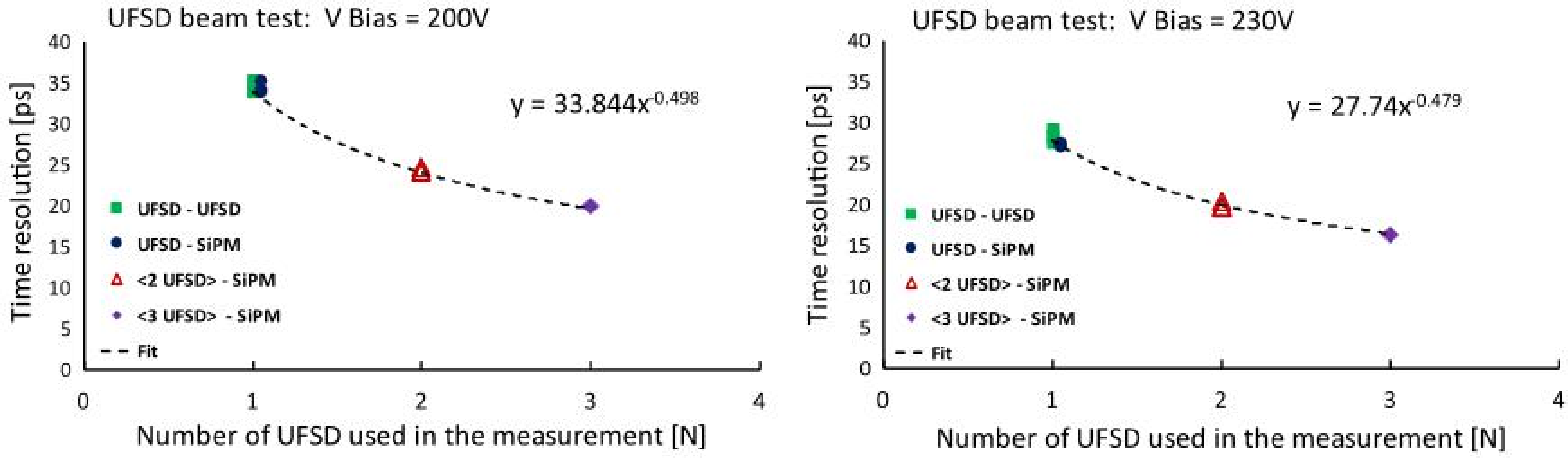

Fig. 8. Timing resolution for: single UFSD (N=1) obtained from the UFSD-SiPM and UFSD-UFSD time differences; averaged pairs of UFSD (N=2) and average of 3 UFSD (N=3) for bias voltages of (left) 200 V and (right) 230 V.

Conclusions

- The reult of the beam test with pions of momentum 180GeV/c demonstrates that UFSD with an active thickness of 45um and 1.7mm2 pad size reaches a timing resolution of 34ps at a bias voltage of 200V and 27ps at 300V. This result is in excellent agreement with what was predicted 3 years ago for thin UFSD by the Weightfield2 simulation program. In the beam test, it was also proved that a telescope comprising 3 planes of UFSD sensors reaches the expected performance improvement given by multiple measurements, i.e. the resolution improves like 1/sqrtN. For a triplet of UFSD, a timing resolution of 20ps at a bias voltage of 200V was achieved, while at 230V the timing resolution was measured to be 16ps.

Questions

- Question from Yuhang:

  - What is the main reason for UFSD to achieve better time resolution than TOF? Material? Structure？

  ➢ Much closer to interaction point. And I think semi-conductor can behave better than PTM.

Questions

- Question from Shan:
  - Can you briefly introduce "multiple sampling techniques"?

➢ https://ac.els-cdn.com/S0168900216308373/1-s2.0-S0168900216308373-main.pdf?_tid=9d1b7697-93f9-4f71-9fa3-232ec6f28cf4&acdnat=1545975846_037f7cc20cfc9ca48b295472f0f16cbe for more information.

Questions

- Question from Amit:

  - What is the meaning of Constant Fraction Algorithm/Constant Fraction Discriminator(CFD)?

  - Can you explain the Fig. 7 because I read in the paper it is somehow related with CFD?

  ➢ Take sigma as time resolution.

Questions

- Question from Xin:
  - In the last section, it says 3 planes of UFSD sensors reaches the expected performance improvement given by multiple measurements, i.e. the resolution improves like 1/sqrt(N). Could you explain why?

Questions

- Question from Ryuta:
  - Description of the event selection (left bottom of p4) briefly explains that "To eliminate the contributions from non-gain events, the time of the pulse maximum has to fall into a window of 1ns. "
  - Do you know/find distribution of "the time of the pulse maximum" from the other references ? (Apart from this specific question, I somtimes wonder how we can effectively separate these two kinds of signals,one which passes trough the multiplication layer, and the other one)

Questions

- Question from Yuzhen:
  - In Fig.6, the Landau MPV and Gauss Sigma increase as the gain (or bias voltage) increase, but why does not the Landau Sigma increase with gain (or bias voltage) ?